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Assessing the Functions and Services of Non-Perennial Waters in Arid Regions

A dissertation submitted in partial satisfaction of the

requirements for the degree of

Doctor of Environmental Science & Engineering

by

Shannon Lea Pankratz

2022

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ABSTRACT OF THE DISSERTATION

Assessing the Functions and Services of Non-Perennial Waters in Arid Regions

by

Shannon Lea Pankratz

Doctor of Environment in Environmental Science & Engineering

University of California, Los Angeles, 2022

Professor Richard F. Ambrose, Chair

There are significant and on-going issues faced by the U.S. Army Corps of Engineers and other federal agencies in regulating and affording protections to arid non-perennial stream resources in western arid regions of the U.S. (i.e., Arid West). The significance of these issues is magnified by the large portion of dryland areas situated within the U.S., as well as worldwide, where non-perennial streams also comprise most of the stream types. It is essential for politicians, decision makers, and those assessing and managing aquatic resources to be aware of the current body of understanding available on these important resources. An in-depth literature and geospatial analysis was conducted on arid non-perennial stream functions as they relate to key climate ecosystem controls, influential environmental parameter controls, and hydrology (e.g., streamflow regime) forcing functions at various landscape scales and settings. Out of the overall stream function categories of Biogeochemical, Habitat, Hydrology, Sediment, Biodiversity,

Energy Dissipation, and Connectivity examined within global and U.S. literature, only Biogeochemical, Habitat, Hydrology, Sediment emerged as the primary function categories of study focus. Global and U.S. data followed similar overall trends with generally a higher coverage of Habitat functions above all other function categories, which was unexpected given the higher importance of Hydrology and Sediment within the overall hierarchy of influences among stream function categories. Other similar overall trends within global and U.S. data included higher occurrences within cold steppe subclimes, steppe precipitation areas, and ephemeral streams. Of the three environmental parameters (watershed position, stream planform type, and riverine corridor sampling location type) analyzed, these patterns tended to be more consistent when compared across watershed positions, with generally more deviation when viewed through the lenses of stream planform types and sampling type locations. Arid non-perennial streams provide critical watershed functions in various arid environs, yet further focused research is needed to augment Biodiversity, Energy dissipation, Hydrology, and Connectivity functions across both ephemeral and intermittent arid streams. Future global and U.S. research is also recommended within cold desert subclimes, across a greater diversity of channel forms and small-scale sampling location types, and with intermittent streams for providing information essential to regional stream assessment, management and regulation of arid non-perennial streams.

This dissertation of Shannon Lea Pankratz is approved.

Peggy Marie Fong

Thomas Welch Gillespie

Kirsten Schwarz

Richard F. Ambrose, Committee Chair

University of California, Los Angeles

2022

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LIST OF ACRONYMS

Corps	United States Army Corps of Engineers
CFR	Code of Federal Regulations
CWA	Clean Water Act
CWR	Clean Water Rule
FWPCA	Federal Water Pollution Control Act of 1972
HGM	hydrogeomorphic classification system/approach
JD	jurisdictional determination
LRR	Land Resource Region
NHD	National Hydrography Dataset
NRWP	non-relatively permanent water (ephemeral/intermittent waters)
NWPR	Navigable Waters Protection Rule
OHWM	ordinary high water mark
RPW	relatively permanent water
RWQCB	California Regional Water Quality Control Board
SAMP	Special Area Management Plan
SN	significant nexus
SWANCC	Solid Waste Agency, Inc. of Northern Cook County
TNW	traditional navigable water
USEPA	United States Environmental Protection Agency
USGS	United States Geologic Survey
WOTUS	waters of the United States

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DISCLAIMER

The views, conclusions, opinions, and positions expressed are my own, and not necessarily represent the views, position or opinions of the United States, the Department of Defense, the Army, the U.S. Army Corps of Engineers, or any of their components.

VITA

1996	Diploma
	Brookside High School
2000	B.S., Biology with Minors in Math, Physics, and Chemistry
	Valparaiso University
1996-2000	Student Aide
	Valparaiso University
1997-2000	Research Assistant
	Valparaiso University
2001	Quarantine and Labeling Blood Laboratory Technician
	American Red Cross
2003	M.S., Environmental Health Sciences
	School of Public Health, University of California, Los Angeles
2001-2005	Graduate Student Researcher
	University of California, Los Angeles
2006-2015	Regulatory Project Manger
	United States Army Corps of Engineers
	Regulatory Branch, Los Angeles District
2015-	Senior Regulatory Project Manger
	United States Army Corps of Engineers
	Regulatory Division, Los Angeles District

CHAPTER ONE: INTRODUCTION

Statement of Problem

This dissertation addresses the issue of assessing the functions and services of arid west waterways, as it directly relates to multiple aspects of the regulation of streams under Section 404 of the Clean Water Act (CWA). To set up the scope of the problem, I describe the authorities under which the Army Corps of Engineers' Regulatory Program (Regulatory) operates, and specifically the past to present functions of Regulatory under Section 404 of the CWA. Then, I discuss the situations and policy that have resulted in the current, significant Regulatory issues faced by the Corps in regulating ephemeral and other arid stream types concentrating on western arid regions of the U.S. Finally, I describe the chapter sections that comprise the dissertation.

This dissertation is written with the combined perspective of a Corps Regulatory employee and a student, benefiting from both practical experience and scholarly analyses under the Environmental Science & Engineering doctoral program. Overall, this dissertation is motivated by the lack of appropriate assessment tools for non-perennial streams in the Arid west, as well as a need to comprehensively synthesize the current body of understanding on these resources, principally in light of regulation and management needs, the prevailing Supreme Court Rapanos decision, the repealed 2015 Clean Water Rule, and an uncertain future of the definition of waters of the U.S. and their protection under the CWA.

Clean Water Act and Section 404

The Corps regulates and protects the nation's aquatic resources under the Clean Water Act. The objectives of the CWA are "to restore and maintain the chemical, physical, and biological integrity of the Nation's waters."

CWA Section 404 waters regulation is performed by the Civil Works Directorate of the Corps under the Regulatory Program (Regulatory). The mission of Regulatory is to balance reasonable development with the protection of national aquatic resources, termed waters of the U.S. (WOTUS[1]). WOTUS are defined in Code of Federal Regulations (CFR) at 33 CFR Part 328.3(a)-(f)[2], and are the only wetland and non-wetland waters regulated and protected under the CWA. The definitions in Part 328.3(a)(1)-(5), commonly referred to for streams, are as follows:

"(a) The term *waters of the United States* means

(1) All waters which are currently used, or were used in the past, or maybe susceptible to use in interstate or foreign commerce, including all waters which are subject to the ebb and flow of the tide;

(2) All interstate waters including interstate wetlands;

(3) All other waters such as intrastate lakes, rivers, streams (including intermittent streams), mudflats, sandflats, wetlands, sloughs, prairie potholes, wet meadows, playa lakes, or natural ponds, the use, degradation or destruction of which could affect interstate or foreign commerce including any such waters:

[1] Common acronyms used for "waters of the U.S." by regulatory agencies, the general public and the scientific community include WoUS and WOTUS. However, as WOTUS is the acronym more commonly used by agencies and the regulated public, WOTUS is the acronym utilized in this dissertation prospectus.
[2] See Appendix A, the "Section 404 of the Clean Water Act and WOTUS Definitions".

(i) Which are or could be used by interstate or foreign travelers for recreational or other purposes; or

(ii) From which fish or shellfish are or could be taken and sold in interstate or foreign commerce; or

(iii) Which are used or could be used for industrial purpose by industries in interstate commerce;

(4) All impoundments of waters otherwise defined as waters of the United States under the definition;

(5) Tributaries of waters identified in paragraphs (a) (1) through (4) of this section;

Importance of the Arid West and Its Aquatic Resources under Section 404

The Arid West are geographic areas where annual evapotranspiration generally exceeds precipitation and encompasses both arid and semi-arid areas, similar to this and the dryland terms used in other scientific works (Bull & Kirkby, 2002; R. Lichvar et al., 2009; Technical Advisory Committee, 2013; Tooth & Nanson, 2000; U.S. Army Corps of Engineers, 2008a). These areas are generally characterized by low humidity, high average temperatures, extreme spatial and temporal variability in precipitation, and a wide variety of topography, landforms, and ecosystems (U.S. Army Corps of Engineers, 2006). Estimates of a third to almost half of the world's land surfaces are categorized as arid and semi-arid areas (Bull & Kirkby, 2002; Millennium Ecosystem Assessment, 2005). Most U.S. mapping classifications include some or a combination of multiple system factors, such as climate, soils, fauna and vegetation and adaptations thereof, hydrology, elevation, land use and geology (Bailey, 2005; McNab, 2005;

Omernik, 1987; U.S. Department of Agriculture, 2006; U.S. Environmental Protection Agency, 2003). Based on historical state and national levels of use, including use in Corps research publications, the Land Resource Regions (LRRs) developed by the United States Department of Agriculture will be utilized in this dissertation to define the Arid West and other geographic regions of the United States. The overall Arid West area contains three LRRs[3] consisting of the Interior Deserts, the Columbia/Snake River Plateau, and Mediterranean California (Figure 1). The Arid West extends over a considerable geographic area, constituting approximately 21% of the U.S. (U.S. Environmental Protection Agency, 2006) and covers the 11 western states of Arizona, California, Colorado, Idaho, Nevada, New Mexico, Oregon, Texas, Utah, Washington, and Wyoming (U.S. Army Corps of Engineers, 2006).

The Arid West comprises not only a significant geographic portion of the U.S., but also contains a significant percentage of non-perennial aquatic resources. Within this large Arid West area, smaller streams are predominantly of ephemeral or intermittent stream types (U.S. Environmental Protection Agency, 2006). Regionally within California, Arizona and Nevada, non-perennial stream types comprise 66%, 94% and 89%, respectively, of the National Hydrography Dataset (NHD) mapped streams (Levick et al., 2008). More recent work by Ode et al. (2011) using NHD Plus data has increased the estimated non-perennial composition of California stream networks alone to 73%. Therefore, as they comprise a significant portion of many Arid West watersheds, it is important to protect and appropriately manage non-perennial streams.

[3] LRRs B, C, and D generally correspond with Level 1 Ecoregions 10, 11, 12 and 13 (U.S. Army Corps of Engineers, 2006).

Nonetheless, there are a number of challenges to the management and protection of non-perennial streams within the Arid West. The large region of the Arid West has a population to match, serving as home to 31% (98.9 million people) of the U.S. population, with California containing the nation's highest state population of 39.5 million, according to U.S. Census data on 2014 annual population estimates. Development expansion into more arid areas away from coastal and developed urban centers has traditionally been encouraged by the availability of land and more affordable housing opportunities. Along with population growth and expansion is the typical and subsequent growth in residential, commercial and industrial development pressures. And most notably the negative effects of development and various land use types on streams and watersheds from increased impervious surfaces, polluted source and non-point source urban runoff, soil erosion, habitat loss, invasive species, flood control and water diversion activities, urbanization, agriculture activities, and mining activities (Field & Lichvar, 2007; Millennium Ecosystem Assessment, 2005; U.S. Environmental Protection Agency, 2006). Urban runoff, groundwater withdrawal, surface water usage and changing weather patterns due to global warming have also produced varying hydrological effects on Arid West systems (Mount, 1995; Newman et al., 2006), including the conversion from ephemeral stream flow regime to perennial flow and vice versa. However, the Arid West also has a relatively newer and compounding development pressure over recent years, the increasing demand for the production of renewable energy sources (Grippo et al., 2015; Renewable Energy Action Team, 2010). Moreover, a vast majority of the percentage of land usable and best suited to the production of solar energy within the entire nation is disproportionally located in the West (Macknick et al., 2013). Lastly, in

addition to the physical and hydrological changes Arid West watersheds are subjected to by development and land uses, are the growing demands and stresses on key water resources. Exacerbated by population growth, water is an increasingly valuable and already limited resource in the Arid West. Water issues are consistently at the forefront of the public attention as growing populations and prolonged drought exacerbate water usage demands of both surface water and groundwater resources. Consumer groups not only compete among themselves over limited water allocations, but also increasingly against water allocations for streams and natural ecological systems (Bull & Kirkby, 2002; U.S. Army Corps of Engineers, 2008b).

In the midst of development and water usage challenges, knowledge of how watersheds function is necessary in order to best manage and regulate valuable watershed resources (DeFries et al., 2004). Stream functions and condition are critical components in addressing a variety of management topics (Stein et al., 2011), including master city and county development plans, water pollution, flood risk management, habitat and wildlife management, special area management plans (SAMPs), water supply, regulation, watershed restoration and conservation, public health and safety, and groundwater recharge. Moreover, overall watershed functions are provided by the total composition of the stream types comprising the watershed (HydroGeoLogic, 2008). Therefore, the understanding of stream functions of different stream types is essential, as well as the subsequent ability to appropriately quantify in some manner the functions and condition of stream types. In addition to governments, knowledge of the functions and services of aquatic resources is key for all levels of local, state and federal regulatory agencies having the ability to successfully carry out their respective duties, including Corps Regulatory's mission of balancing development and growth with protection of aquatic resources.

This is especially true for Arid West watershed systems and the significant pressures on these aquatic resources. There are several steps within the overall Corps (Regulatory) project evaluation process where information on the functions and services of WOTUS, and on assessments of WOTUS, are essential in order to appropriately conduct project evaluation (Figure 2). These various steps in the Corps' permitting process combine to result in Regulatory's final permit decision for a given project.

The Regulatory Program and the regulation of aquatic resources under the CWA have evolved over time, reflected in large part by changes in federal laws, court decisions and mandates, agency rulemaking, science and policies (Figure 3).). Laws have progressively extended Regulatory authority from navigable waters and canals to the upstream, non-navigable portions of those watersheds. Legal court cases have tended to generally restrict the authority of Regulatory, such as in eliminating regulation of isolated waters and questioning limits of jurisdiction under Section 404 of the CWA. Rulemaking has also changed or attempted to clarify waters under the jurisdiction of the Regulatory Program, most notably the recent rulemaking by USEPA and Corps for re-defining waters of the U.S. Rulemaking is briefly discussed in the following sections.

Science and Judicial System Influences on Clean Water Act Regulation: Crisis and Opportunity

The federal courts have a substantial role in influencing Regulatory's regulation of waters under the CWA (Figure 3). Of particular note are the 2001 Supreme Court decision in *Solid*

Waste Agency of Northern Cook County v. U.S. Army Corps of Engineers (SWANCC) and the following 2006 decision in the consolidated cases of *Rapanos* and *Carabell* (Rapanos). Both SWANCC and Rapanos decisions had a significant impact in limiting the aquatic resources regulated and protected by the CWA. The SWANCC decision resulted in geographically isolated, intrastate, non-navigable waters lacking a nexus to commerce as no longer regulated as WOTUS, and thus no longer being afforded protection under the CWA. The 2006 Rapanos decision has resulted in widespread confusion and complexities regarding non-relatively permanent waters (NRPWs), or non-perennial waters, and their status under the CWA. Prior to Rapanos, essentially any aquatic resource ultimately tributary to tidally influenced waters, interstate waters, or traditionally navigable waters (TNWs) was defined as a WOTUS and thus regulated under the CWA. Post Rapanos however, Justice Scalia's plurality opinion and Justice Kennedy's opinion have formed the two current standards by which Corps Regulatory determines if a water is regulated under the CWA. In brief, the plurality opinion defined WOTUS as solely consisting of relatively permanent waters (RPWs), including perennial and seasonally-perennial streams and wetlands with a continuous surface water connection to these streams. Justice Kennedy defined waters of the U.S. to otherwise also include NRPWs and adjacent wetlands if a significant nexus could be established between those individual waters and the nearest downstream TNW based on chemical, physical and biological integrity factors. As such, Justice Kennedy's opinion did not outright exclude ephemeral and intermittent streams and any adjacent wetlands from regulation under the CWA. However, it resulted in establishing a highly intensive and arguably subjective and inconsistent, field level case-by-case significant nexus evaluation process, no longer guaranteeing non-perennial streams protection under the

CWA. The significant nexus evaluation process also restricted such a determination to only consider in isolation the individual subject stream and its effect on the nearest downstream TNW, ignoring the combined effect of all such similar resources within the watershed.

In light of issues and confusion within and outside the regulatory communities from Rapanos, the 2015 Clean Water Rule (CWR), as joint rulemaking by the Corps and USEPA, intended to both clarify and re-define WOTUS (Appendix A). The CWR and its support documents[4] essentially provide arguments for various waters that should be defined automatically (by rule) as WOTUS without needing a significant nexus evaluation, including non-perennial streams. The rulemaking also made an obvious attempt to bring science back into the regulatory process, with the text extensively citing use of available published scientific information. Of note, the CWR also addressed a few aquatic resource types for which a significant nexus evaluation would still be required and thus conducted on a case-by-case basis. But those circumstances would be limited, would allow the same type of aquatic resource to be aggregated for analysis within the watershed, and would more appropriately capture the real cumulative effect of the aquatic resource functions from the same resource type on the downstream TNW (Levick et al., 2008). Nonetheless, the CWR was immediately challenged with several lawsuits once it was published in the Federal Register, and the Sixth Circuit issued a nationwide stay of the CWR on October 9, 2015. With the number of cases brought against the CWR in different court circuits, by 2019 various district court rulings resulted in roughly half of

[4] (U.S. Environmental Protection Agency, U.S. Army Corps of Engineers, 2015)Technical Support Document for the Clean Water Rule: Definition of Waters of the United States. As stated in the Technical document, "The Preamble, the Science Report, this Technical Support Document, the Response to Comments, and the rest of the administrative record provide the basis for the definition of "waters of the United States" established in the rule."

the states being regulated under the Rapanos guidance with the other half under the CWR. Following the Obama administration, the Trump administration repealed the CWR in 2019 and briefly reinstituted the 1986 regulations defining WOTUS, which were subsequently replaced with the Navigable Waters Protection Rule (NWPR) in 2020. The NWPR significantly reduced the aquatic resources protected under the CWA, including the removal of ephemeral streams. However, as with the CWR, the NWPR was also litigated, resulting in the vacatur and remand of the NWPR nationwide by an Arizona District Court in mid-2021. Though the current Biden administration as of February 2002 is undertaking an administrative rulemaking process to yet again re-define what aquatic resources are WOTUS, and thus regulated and protected under the CWA, the 1986 CWA regulations as modified by Supreme Court cases are implemented for defining WOTUS. Thus, to-date, the Rapanos decision is still the overriding guidance when determining the jurisdiction of NRPWs in the U.S.

The prevailing Justice opinions in Rapanos underscored questions of the functions and services provided by non-perennial streams, and the repercussions of this case markedly affects the Arid West region of the U.S. In addition, this case indirectly brought to question how to appropriately assess these resources in determining the significance of their downstream connections. Yet despite the confusion, concerns, and regulatory problems stemming from the Rapanos case, it had much value in spurring the subsequent increased interest in and generation of scientific research literature on these important non-perennial stream resources (Leigh et al., 2016). Moreover, the impacts of the Rapanos case reiterates the importance of synthesizing the growing body of science on the functions and services of non-perennial streams, including

application of the body of understanding for improved assessment and management of these vital resources in the Arid West.

The reactions to Rapanos, from CWA rulemaking spurred by the White House administration to CWR and NWPR court challenges and suspensions, also underscored questions on the role of scientific information in the politics, law and regulation of non-perennial Arid West streams. Though scientific knowledge is critical for informing federal regulation and protection of aquatic resources, it is but one of many factors in environmental politics, law and public policy (Cimorelli, 2005; de Groot, 2006; W. L. Graf, 1992). Therefore, the assessment of future CWA regulation and protection of Arid West non-perennial streams is a focus of this dissertation.

Consequences for Arid Stream Regulation

Overall, this dissertation is motivated by the need to comprehensively synthesize the current body of understanding on these arid non-perennial stream resources, principally in light of regulation and management needs worldwide and within the U.S., and the prevailing Rapanos decision and uncertain future of WOTUS definitions. Corps Regulatory decisions should be law abiding, scientifically-defensible, accurate and consistent in order to maintain credibility as a regulatory agency and to successfully carry out its overall mission in service of the public. Though the focus of this dissertation chapter has been on the federal Regulatory Program within the U.S., it is important to note the same concepts and watershed regulation and management responsibilities are inherent to all regulatory agencies and levels of government on a global scope, including cities, counties, and states. Comprehensive knowledge of non-perennial aquatic

resources, and the ability to assess, is fundamental to informed and appropriate regulation and management of these important and widespread resources.

Dissertation Objectives

The objectives of this dissertation are (1) to provide a comprehensive assemblage and evaluation of the documented functions and services of arid non-perennial streams in western regions of the U.S. and worldwide, and (2) the subsequent associations of those functions among ecosystem controls and environmental parameters for non-perennial arid stream functions. The dissertation is comprised of the following components:

Chapter II: A Global and U.S. Arid West Region Evaluation of Functions of Arid Non-Perennial Streams in Relation to Large Ecosystem and Smaller Scale Environmental Controls

This study component investigates the functions and services of non-perennial streams in the Arid West and in arid areas globally as described in the current literature, and how these arid stream functions are associated with ecosystem controls and environmental parameters. There are several sections in providing the data results in a subsequent manner, beginning with generalized results and in layering the data with climate and environmental parameter factors.

Chapter III: Conclusions and Recommendations

This study component brings together the literature data of the environmental parameter results sections, and explores the implications for non-perennial stream assessments and future regulation of these aquatic resources within the U.S.

Following the spirit and intent of CWA laws and regulations, this dissertation is a step forward in incorporating current knowledge on non-perennial arid streams into Corps Regulatory stream management and policy considerations. The results will be valuable and practical in multiple aspects of Corps Regulatory actions, including implementation of watershed approaches, permit decisions, impact assessments, compensatory mitigation considerations, and project alternative analyses. Furthermore, this work will provide critical insight into successful federal regulation of waters in terms of science and other public policy factors. Lastly, the results of this work will be useful beyond Regulatory, including for other federal and state agencies, the scientific community at large, and the general (CWA-regulated) public.

Figures



Figure 1. The Arid West and other regions mapped throughout the United States, based on Land Resource Regions (LRRs), and as modified from Berkowitz et al. (2011), R. W. Lichvar and McColley (2008), Wakeley (2002).

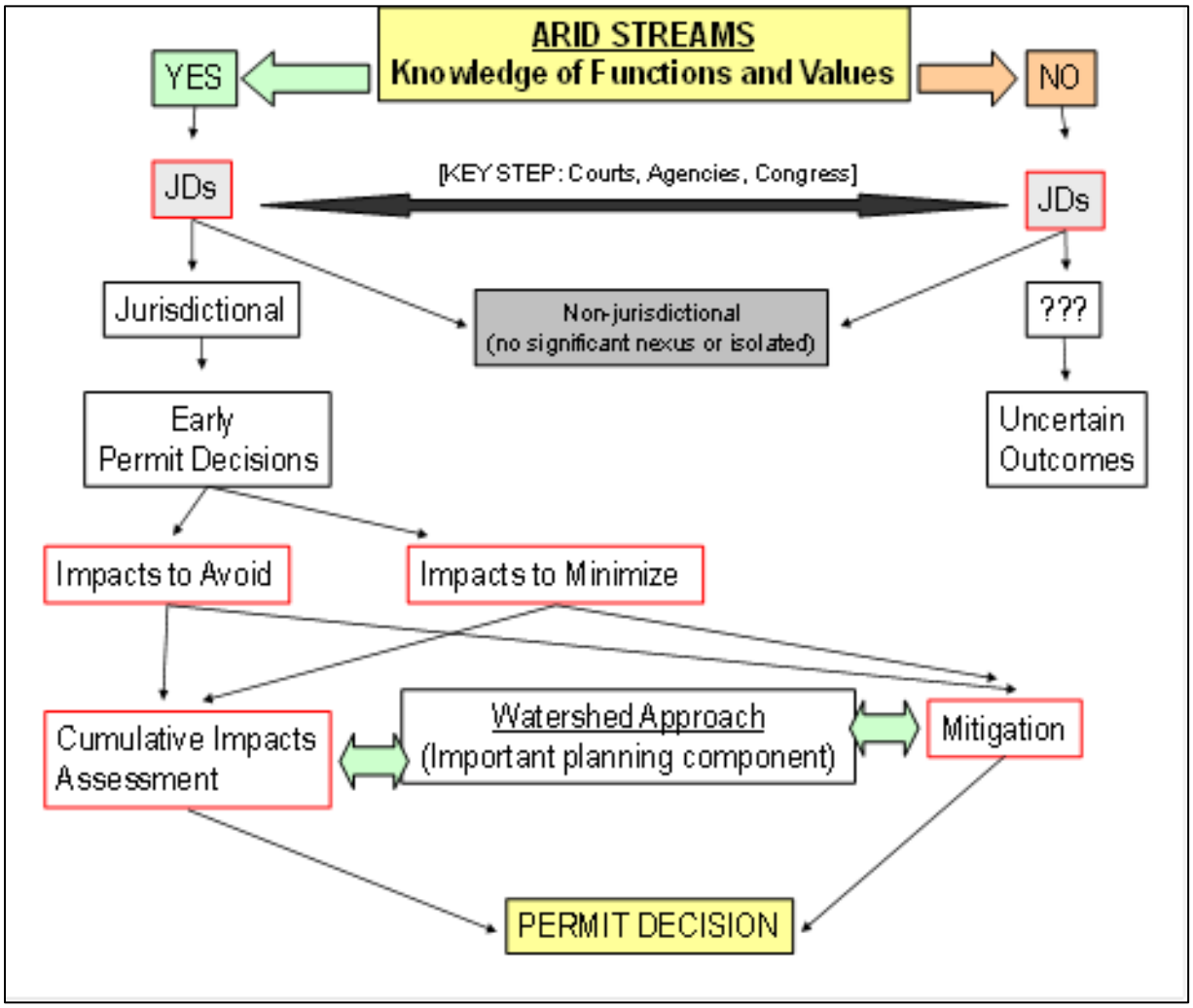


Figure 2. Corps Regulatory processes and reliance on available, accurate information of the functions, services, and assessments of streams in western arid regions of the U.S., including jurisdictional determinations (JDs) regarding WOTUS.

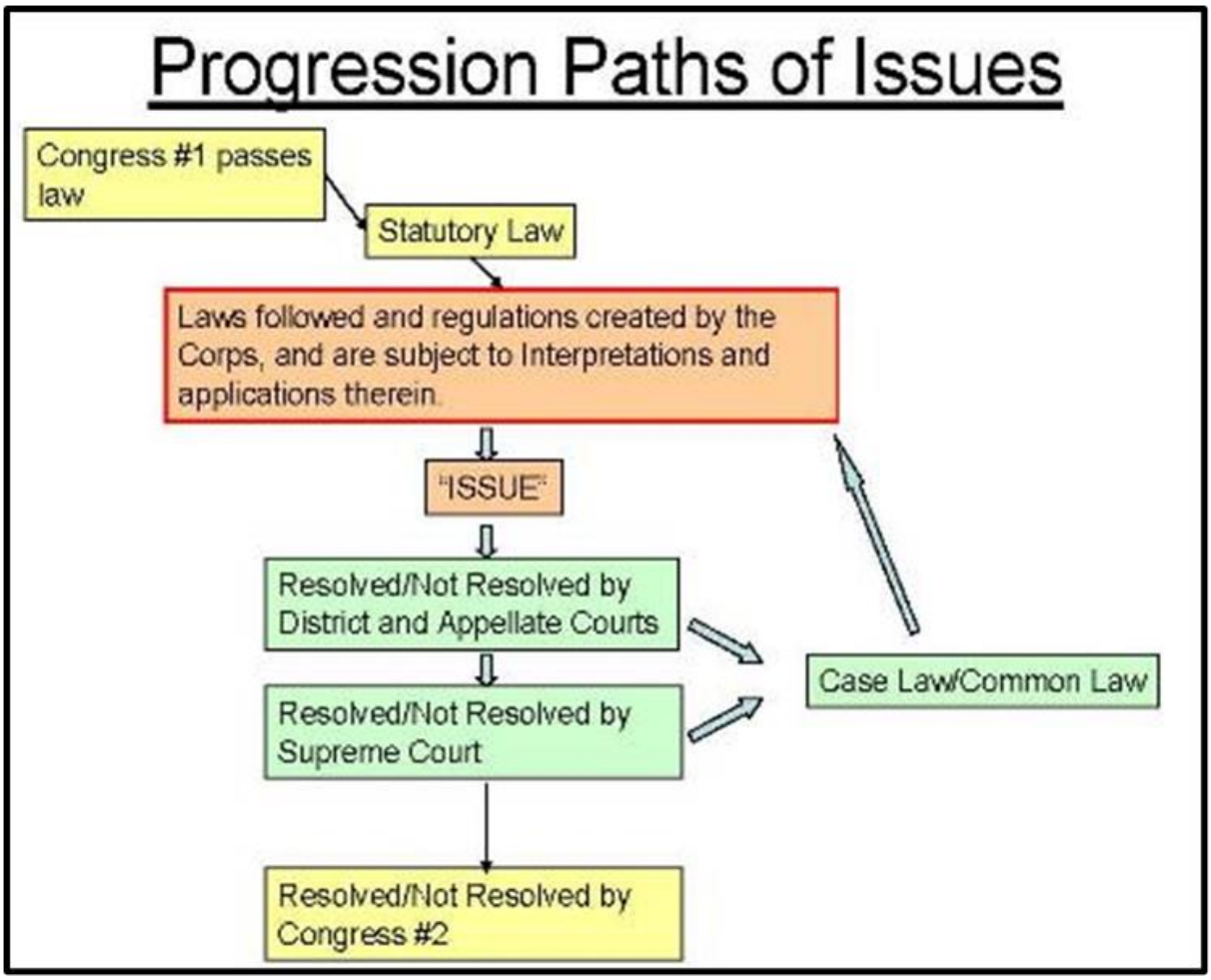


Figure 3. Simplified view of the general progression of a Corps Section 404 issue, through different levels and parts of government.

CHAPTER TWO: A GLOBAL AND U.S. ARID WEST REGION EVALUATION OF FUNCTIONS OF ARID NON-PERENNIAL STREAMS IN RELATION TO LARGE ECOSYSTEM AND SMALLER SCALE ENVIRONMENTAL CONTROLS

Introduction

Non-perennial streams are under a myriad of development pressures and regulatory and management challenges, yet they are widespread and comprise most of the aquatic resources within the Arid West region of the United States and in other areas worldwide (Datry et al., 2018; Leigh et al., 2016; Shanafield et al., 2021). Appropriate and improved management, regulation and protection of these important resources critically depends on a comprehensive understanding of different stream types functions and services, as well as the subsequent ability to suitably assess in some manner the functions and conditions of streams.

The challenges in management, protection and regulation of non-perennial streams are complicated by on-going scientific development of information on arid waters, as well as on-going judicial and political challenges to the regulation of these resources in the United States. Historically, there has been less scientific research on non-perennial streams than perennial streams (McDonough, 2011; Vyverberg, 2010). Several papers note the developing body of understanding on non-perennial streams (Leigh et al., 2016; Levick et al., 2008; McDonough, 2011; Shanafield et al., 2021), which even in recent times is not far advanced (Bull & Kirkby, 2002; Datry et al., 2018; Datry et al., 2014). Outstanding research needs range from gathering baseline information and inventories on wildlife and vegetation to better understanding and

documenting the ecological, biological, and physical connections and interactions of non-perennial streams (Flotemersch et al., 2010; Levick et al., 2008; Stein et al., 2011; M. C. Thoms & Parsons, 2002).

Parallel to the developing body of non-perennial stream research, there has been an overall trend in the United States of decreasing federal regulation of non-perennial streams. In 2001 the Supreme Court decision in Solid Waste Agency of Northern Cook County v. U.S. Army Corps of Engineers resulted in geographically isolated, intrastate, non-navigable waters lacking a nexus to commerce no longer being afforded protection under the Clean Water Act (CWA). The later 2006 decision in the consolidated cases of Rapanos and Carabell (Rapanos) resulted in widespread confusion and complexities focusing on non-relatively permanent waters (NRPWs), or non-perennial waters, and their protection status under the CWA through highly intensive and arguably subjective and inconsistent case-by-case significant nexus evaluation processes. The Obama administration intended to resolve jurisdictional issues from Rapanos and to further support the definition of waters with published science by establishing the 2015 Clean Water Rule (CWR), whereby intermittent and ephemeral streams were jurisdictional by rule without the need for significant nexus evaluations. However, once published the 2015 CWR was immediately litigated, and by 2019 various district court rulings resulted in roughly half of the states being regulated under the Rapanos guidance with the other half under the 2015 CWR. In 2019 the Trump administration revoked the 2015 CWR and replaced it with the Navigable Waters Protection Rule (NWPR) that became effective on June 22, 2020. The NWPR specifically excluded CWA protections for all ephemeral streams, as well as portions of streams and other aquatic resources that do not have a downstream surface hydrological connection in a

typical year. Similar to the 2015 CWR, the NWPR also came under litigation, ultimately culminating in an Arizona District Court order vacating and remanding the NWPR on August 30, 2021. Therefore, the 1986 definitions of WOTUS, as modified by the SWANCC and Rapanos Supreme Court rulings, are presently utilized for the Regulatory Program. Independent from activity within the courts, the current Biden administration had also been working on a formal rulemaking process to formally repeal and replace the NWPR with a new durable definition of WOTUS. The first step began in November 2021 when USEPA and the Department of the Army signed a proposed rule to revise the NWPR WOTUS definition, with a public notice period that had extended through early February of this year. The second step is likely to occur later this or next year, where the agencies will incorporate public notice comments and issue a final rule repealing the NWPR and instituting a familiar yet modified 1986 WOTUS definition that is consistent with past Supreme Court decisions and incorporates best available science.

Because of the judicial and political challenges to federal regulation of non-perennial streams, there is widespread interest and value in identifying, predicting, and ultimately assessing stream functions through channel classifications and other physical parameters (D. E. Somerville, Pruitt, B.A. , 2004). River systems differ due to regional differences in climate, geology, and tectonic processes (William L. Graf, 1988; Leopold, 1964; Mount, 1995), which ultimately result in different hydrology inputs, stream flow regimes, stream transmission losses, landscape settings, vegetation and stream geomorphology (Field & Lichvar, 2007; U.S. Army Corps of Engineers, 2004). Consequently, the specific functions a stream may provide are in context of the fundamental system factors controlling channel form (geomorphology) and function, acting in concert with watershed and landscape parameters (environmental setting)

(Figure 4). Several papers across both perennial and non-perennial stream types discuss linked relationships between the processes resulting in channel geomorphology and conditions, and subsequently the biotic and/or abiotic functions that may be provided within a particular stream area (Alluvium, 2010; Bagstad, 2006; Boys, 2006; Davies et al., 2000; Flotemersch et al., 2006; Flotemersch et al., 2010; Levick et al., 2008; Richards, 2002; Sullivan, 2004; M. C. Thoms & Parsons, 2002; Young, 2002). Other recent stream assessment methods have also incorporated related concepts of stream process/form affecting ecosystem structure and function, termed "functional process zones", in context of various channel forms (Martin C. Thoms & Parsons, 2003; James H. Thorp et al., 2010; James H. Thorp et al., 2006; J. H. Thorp et al., 2008). A parallel concept is also expressed through the hydrogeomorphic (HGM) approach for assessing wetland functions, where wetlands within a classification have the same hydrology sources and dynamics and landscape position (including gradient) and thus are expected to provide the same physical, chemical and biological functions (Brinson, 1993; Brinson et al., 1995; Clairain, 1985).

Consequently, detailed information of stream functions as they relate to ecosystem controls and environmental settings, including climate, channel classifications, watershed and landscape parameters would be valuable in improving both qualitative and quantitative assessment methods of non-perennial arid streams in the Arid West and other similar regions across the world. Yet despite this, the available data on documented arid non-perennial stream functions as they relate to ecosystem controls and environmental parameters within the current body of literature has not been thoroughly reviewed. Therefore, the main goal of this dissertation chapter is to comprehensively assemble and evaluate the current scientific literature on two specific areas: (1) the documented functions and services of non-perennial streams in arid

systems, and (2) the subsequent associations of those functions among ecosystem controls and environmental parameters for non-perennial arid stream functions.

Figures

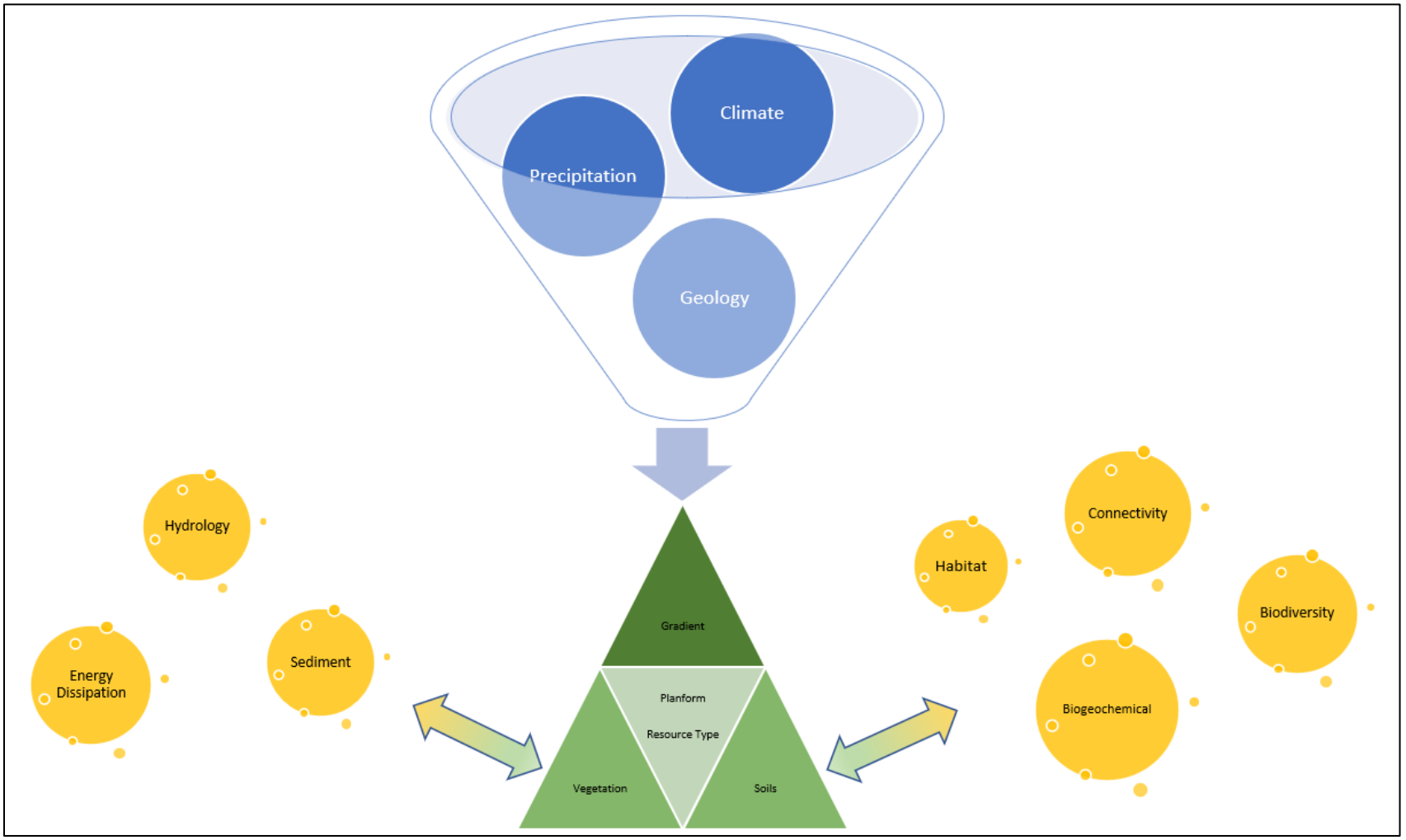


Figure 4. Conceptual relations of ecosystem controls and interrelated stream system forms, environmental parameters and broad function categories.

Methods

To address the functions and services of non-perennial arid streams, a comprehensive, systematic search and evaluation was conducted of peer-reviewed literature. Literature databases were selected for their applicability to relevant subject matter and for peer-reviewed content (Appendix B). The global scientific literature was gathered from a total of ten databases and over 1,100 search queries (Appendix C).

Keywords for performing the structured literature searches for functions and services of non-perennial streams (Table 1), including ephemeral and intermittent streams, were initially identified and developed through primary and secondary background literature (Appendix D) (Table 42). The first main search terms consisted of the category names frequently used to describe arid non-perennial waters in the literature. The full word search strings were generally comprised of three to four search term words, consisting of the type of non-perennial aquatic resource, then "stream" or "river", followed by a stream topic category. The title, abstract, keywords, text, and to a limited extent topic/subject were searched (where available) up through the year 2017, based on a string of search term combinations listed within Table 1. As databases varied widely in design, some word search strings were modified to include only the aquatic resource type names and/or included quotation marks around the search phrase. However, where possible the consistency of searches was maintained within and between databases. Wildcard symbols (typically "*") were also used as necessary for capturing tenses. These modifications provided the necessary flexibility in adjusting search term strings to obtain a higher or lesser number of search results, to ensure the overall amount of literature gathered was of a manageable

size. Appendix C contains flowcharts of the various keyword search approaches utilized for each unique database.

All journal article references gathered using multiple search term combinations, across all ten databases, were compiled, categorized, and analyzed with EndNote X7 and Microsoft Office 365 Excel programs. Reference results were imported into EndNote and combined by main search term categories for each database, with duplicates and irrelevant results then removed. Next, all references for all databases were compiled together by the main search term categories "non-perennial", "intermittent", "ephemeral", "arid", "semiarid", "dryland", "temporary", and "desert", with subsequent removal of duplicates and any irrelevant results. For the purposes of limiting the literature to a manageable volume, as well as to utilize result sets that generally appeared to contain the most relevant results, references from the "arid", "semi-arid", and "ephemeral" main search term categories were ultimately selected and carried forward for further refinement and evaluation. Appendix D includes an additional table and figures depicting various stages of the literature refinement, selection and analyses processes. Electronic PDF copies of all references were obtained through a variety of online sources. The references were updated or corrected in Endnote, along with remaining duplicates removed by both manual and automated methods. The large number of references were subsequently reduced by extensive efforts to remove duplicate references, as well as by initial identification of all inappropriate and irrelevant articles.

Retained articles were subsequently reviewed in depth, aided by within-PDF keyword searches. The available information collected from this in-depth review was initially recorded within Endnote, including country, state, county and city of the study location, watershed and

waterway names, climate classifications, study coordinates, latitude range, the type of study, the types of water(s), the stream functions studied, and a brief description of article content. The Endnote reference information and collected article data were exported to an Excel database and expanded and standardized into single-content columns for ease of manipulation and query analyses. A two-tier hierarchal evaluation was conducted by further in-depth review of journal article content (Figure 5). The first-tier evaluation of the global literature focused on the exclusion of studies based on reasons other than relevant climate type. Each reference was placed into one of four exclusion categories based on a study: lacking subject matter relevance (irrelevant), not involving aquatic resources (not waters related), not involving non-perennial aquatic resources (other waters), or whose stream or flow regime types were not stated or readily discernable (unknown waters). Brief examples of the above excluded irrelevant, not waters related, and other waters article categories included various literature from the medical field, geologic history, computer programming, natural resource mapping, upland-related studies, and studies on wetlands, marine areas, and other non-stream aquatic features. As the focus was on primary literature, non-perennial stream reviews and modeling studies were further eliminated. As information was not consistently located or limited to within title and abstract, full articles for over 2,000 studies were obtained for gathering the information through various body text sections and sometimes through supplemental article documents. The second-tier evaluation focused on the identification and exclusion of studies situated within polar, boreal, equatorial, and warm temperate climate areas, as defined by the Koppen-Geiger climate classification system. Studies that occurred over multiple climate areas were included if non-perennial streams were located within arid climates. For articles that provided general, specific, or no study

sampling coordinate locations, those data were verified, corrected, or generated through an analysis of aerial imagery utilizing Google Earth Pro with high resolution Koppen-Geiger data layers (version March 2017, http://koeppen-geiger.vu-wien.ac.at/present.htm). In some cases, study location identification was also assisted by or relied on information within reference citations, other related published studies, or website information of conservation or watershed areas. The identification and characterization of study locations within the U.S. was further assisted by U.S. Environmental Protection Agency "WATERS Feature Layers" data layers, as well as data layers of the U.S. Army Corps of Engineers' wetland delineation regions and Regulatory and Civil Works boundaries (provided through Data.gov). All GIS study information collected was entered into the Excel database.

The remaining set of arid non-perennial global literature was comprehensively assessed with a focus on gathering further detailed information on the functions and aquatic resources studied and the ecosystem and environmental parameters present (Table 2). The supplementary information collected, recorded and standardized within the Excel database for this final literature set of non-perennial arid stream resources included: the study type(s), the geographic place or region name, name of the resource(s) studied (as applicable), the aquatic resource types and subtypes, confidence of identified study location, stream flow regime type(s), system salinity, function details, classes, and descriptors, channel classification(s), riverine corridor sampling subarea location(s) for applicable non-perennial resources, substrate types, cross-sectional geometry and stream size, watershed sampling position(s), gradient, stream planform type(s), elevation, and habitat cover and type. As part of the analysis of the final literature set, comparisons were made among global and U.S literature subsets across a set of broad functions

comprised of the following categories: Biodiversity, Biogeochemical, Connectivity, Energy dissipation, Habitat, Hydrology and Sediment. These categories were based on a variety of background literature (Appendix D) and to facilitate data categorization across the vast breadth of subject literature, study types and purposes. Some of the broad function categories included subcategories to split out discrete subtopics, such as “animal” and “plant” within the broad Habitat category (Table 2). If more than one function category was included within a study, the main function examined was assigned a “primary” designation, with other functions recorded in descending order of study focus.

Not all environmental parameter information selected for evaluation was obtainable or utilized from the set of studies. The limited gradient, elevation, cross-sectional form and stream size data were not analyzed, as most arid non-perennial stream literature did not include this information. However, watershed position was included or surmised from approximately half of studies, and as a common proxy for gradient and system energy this information was utilized in further analyses. Soils information was also available in roughly half of the studies, and vegetation information had been included in most articles. However, the information provided for these environmental parameters was general in nature and not necessarily limited to in-channel and/or associated floodplain, with occasional references to the soils or vegetation being provided as occurring within the general vicinity of the area or study region. Therefore, due to inconsistencies and lack of specificity, soils and vegetation were not carried forward for further data analyses. Appendix G includes figures depicting the availability of environmental settings data. Thus, the core analyses focused on arid non-perennial stream functions as they relate to climate and streamflow for the global and U.S. literature, with the inclusion of the environmental

parameters. Similarly, for the purposes of focused data analysis, only the primary stream function category of each study was addressed. Analyses were conducted through combinations of Excel data set queries and pivot tables and focused on the presence and associated patterns of independent ecosystem drivers and localized dependent environmental parameters in relation to documented functions, including basic reference information, geographic location, arid climate aspects of temperature and seasonality of precipitation, stream flow regime, stream planform, river corridor sub-resource type, and watershed or stream network positions.

Overall results were typically examined in terms of available information, across climates and arid subclimate types (subclimes) (hot desert - BWh, hot steppe - BSh, cold desert - BWk, and cold steppe – BSk), all non-perennial stream types, and global and U.S. studies. Due to the importance of hydrology in these water-limited systems, results were also grouped and evaluated in part by the arid non-perennial stream data set as a whole, as well as by a data subset including only those studies with specified ephemeral and intermittent streamflow. The non-perennial stream data set included all streamflow categories of ephemeral, intermittent, and unspecified non-perennial and all other data subcategories (including “unknown”). The focused ephemeral and intermittent streamflow data set excluded studies that could only be assigned a generic non-perennial streamflow classification and excluded “unknown” value categories. As these arid stream systems are fundamentally water-limited, differences due to hydrology are expected in part by seasonal precipitation (steppe and desert) and in part by streamflow regime (ephemeral and intermittent). Furthermore, these systems are inherently subject to other governing climatic aspects, including temperature. Therefore, primary function data was viewed in both detailed combination and summary formats with various data layer combinations,

including with and without temperature (hot and cold, and subclimes), and separately and in combination with precipitation and streamflow. While the non-perennial stream data set was used for basic data layering comparisons of an environmental parameter with primary functions, with primary functions and subclimes, and with primary functions, subclimes and streamflow, the focused ephemeral and intermittent streamflow data set was utilized for those same data layerings and all other associations of primary functions with streamflow, temperature (hot and cold, sublimes), precipitation, and individual environmental parameters. These data layer relationships were examined by counts and percentages as they related to the primary function categories, as well as from the contrasting perspective of by percent primary function categories within data layers.

Tables

Table 1. Systematic keyword and main search term categories for stream functions, services, characteristics and values literature are depicted in columns 1-2. These are in part developed from the literature in Table 42, as well as (Lefebvre, Lichvar, & Curtis, 2013) and (Lefebvre, Lichvar, Curtis, et al., 2013).

First Literature Search Term: Aquatic Resource, Climate	**Second Literature Search Term: Basic Functions**
Non-perennial Intermittent Ephemeral Arid Semiarid Dryland Temporary Desert -Stream -River	Functions Services Values Characteristics Classification

Table 2. Broad function categories and environmental parameters utilized for data collection within the literature. These are in part developed from the literature in Table 42, as well as (Lefebvre, Lichvar, & Curtis, 2013) and (Lefebvre, Lichvar, Curtis, et al., 2013).

Within Literature: Broad Categorization of Functions	**Within Literature: Categorization of Hydrogeomorphic, Watershed, Landscape and Location Study (Environmental) Parameters**
Functions	***Physical Parameters***
Biogeochemical	Channel form* (see below)
Nutrients/Heavy metals/Radioactive	Cross-sectional form
Organic matter/carbon	Elevation
Physicochemical/salinity/other	Gradient/slope
Sediment	Soil/substrate type
Suspended/Dissolved	Habitat/vegetation cover types
Bedload	Stream size/width
Sediment	Riverine corridor subareas
Channel form	***Stream Planform Type****
Habitat	Alluvial fan
Animal/Invertebrate/Diatom	Single-thread/single/straight (upper/middle/lower)
Plant/Zooplankton/Fungi	Meandering
Bacteria/Microorganism/Algae	Compound
Energy Dissipation	Braided
Hydrology	Discontinuous
Biodiversity	Anastomosing/anabranching
Connectivity	Headwaters
Ecological/landscape	classification
Vertical/Longitudinal/Lateral	Prairie
	Delta
Function Descriptors	Distributary
Storage/Retention/Detention	
Removal/Sequestration/Sink	
Source/Supply	
Cycling/Spiraling/Transformation	***Other***
Transport/Exchange	Flow regime
Regulation/Moderation/Lag	Climate
Maintenance/Support	
Quality/Quantity	

Stream/Watershed Location
Stream order/type
Watershed position (upper/middle/lower)
Country/State/County/City
Latitude/Longitude
LRR (U.S.)
Corps Division (U.S.)
Corps Region (U.S.)
Koppen climate

Figures

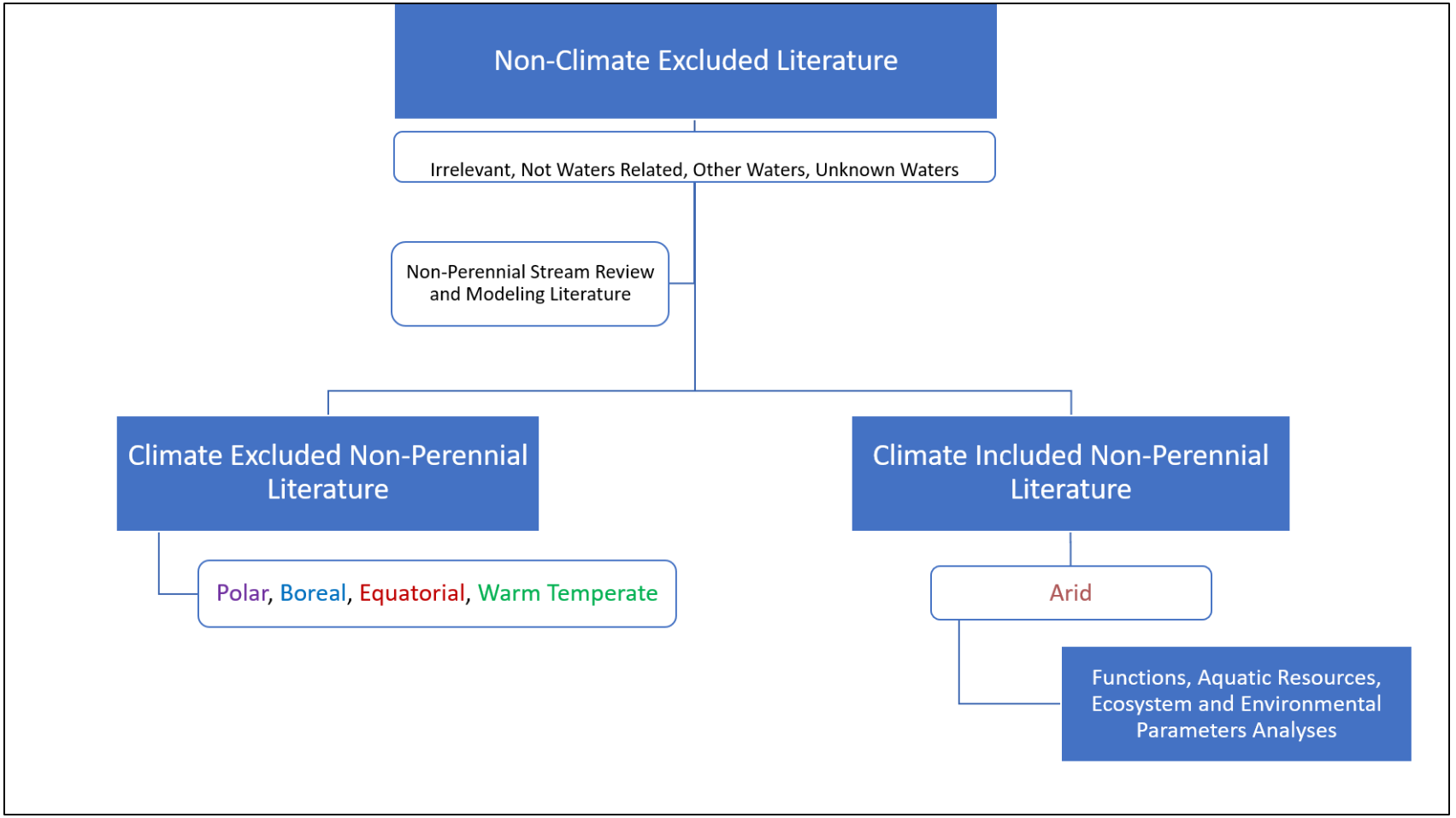


Figure 5. Two-tiered hierarchal evaluation of literature, excluding studies for non-climate reasons, geospatial analyses and exclusions for climate reasons, and subsequent analyses of arid non-perennial stream studies.

Results and Discussion

Literature Results Summary

The database searches resulted in a much larger volume of literature than anticipated. A total of 5,353 references comprised the initial condensed set of literature. Within the first evaluation tier the large number of references were subsequently reduced by extensive efforts to remove duplicate references, as well as to identify all appropriate and relevant articles (Appendix D). The second tier of literature evaluation included the georeferencing and assignment of Koppen-Geiger climate classification for 493 studies. Though non-perennial stream studies were found within other warm temperate, equatorial, boreal and polar climates, as they are not within the scope of this study those results are presented in Appendix E. The final complete set of arid non-perennial stream literature totaled 310 studies worldwide (Appendix H), spread over 30 countries (Figure 6).

The highest global occurrence of research locations including arid non-perennial streams was within the U.S. (37%), surpassing both Spain (10%) and Australia (17%), followed by Israel (9%) and China (5%) as the top five countries. This was unexpected, given the majority of Australia is semi-arid and that Africa contains the highest percentage of the world's arid areas (Tchakerian & Pease, 2015). Most large arid regions have been noted generally to occur within the 24-degree latitude bands in the northern and southern hemispheres (Tchakerian & Pease, 2015), but the results from this study reflect most research locations (80%) occurring at higher latitudes (Figure 8). It's possible this difference is attributable to the conservative nature of Koppen-Geiger arid climate classifications, which was noted during the process of

georeferencing studies. Furthermore, over half of the studies were situated within the northern hemisphere, as compared to slightly over a quarter of the studies falling within the southern hemisphere. Only two of the 310 global studies included arid non-perennial stream sampling co-locations in another country, and 15% of the studies included research locations across multiple subclimes. In the U.S., within the nine states where arid studies involving non-perennial streams occurred, there was also a pronounced concentration of study locations (86%) within two states, Arizona and New Mexico. These two states, however, only comprise slightly over a quarter of the entire area of all eleven states encompassing the Corps' Arid West delineation region (Figure 7). Similar to worldwide literature, only three out of 115 studies within the U.S. co-occurred in multiple states, along with almost a quarter of studies including research locations across multiple subclimes. As to how studies from the global and U.S. literature sets gathered data on arid non-perennial streams and functions, field data collection dominated all broad function categories, followed by remote sensing (Figure 15). This trend was also present within data gathered within U.S. states (Figure 16). Over time, U.S. studies generally matched global trends with increases in field studies, as well as decreases in laboratory studies, though at lesser rates. (Figure 17, Figure 18).

In terms of arid non-perennial stream research published over time, it also appears the events beginning with and following Rapanos at least in part contributed to an upward trend from the year 2006, within both the U.S. and worldwide (Figure 9). Although these results are specific to arid climate non-perennial stream studies, they are consistent with a larger broad trend of increased non-perennial stream research over time as noted in other papers (Leigh et al., 2016). Though studies within the U.S. are greater on average post-Rapanos as compared to pre-

Rapanos, research in the U.S. appears to have plateaued, while global studies have continued to increase. Worldwide attention to climate change and water resources may also be fueling both global and U.S. arid non-perennial research. The overall static trend within the U.S. is surprising considering the numerous WOTUS regulation changes from different Administrations and associated litigation that has occurred through 2017. However, the overall U.S. trend only captures arid non-perennial studies as compared to non-perennial studies throughout all climate types, and it is also influenced by the predominance of studies within arid cold climates. When observing the major hot and cold climate divisions of arid global and U.S. studies over time, both climate areas within the U.S. are on a slowly increasing trajectory, while those in all global literature have similar but steeper trends (Figure 4, Figure 10).

Use of the Koppen-Geiger climate classification system of study locations allowed for evaluation of the arid subclimes, as well as the subclime subdivisions of hot and cold arid (temperatures) and steppe and desert (precipitation types) worldwide (Table 3). Climate is a fundamental system control on the formation and maintenance of and physical, chemical and biological processes within watersheds (Figure 4) (David et al., 2021; Harman et al., 2012). Global arid studies have a slightly higher occurrence in hot compared to cold arid regions. Yet the opposite was true for study locations within the U.S. Furthermore, there is a similar trend of most study occurrences within cold steppe subclime areas of global and U.S. arid regions (Figure 11), followed closely by occurrences in the opposite end of the subclimes spectrum, hot desert areas. In terms of patterns of global and U.S. research occurring within the various arid subclimes over time, U.S. and global studies display similar trend with the highest situated within the cold steppe subclime, followed in order of decreasing rate by hot desert, hot steppe,

and cold desert (Figure 12). Future estimates of climate change influence on the occurrence of arid climates by latitude predict an expansion of these subclimes to mid- and high latitude regions, as well as an increase in arid areas within the U.S. (Cui et al., 2021).

Though precipitation is an inherent element of climate, it is also a critical component of the overall system hydrology (along with streamflow) within these arid water-limited systems (Hammond et al., 2021; Harman et al., 2012; Shanafield et al., 2021). In terms of the Koppen-Geiger seasonal precipitation patterns, both global and U.S. studies generally have a higher occurrence in steppe compared to desert areas (Figure 13). When observing these major precipitation types within arid global and U.S. studies over time, both U.S. and global studies exhibit similar trends of steppe situated studies outpacing increases in desert situated study locales (Figure 14).

The terminology and definitions used in the global literature to describe ephemeral and intermittent stream types and their associated flow regimes was highly inconsistent, and frequently streamflow terms were not used at all within the published studies. Moreover, in some cases the description of the hydrologic regime or streamflow types was in direct conflict with the streamflow terms used. Others have noted these issues with streamflow definitions and inconsistencies (Arthington, 2014; Shanafield et al., 2021), though the degree to which that was encountered was still surprising. Both global and U.S. literature sets examined arid ephemeral streams the most, followed by intermittent streams and then the generic non-perennial streams classification for studies whose specific flow regime could not be readily determined (Figure 19). This non-perennial streamflow group comprised 15% of the global studies, followed slightly by 8% for U.S. studies. Though this lack of streamflow specificity was lower for U.S. studies, for

the states of California and New Mexico, with New Mexico being one of the two states that dominated most of the U.S. literature, there was the highest percentage of state studies that lacked clear streamflow regime information. Fortunately, the trend over time in U.S. for studies including unspecific non-perennial streams has been almost static, while increases are highest for ephemeral streams, followed by studies involving intermittent streams. These trends are the same for the global literature set, though the rates of increase are greater for all three flow regime categories, including for those studies with general non-perennial flow regimes (Figure 21, Figure 22). As arid, non-perennial stream systems are fundamentally water-limited, and hydrology has been described as the prevailing forcing function (Hart & Finelli, 1999; Naiman, 2008; Poff et al., 1997), differences due to hydrology are expected in part by streamflow regime (ephemeral and intermittent). Thus, it's imperative that published studies continue on a trend of clearly include accurate information on streamflow regime, for both individual study and wider meta-studies applicability.

Similar to streamflow regimes, several other basic study information categories as a whole were not ubiquitously present within published literature (Appendix G), were present but not in compatible formats, or had questionable accuracy. This has significant implications and complications, as it could result in individual studies neglecting the consideration of relevant factors within their analyses, as well as exclude the use of valuable data outside of the individual study. Furthermore, as there is an increase in quantitative synthesis and reviews conducted on the growing bulk of literature, those efforts would continue to be hampered by the lack of core background study information that would be ideal to include within all published studies. Availability of some basic study information, such as soils, habitat, elevation, gradient, elevation,

cross-sectional channel form and stream size, limited data that could be initially collected as part of this study. Other data, such as specific coordinates of sampling sites, flow regimes, watershed and hydrogeomorphic parameters, then further complicated or limited the analyses that could be conducted due to their importance in arid non-perennial stream systems and their functions. In the absence of universal publishing standards, researchers should take care to provide in a standardized format the basic study background information for the purpose of expanding the applicability and used of data beyond individual studies.

The following sections cover in more detail the overall results on stream functions, along with stream functions in the context of climate, hydrology components, and environmental parameters.

Tables

Table 3. Global and U.S. non-perennial stream locations and occurrences by study countries within Koppen-Geiger broad hot and cold arid climates, with further subdivisions among temperature and seasonal precipitation types.

Study Locations	Hot Arid		Cold Arid	
Worldwide	200		160	
U.S.	60		83	
(U.S. %)	(30%)		(52%)	
	Desert	Steppe	Desert	Steppe
Worldwide	110	90	35	125
U.S.	30	30	10	73
(U.S.%)	(27%)	(33%)	(29%)	(58%)

Figures

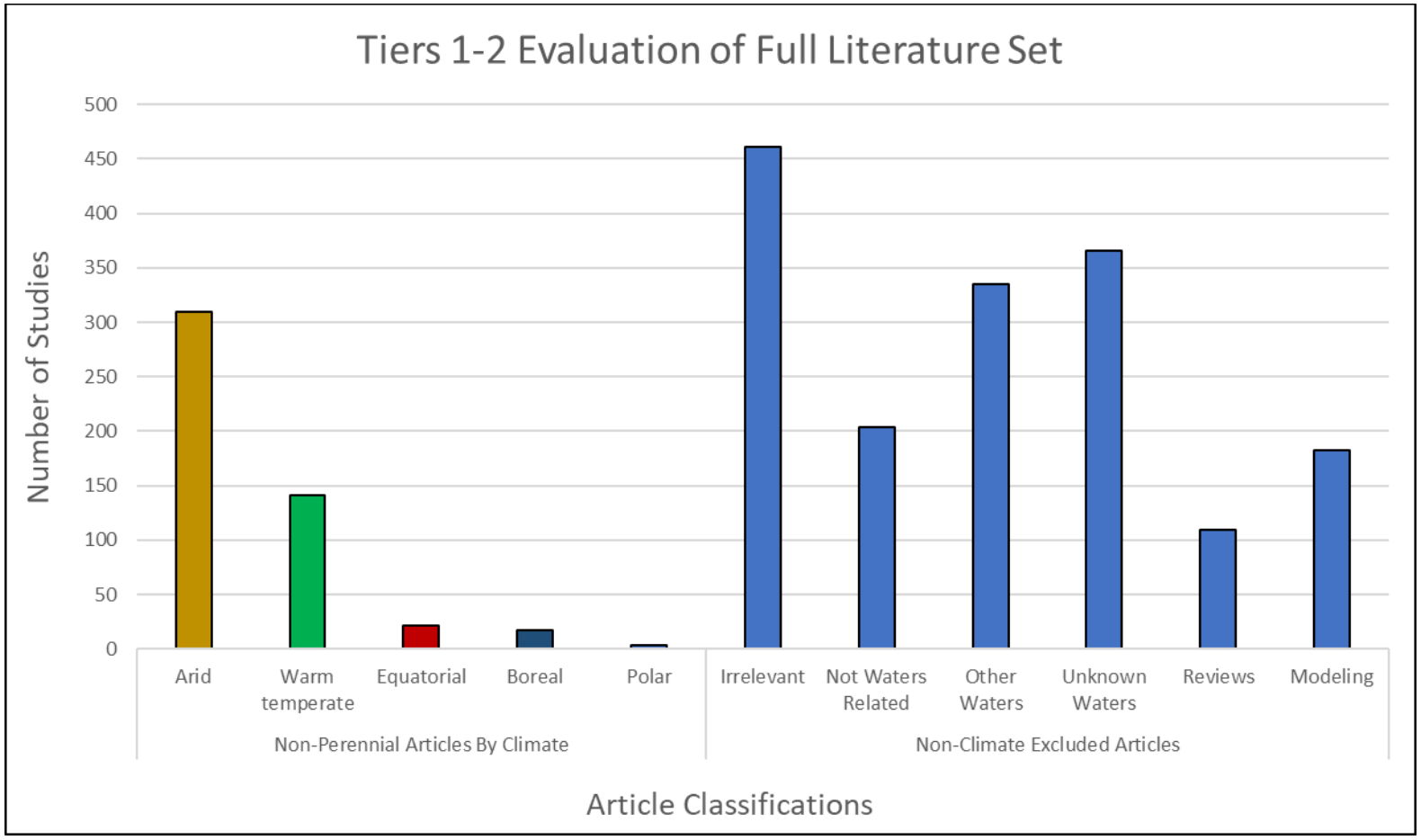


Figure 6. Final literature results across climate and other article classification categories.

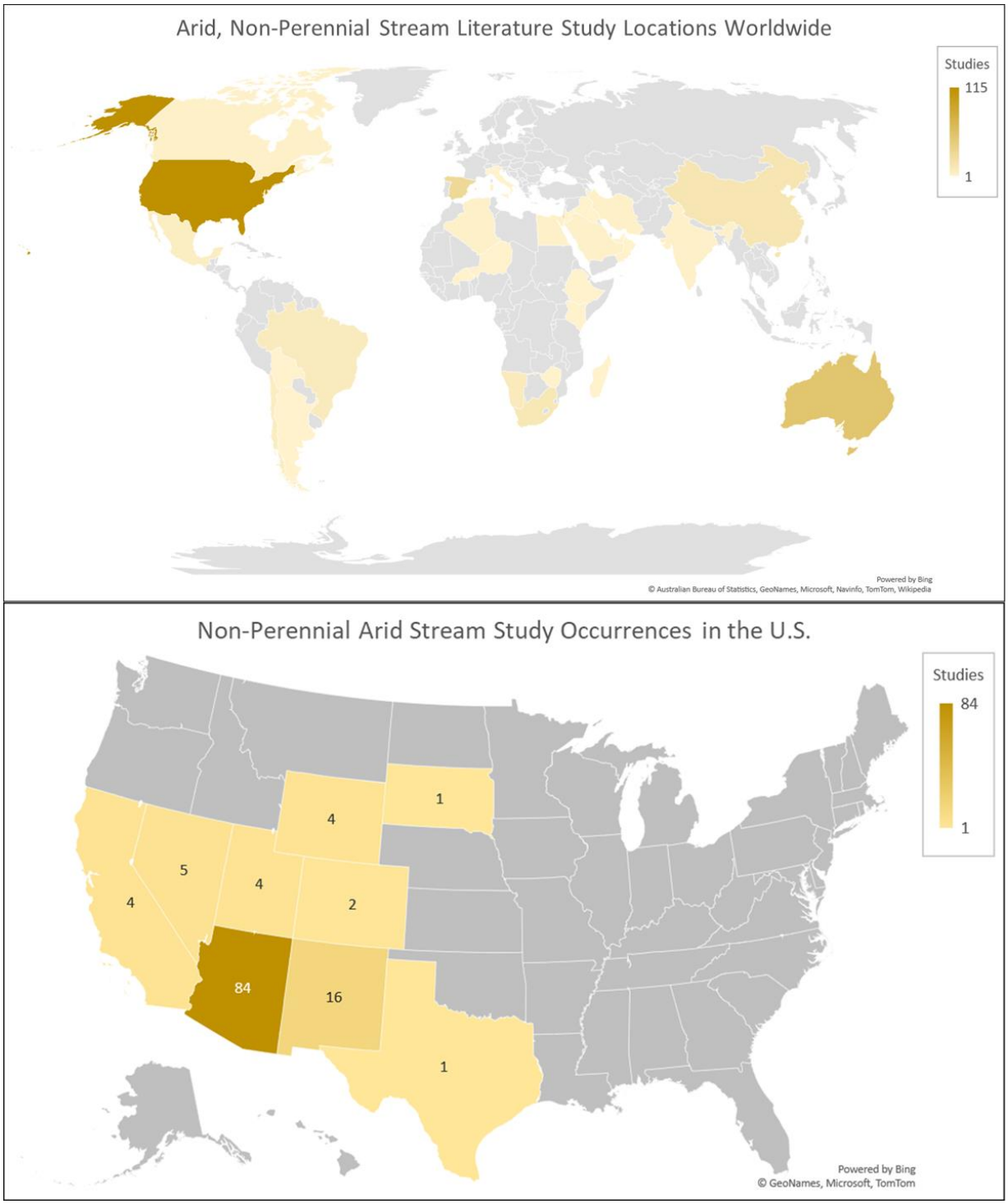


Figure 7. Global and U.S. study locations of articles located in arid climates. The Corp's Arid West region encompasses portions of California, Nevada, Oregon, Washington, Idaho, Wyoming, Utah, Colorado, Arizona, New Mexico, and Texas.

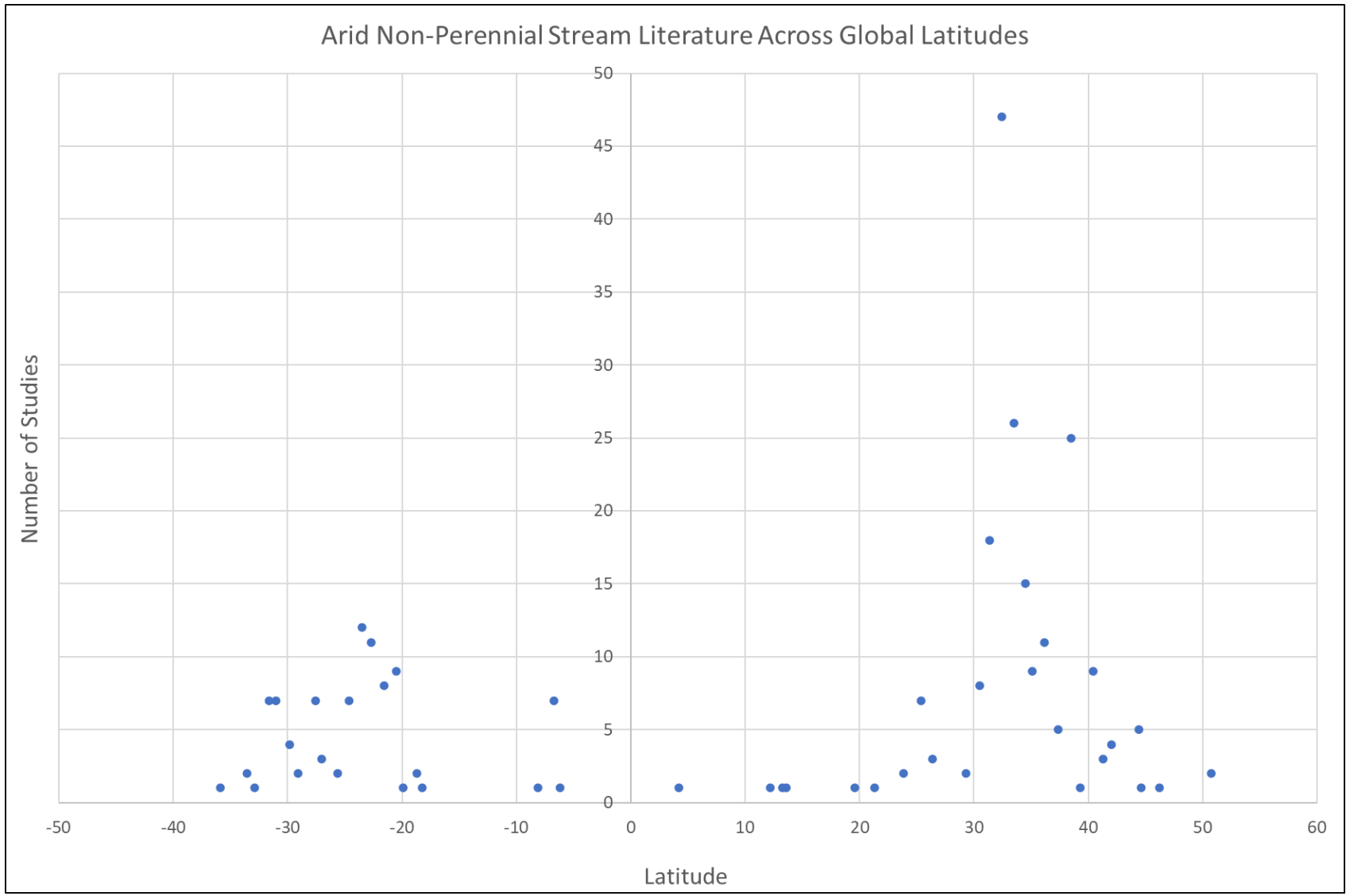


Figure 8. Distribution of georeferenced non-perennial stream study locations in arid climates worldwide by latitude.

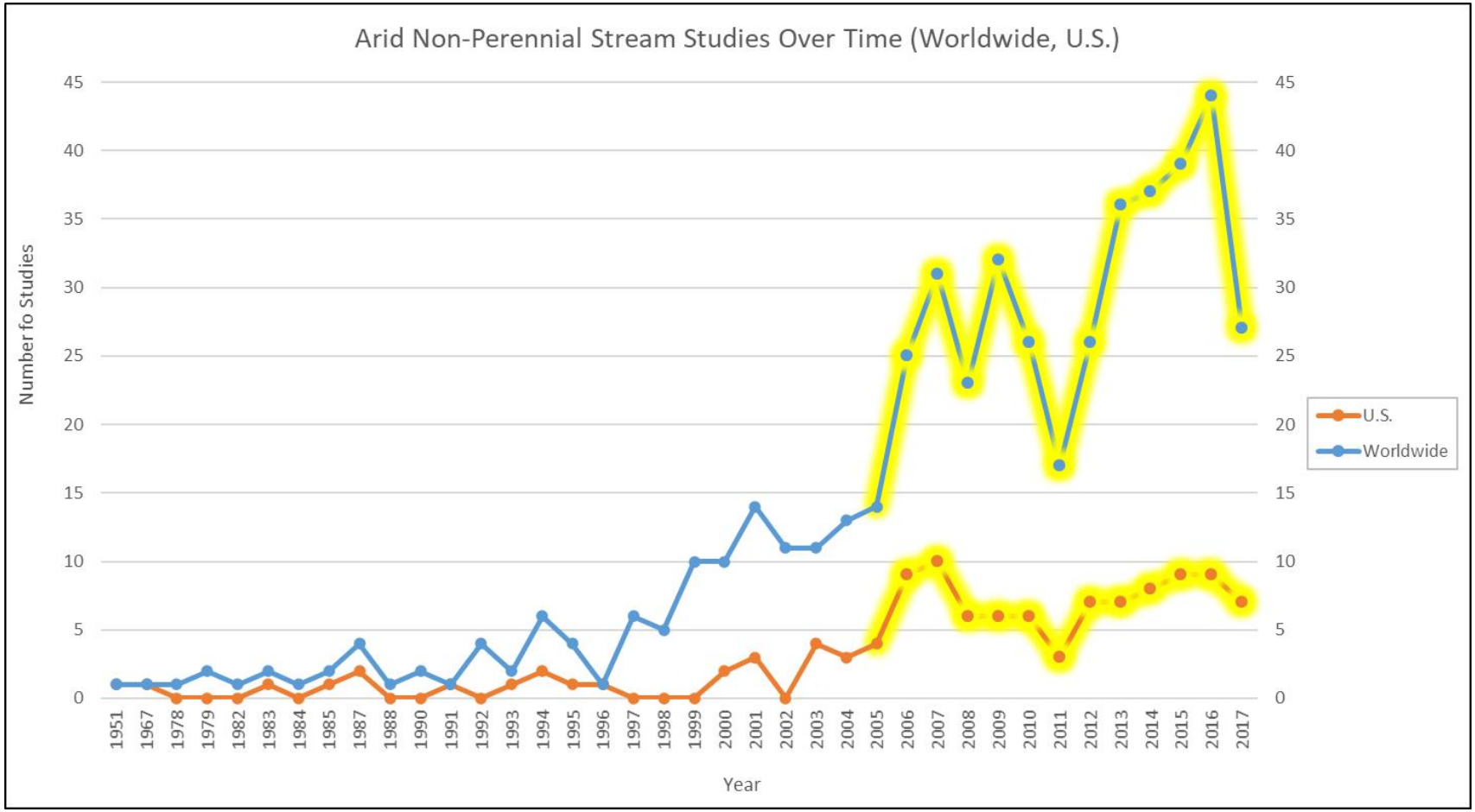


Figure 9. Comparison of pre-and post-Rapanos (highlighted) arid non-perennial stream literature produced globally and within the U.S.

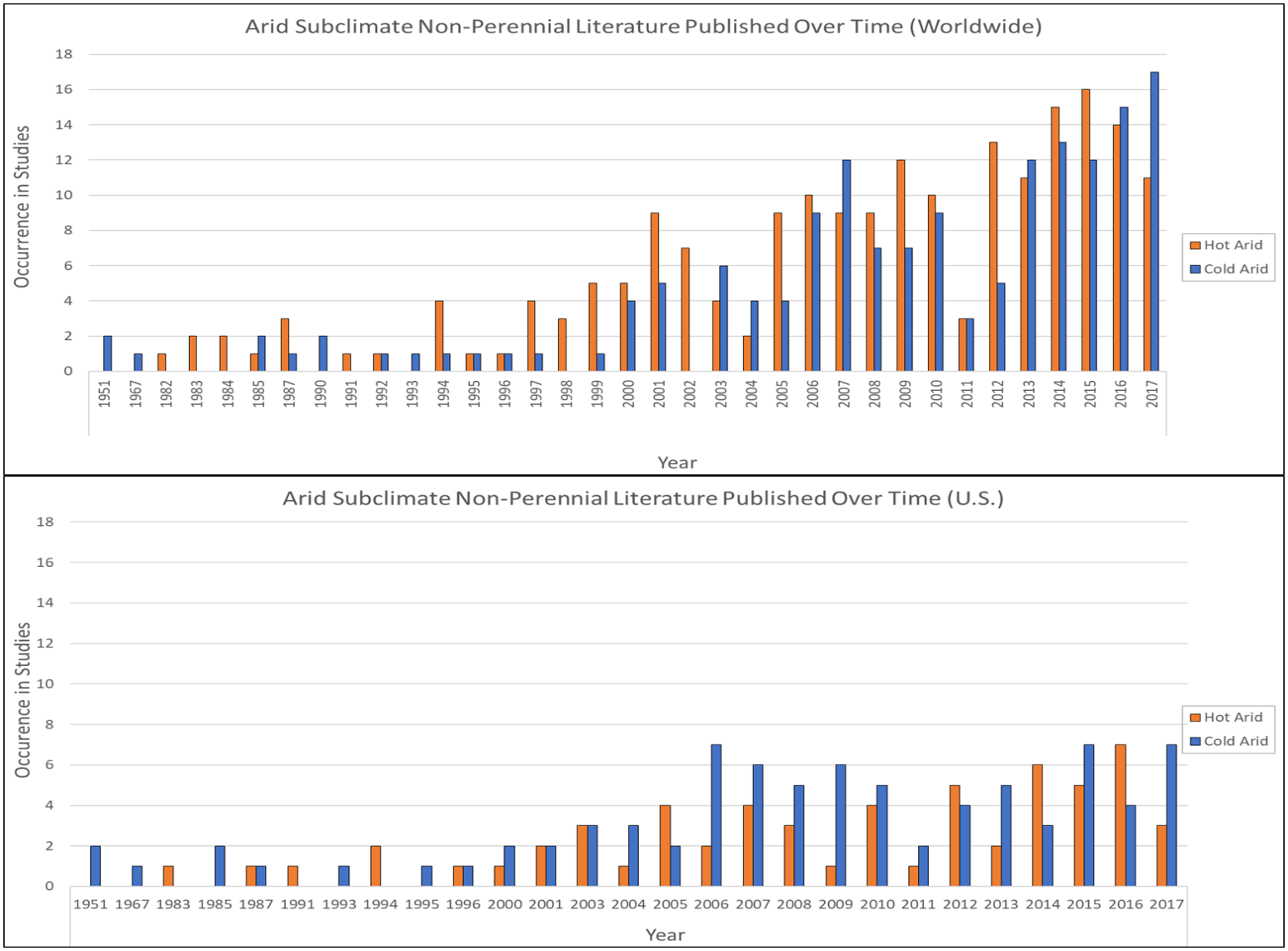


Figure 10. Non-perennial stream studies of hot and cold arid subclimates published over time worldwide and within the U.S.

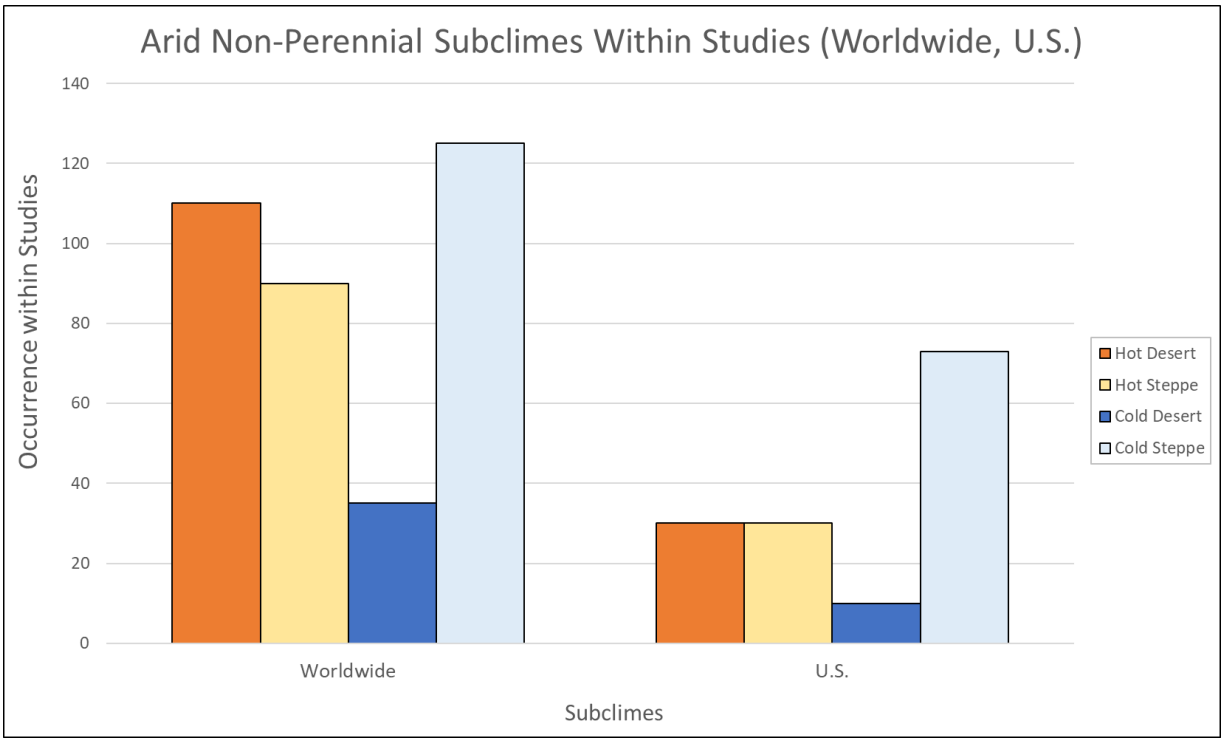


Figure 11. Non-perennial arid stream studies by subclime type, globally and within the U.S.

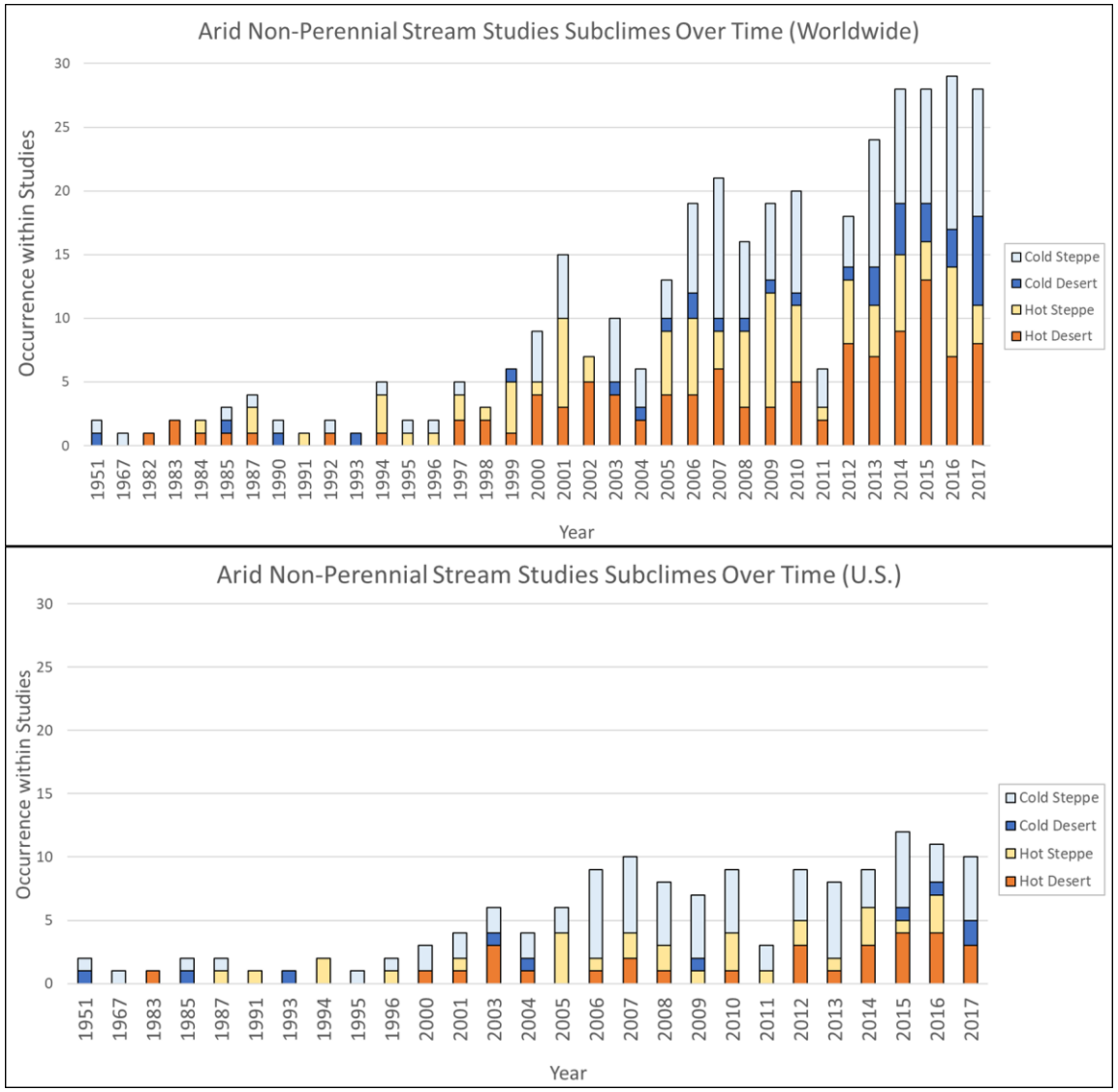


Figure 12. Non-perennial arid stream studies published over time by subclime type, globally and within the U.S.

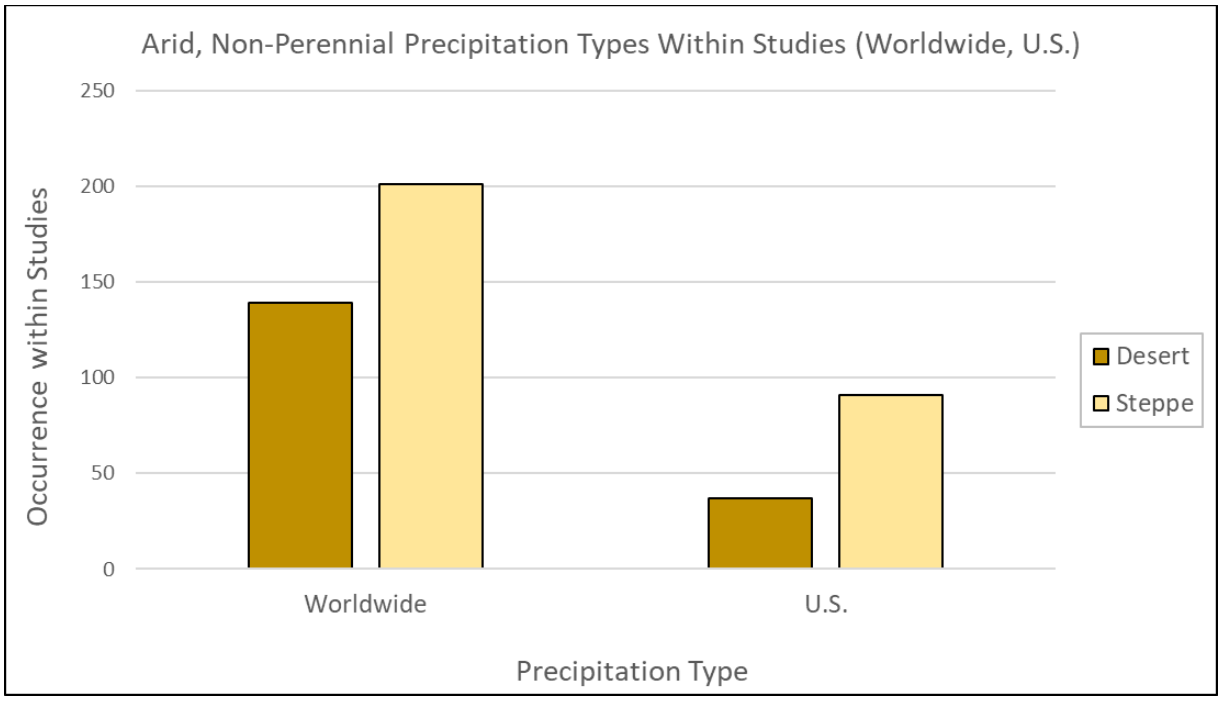


Figure 13. Non-perennial arid stream studies by precipitation type, globally and within the U.S.

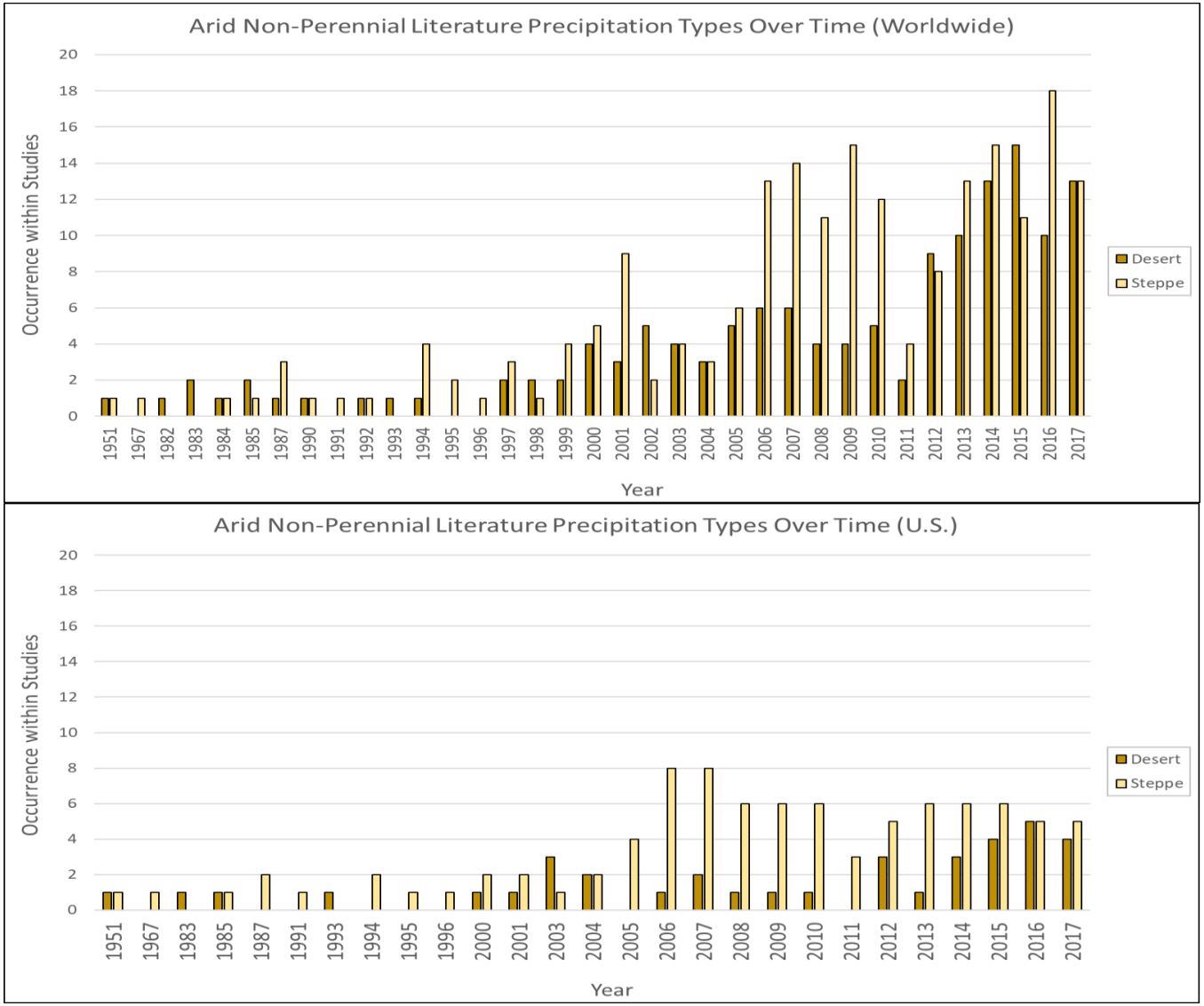


Figure 14. Non-perennial arid stream studies published over time by precipitation type, globally and within the U.S.

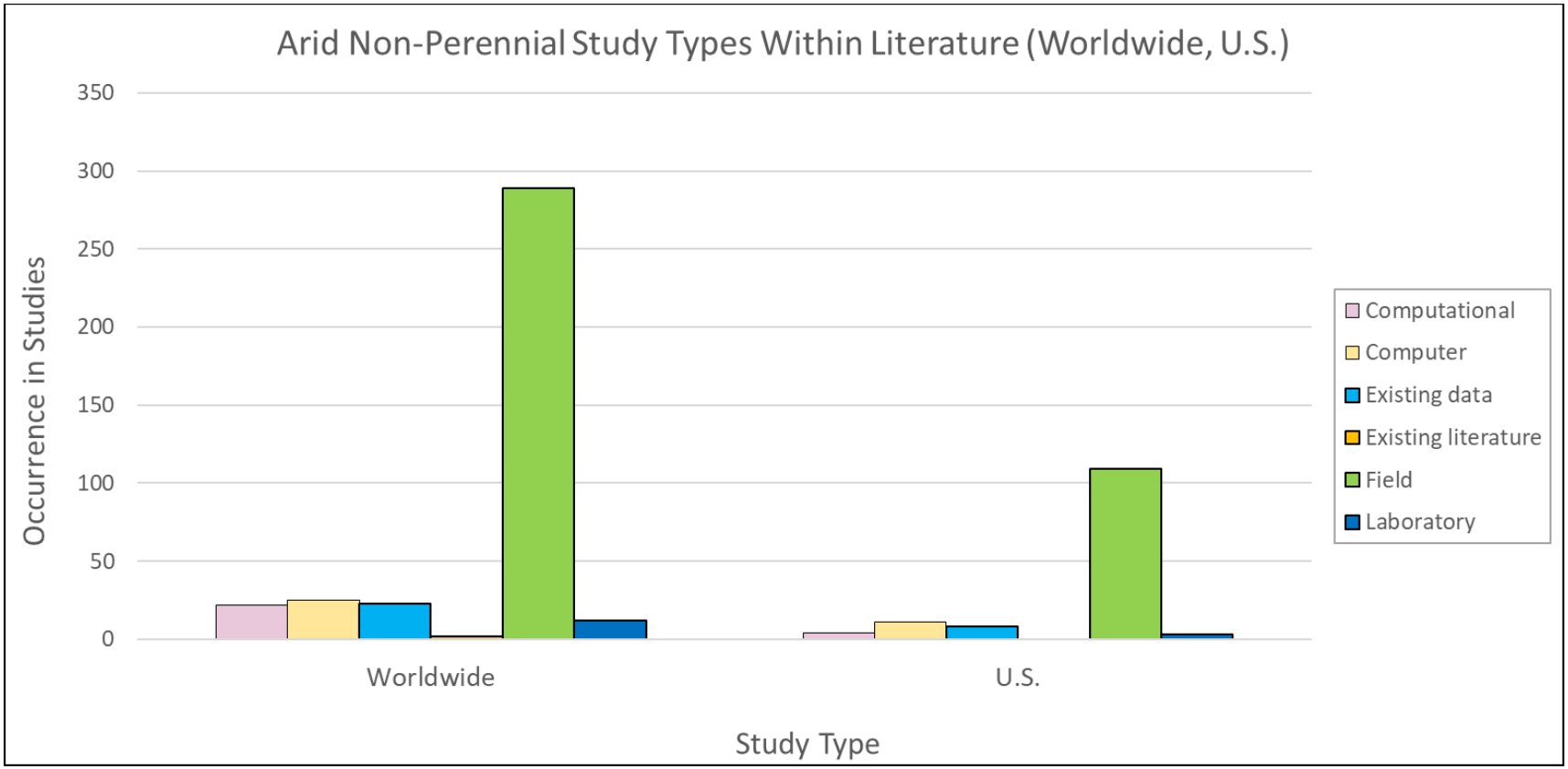


Figure 15. Occurrence of study types across non-perennial arid literature, globally and within the U.S. The computer and computational categories include remote sensing and equation computations, respectively.

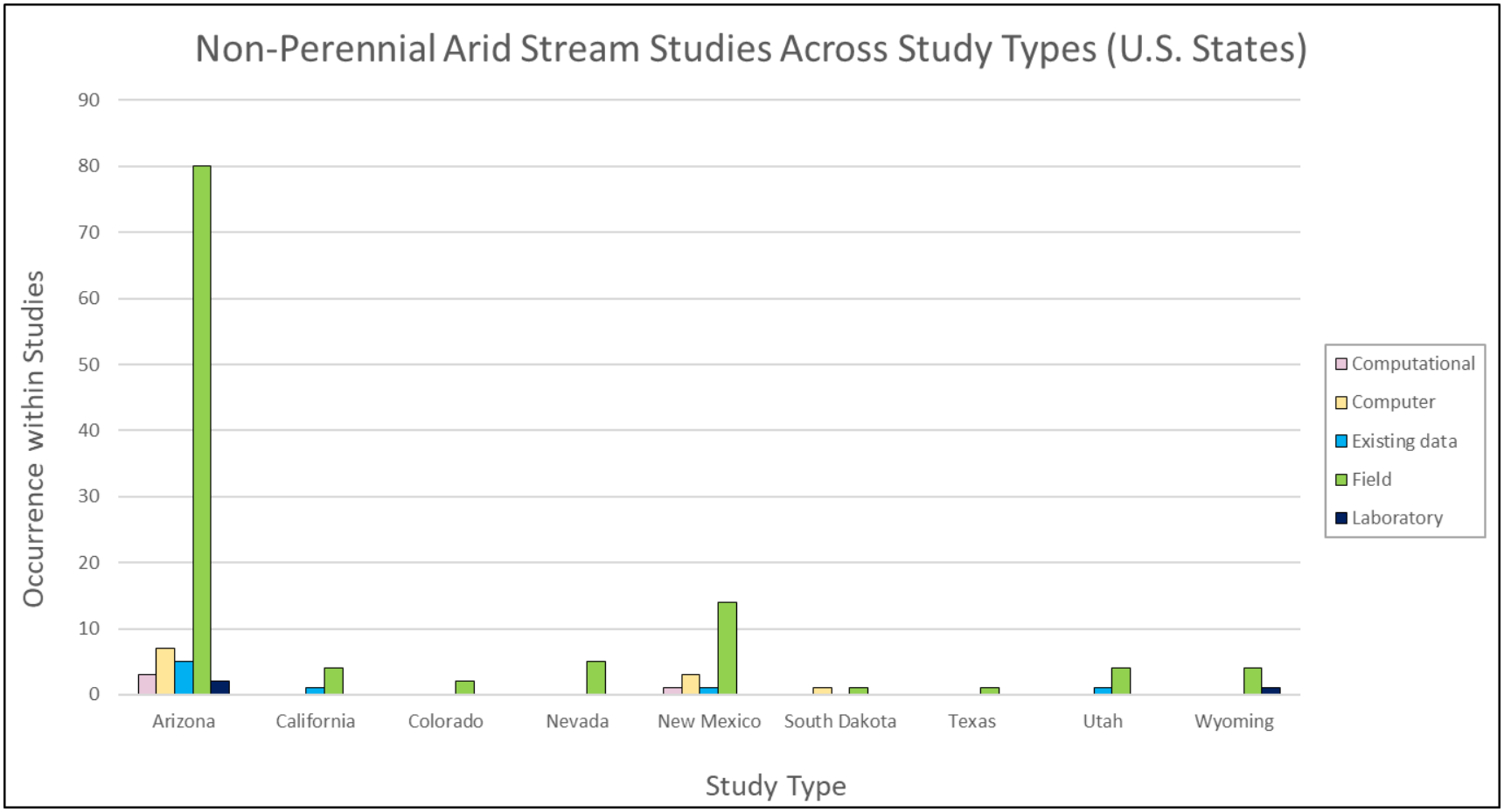


Figure 16. Non-perennial arid stream studies by study type within U.S. states.

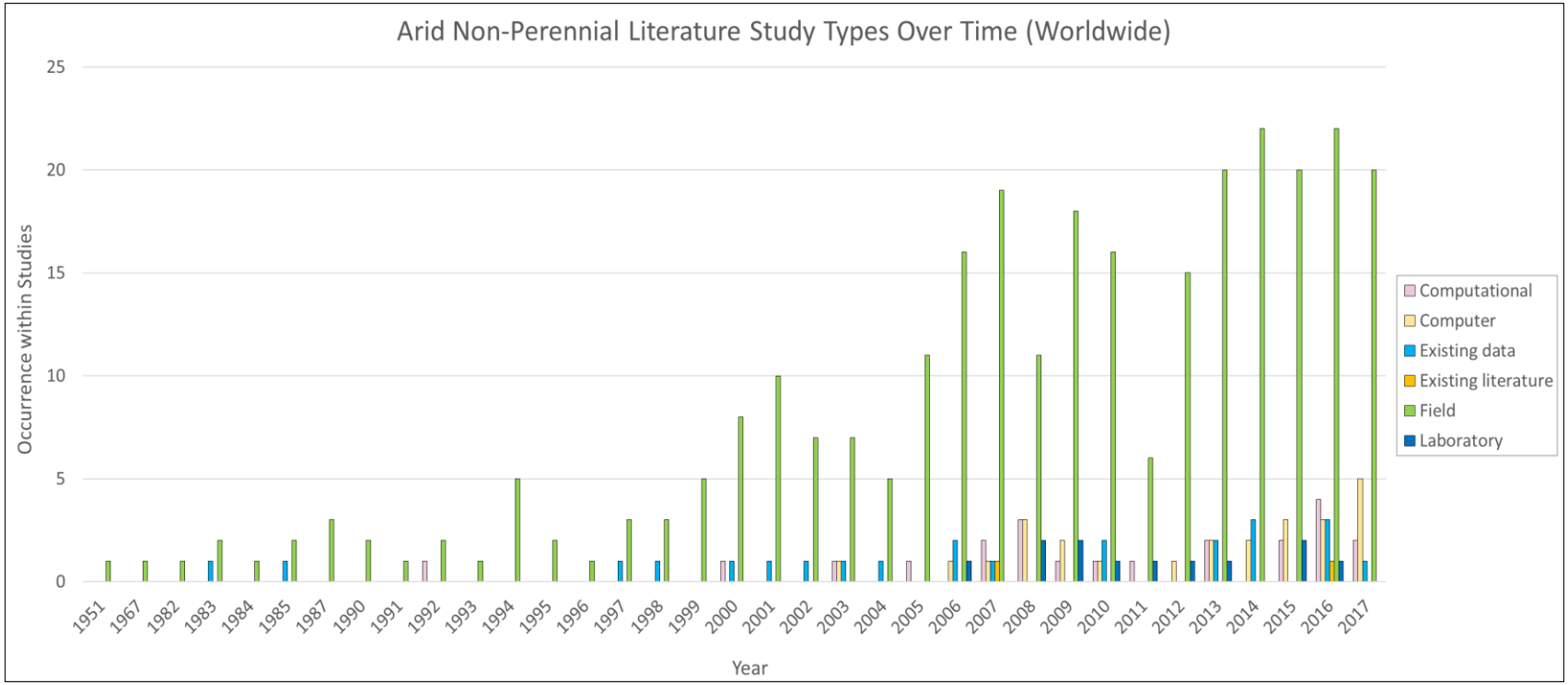


Figure 17. Non-perennial arid stream studies published over time by study type, globally.

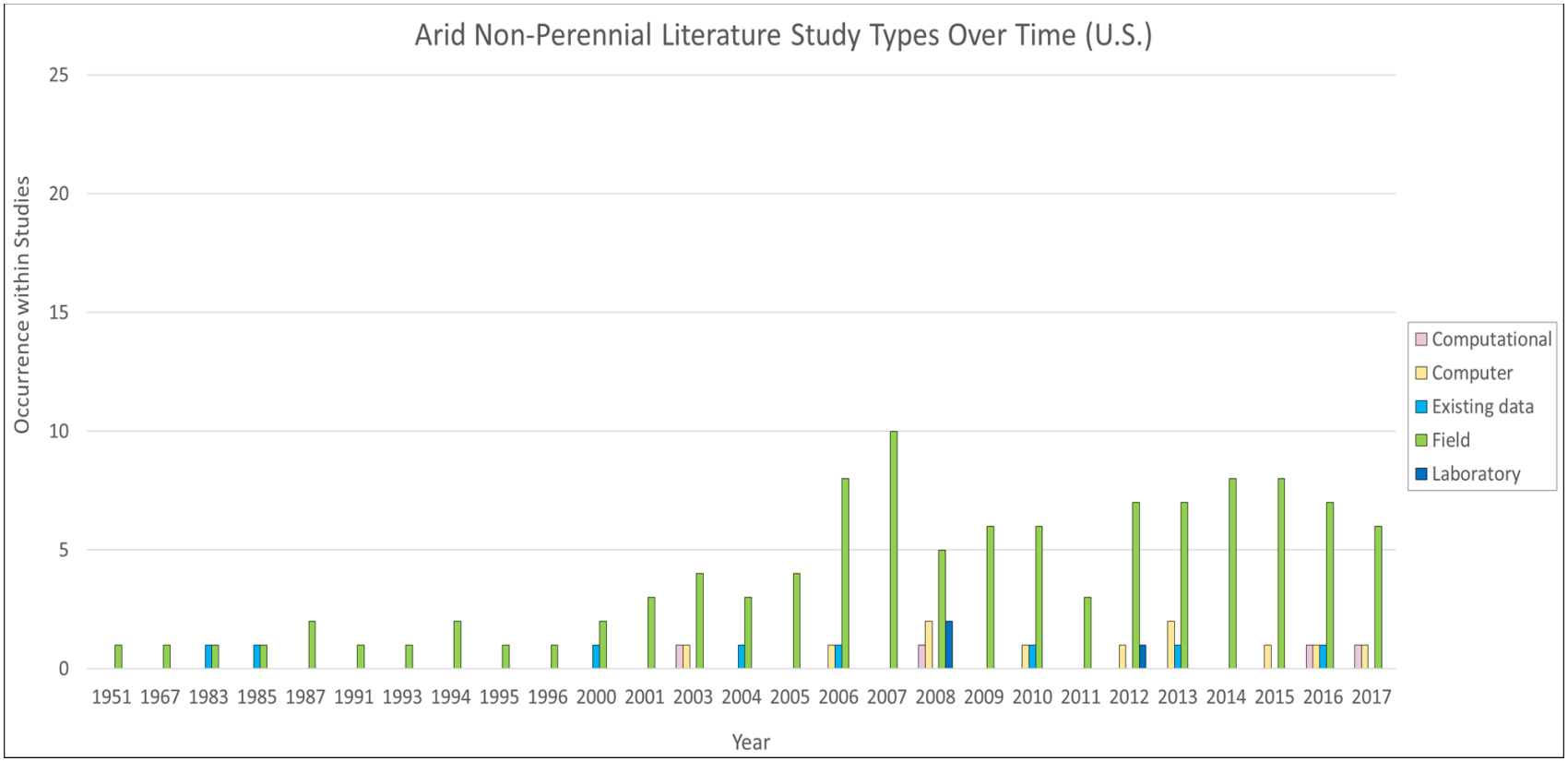


Figure 18. Non-perennial arid stream studies published over time by study type, within the U.S.

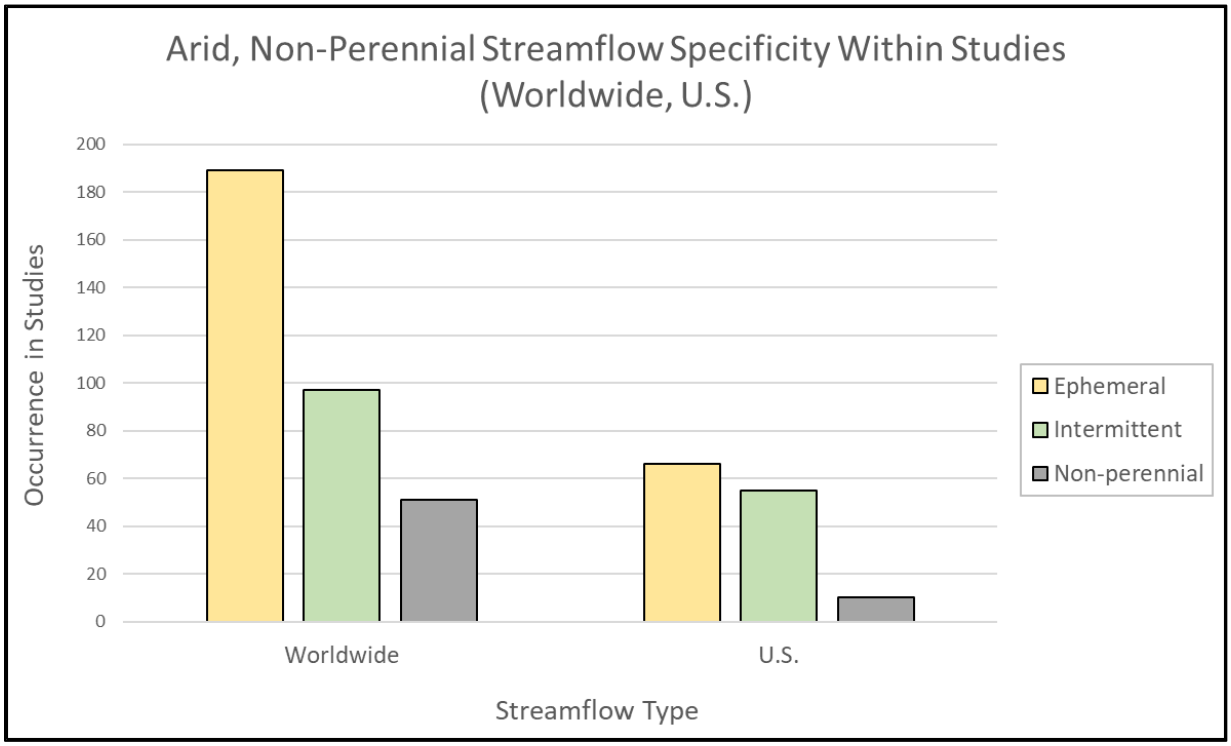


Figure 19. Non-perennial arid stream studies by streamflow specificity type, globally and within the U.S.

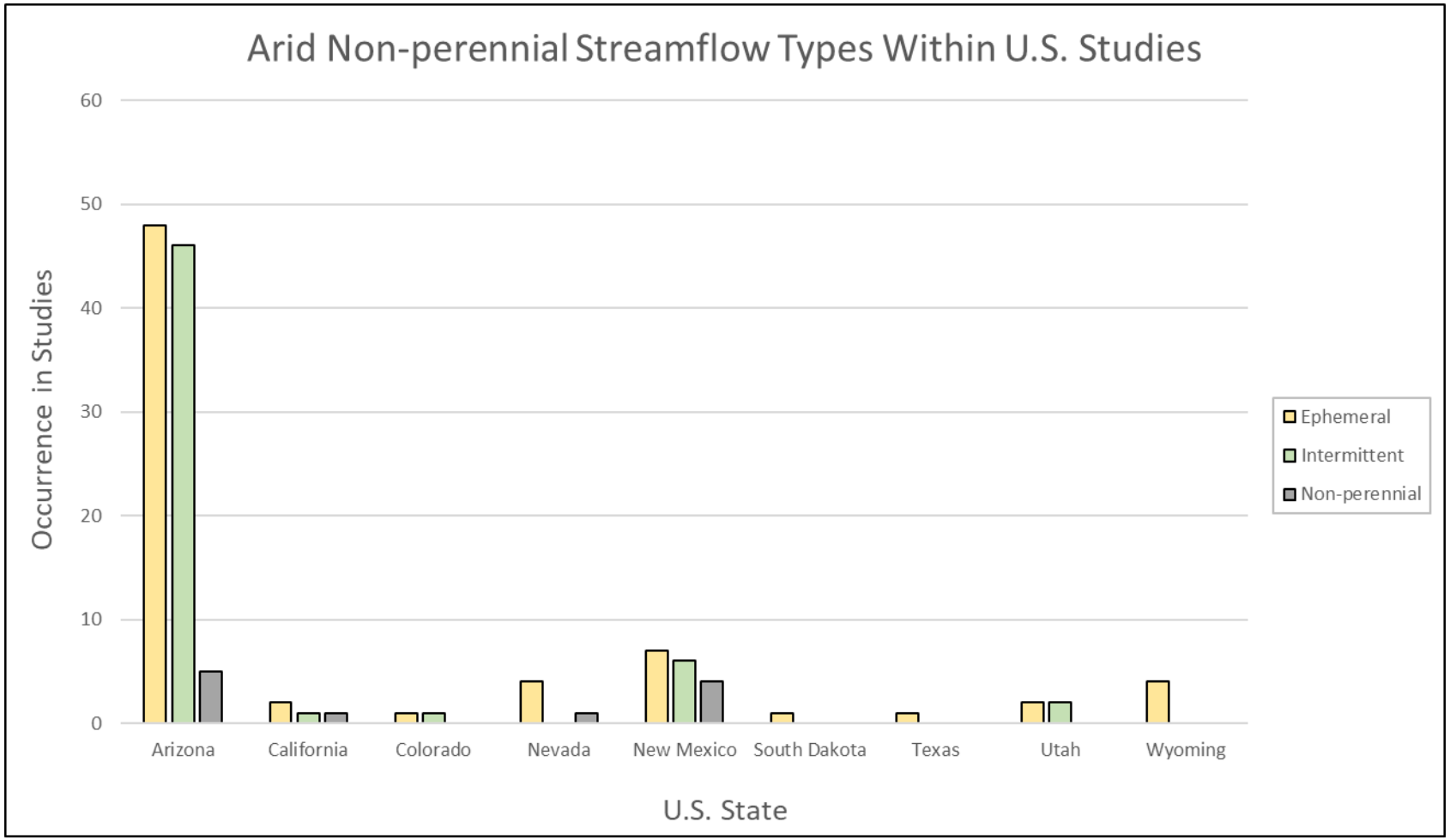


Figure 20. Non-perennial arid stream studies by streamflow specificity within U.S. states.

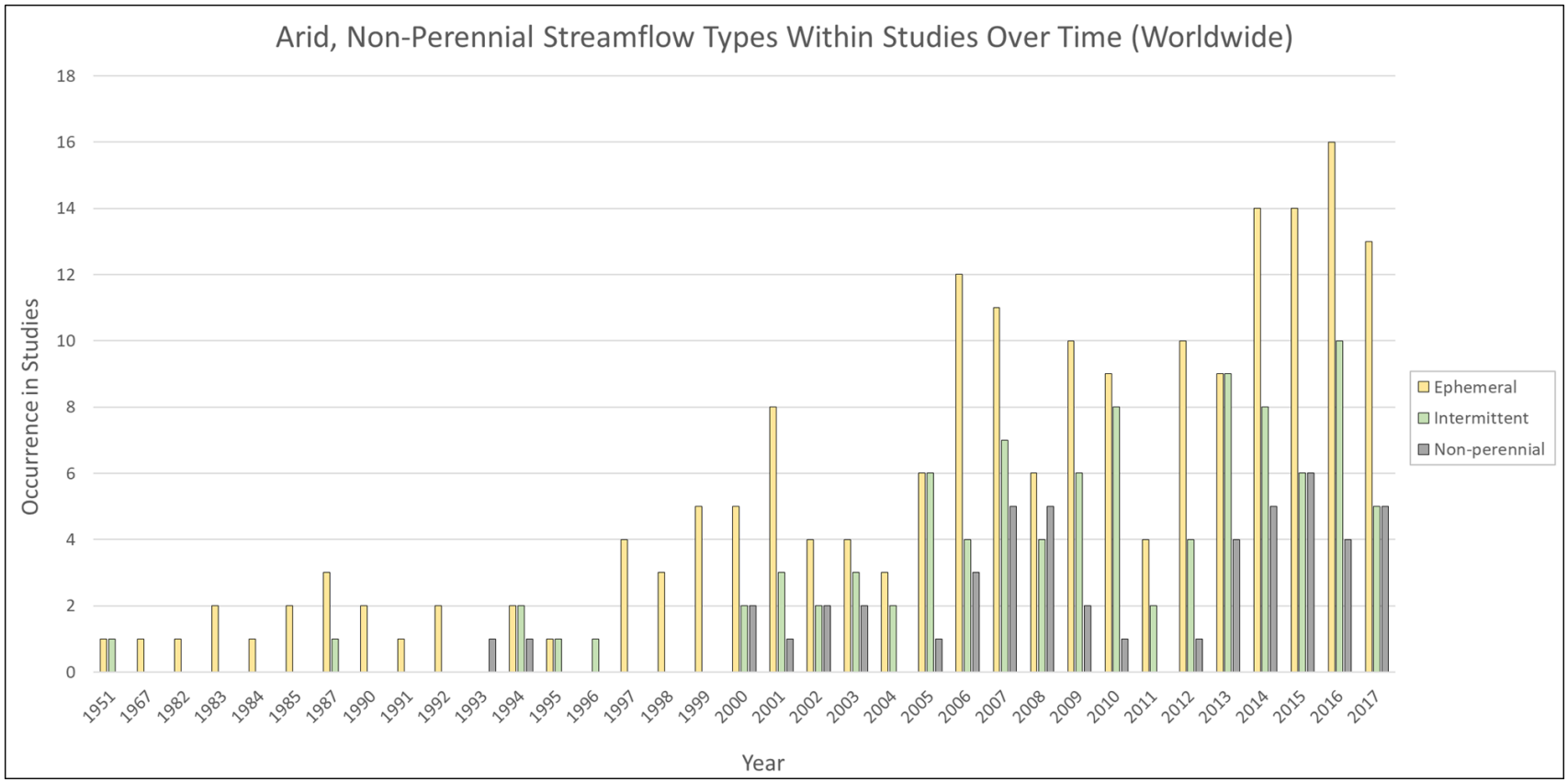


Figure 21. Non-perennial arid stream studies published over time by specificity of streamflow type, globally.

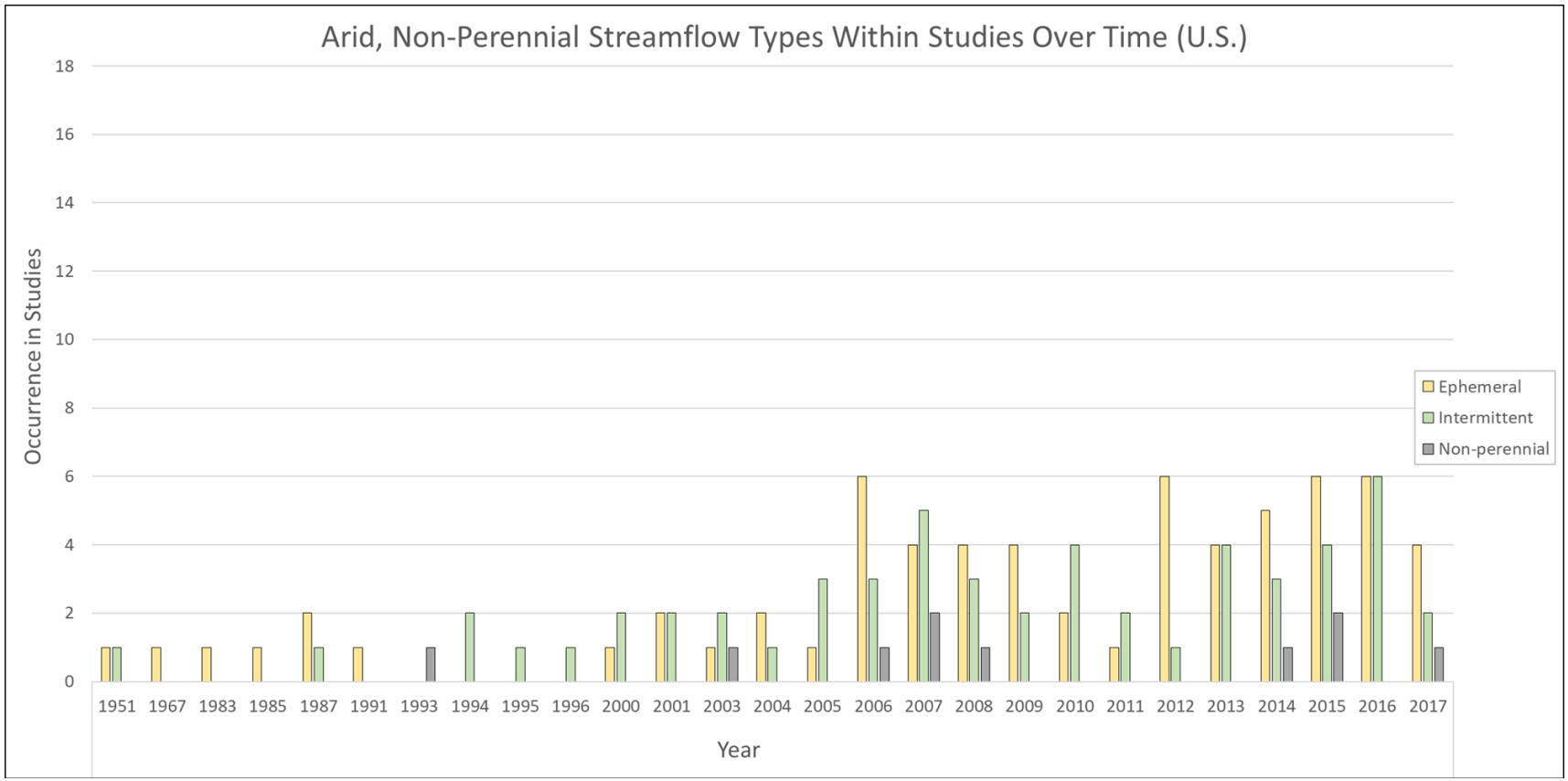


Figure 22. Non-perennial arid stream studies published over time by specificity of streamflow type, within the U.S.

Functions

Across the global and U.S. literature, only four of the seven broad function categories were present as the most prominent, or primary, function category of research focus: Biogeochemical, Hydrology, Habitat, and Sediment (Appendix F). Though the other three broad function categories of Energy Dissipation, Biodiversity, and Connectivity were present within some studies, they were not the primary function focus of any studies. Nonetheless, these four broad function categories in large part encompass the physical, chemical, and biological aspects of streams regulated under the Clean Water Act within the U.S. Moreover, they also reflect core categories of stream functions introduced by Fischenich (2006) and the pyramid hierarchy of stream functions and process presented by Harman et al. (2012). However, there was a disparity in the coverage of these four function categories. Habitat by far was the most common primary broad function category studied, followed (in decreasing order) by Biogeochemical, Sediment and Hydrology function categories, for all global and most U.S. studies (Figure 23). Also, the Habitat and Biogeochemical function categories comprised the majority of global and U.S. studies. Furthermore, the global and U.S. trends over time is the greatest increase for Habitat studies, followed by Biogeochemical and Hydrology studies, with only slight increase in Sediment function studies (Figure 28, Figure 29). It may not be coincidental that these four functions were commonly evaluated by the field studies, with 77% of all studies being comprised of field studies, followed by 7% including remote sensing studies and 6% utilizing existing data (Figure 34). As U.S. studies had similar overall patterns to global studies, Figure 35 depicts how the primary broad function categories data were generated through use of the various study types over time. In general, across all four broad function categories, there is a significant increase of

field studies over time. Similarly, computational and remote-sensing studies had small increases, while the remaining study types had little if any rates of increase over time. When looking at geographic position within the U.S., most studies of these four primary function categories fell within the Corps' South Pacific Division, with a small number situated within the Northwestern Division (Figure 24). This is not surprising, given a majority of the Corp's Arid West wetland delineation region overlaps with the South Pacific Division. Similarly, most studies were also situated within the Corp's Arid West wetland delineation region, with a small number within the Great Plains and the Western Mountains, Valleys, and Coast regions. These location discrepancies with the Koppen-Geiger climate mapping is likely due to highly generalized mapping of those Corps delineation regions, where arid areas may exist within the boundaries of regions surrounding the Arid West, and transition zones between regions likely exist (U.S. Army Corps of Engineers, 2008a).

The Habitat, Biogeochemical, and Sediment broad function categories were divided into several subcategories each, as depicted in Figure 25, Figure 27, and Figure 26, respectively. The Hydrology function category studies did not include several subtopics as did the other function categories, and thus is not further discussed in this section. Global studies in the Habitat function category mostly covered the vegetation subcategory, and subsequently were evenly split between animal and invertebrate studies to round out the majority of Habitat research. Studies in the U.S. followed this pattern, with the exception of vegetation and invertebrate studies comprising over half the studies. Both subcategories of nutrients and physicochemical under the Biogeochemical function category comprised over half the global and U.S. studies. And while the sediment subcategory for the Sediment function category made up over half of the U.S. studies, global

studies included the channel form subcategory for rounding out the majority of those studies. In contrast for both global and U.S. studies, what was relatively under-researched included the subcategories of bacteria, fungi, and diatoms for Habitat, salinity, suspended sediment, and other parameters for Biogeochemical, and bedload for Sediment.

Several descriptor subcategories were used to characterize the primary broad function categories, with the majority of studies covering transport and quantity in both global and U.S. literature. These two descriptor subcategories were split across the function categories similarly for both global and U.S., with most Biogeochemical and Habitat studies consisting of quantification and most Hydrology and Sediment studies concerning the topic of transport. In terms of patterns of research using the primary function descriptors over time, the U.S. data was limited compared to the global literature set thus depicted in Figure 31. The trends over time for the primary broad functions were also positively reflected in terms of the dominant descriptors of quantification and transport. Most descriptors with data for the Biogeochemical function category have a low increase over time with a moderate increase for quantification, with only the transport descriptor on a slight decline. The Habitat function category has a significant upward trend for studies involving quantification, while use of the other descriptors with data had only slight to small increases. In a similar fashion, both the Hydrology and Sediment function categories had static to small upward trends in utilization of descriptor categories with data, with a moderate increase in transport related studies.

In the layering of streamflow regime data as a hydrological component across all four primary function categories, both global and U.S. literature sets examined arid ephemeral streams the most, followed by intermittent streams and then generic classified non-perennial

streams (Figure 32). However, specifically for Habitat function studies, streams with intermittent flows were examined the most. This could be a simple function of riparian habitat being more prominent in intermittent streams due to effects of increased hydrology. Furthermore, in trends over time with streamflow types included in arid studies, U.S. patterns mirrored that of global studies in Figure 33. Fortunately, the trend over time in global for studies including unspecific non-perennial streams has been a slight increase for Sediment and Hydrology functions, though there are moderate increases across Biogeochemical functions and significant increases across Habitat function studies. Research covering intermittent streams for the Sediment function category have been relatively static, with small increases over time for Hydrology studies, a moderate increase for Biogeochemical studies, and a high rate of increase for Habitat studies. Studies involving ephemeral streams have increasing trends across all four function categories, with the greatest also for Habitat studies.

Figures

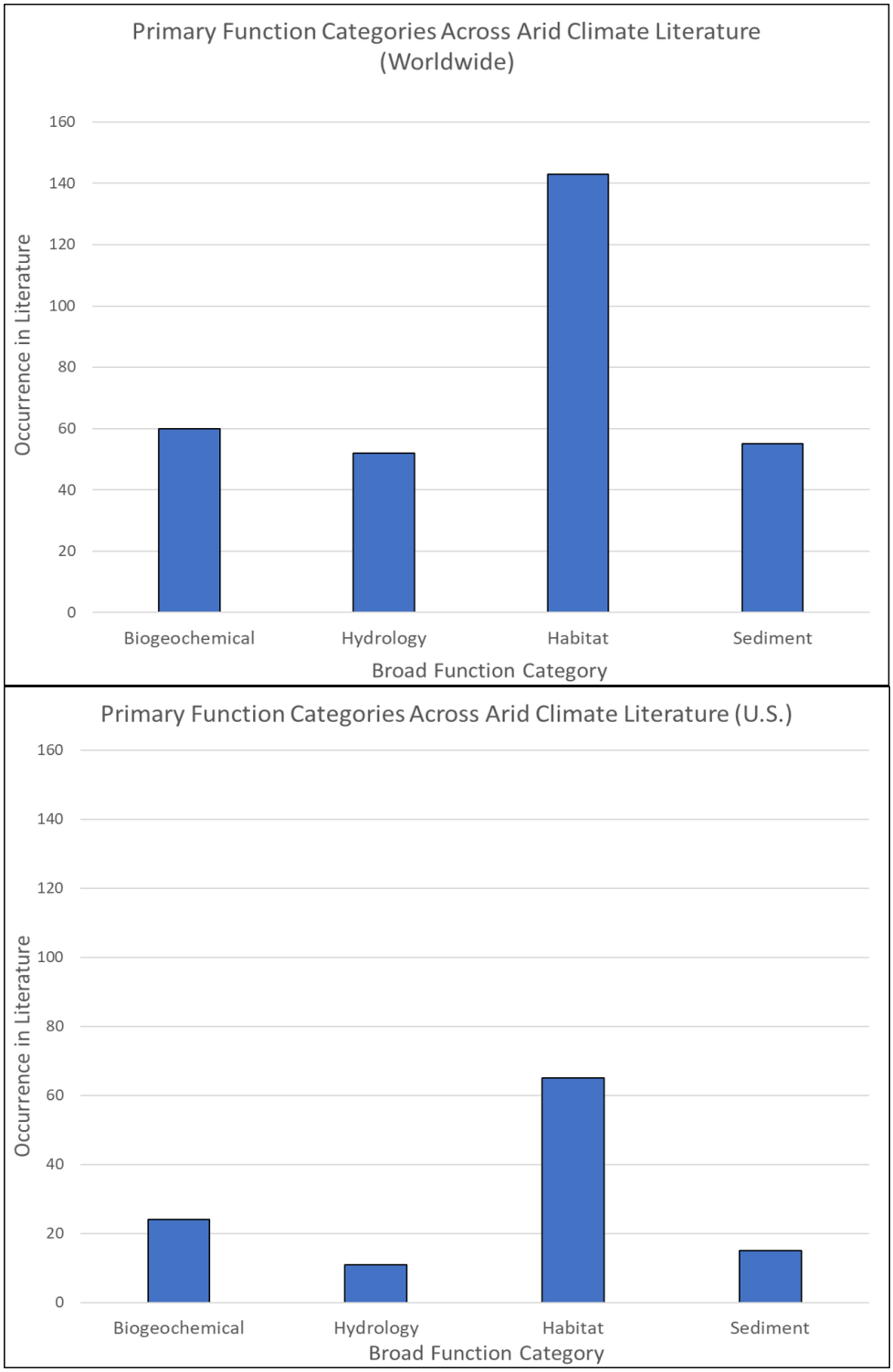


Figure 23. Occurrence of primary broad function categories across U.S. and global arid literature.

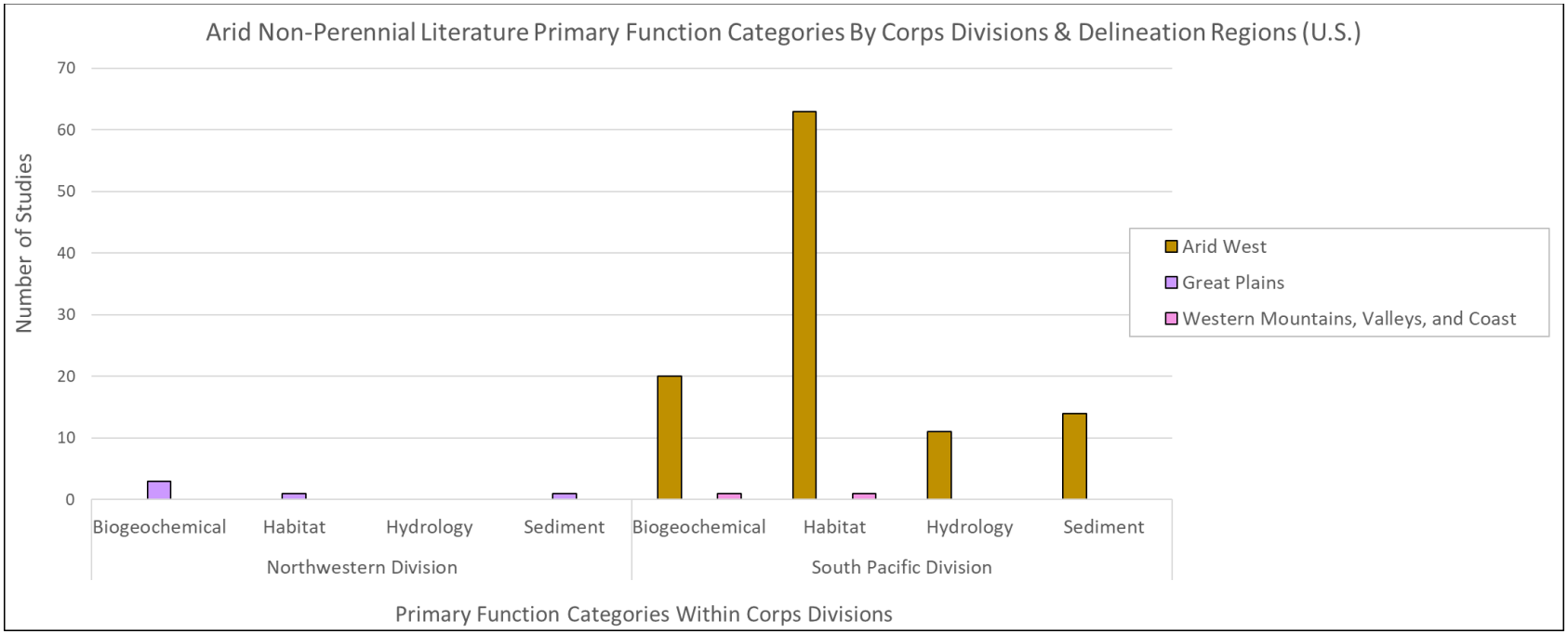


Figure 24. Arid non-perennial stream study locations comparison by Corps Civil Works Divisions among Corps delineation regions, within the U.S.

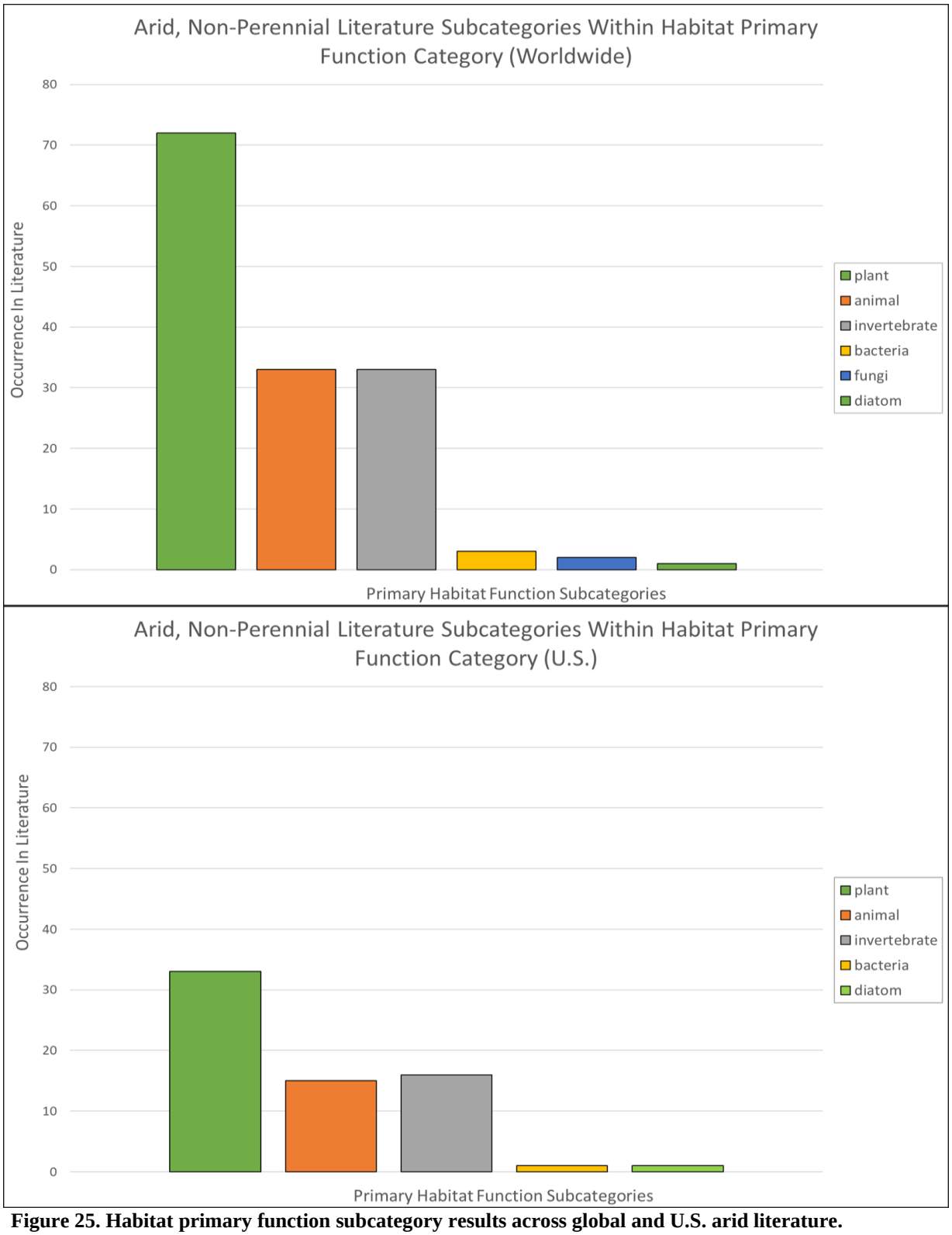


Figure 25. Habitat primary function subcategory results across global and U.S. arid literature.

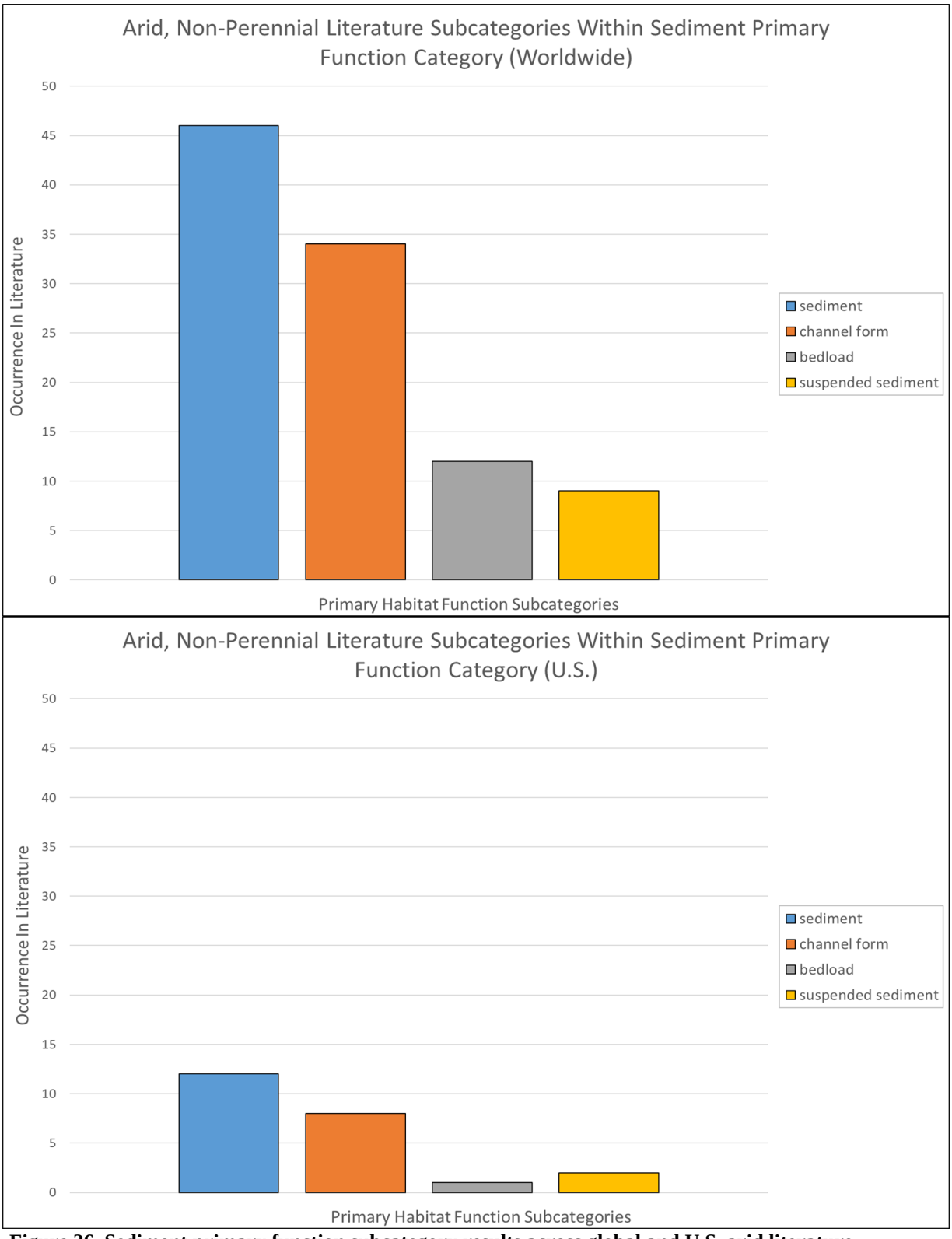


Figure 26. Sediment primary function subcategory results across global and U.S. arid literature.

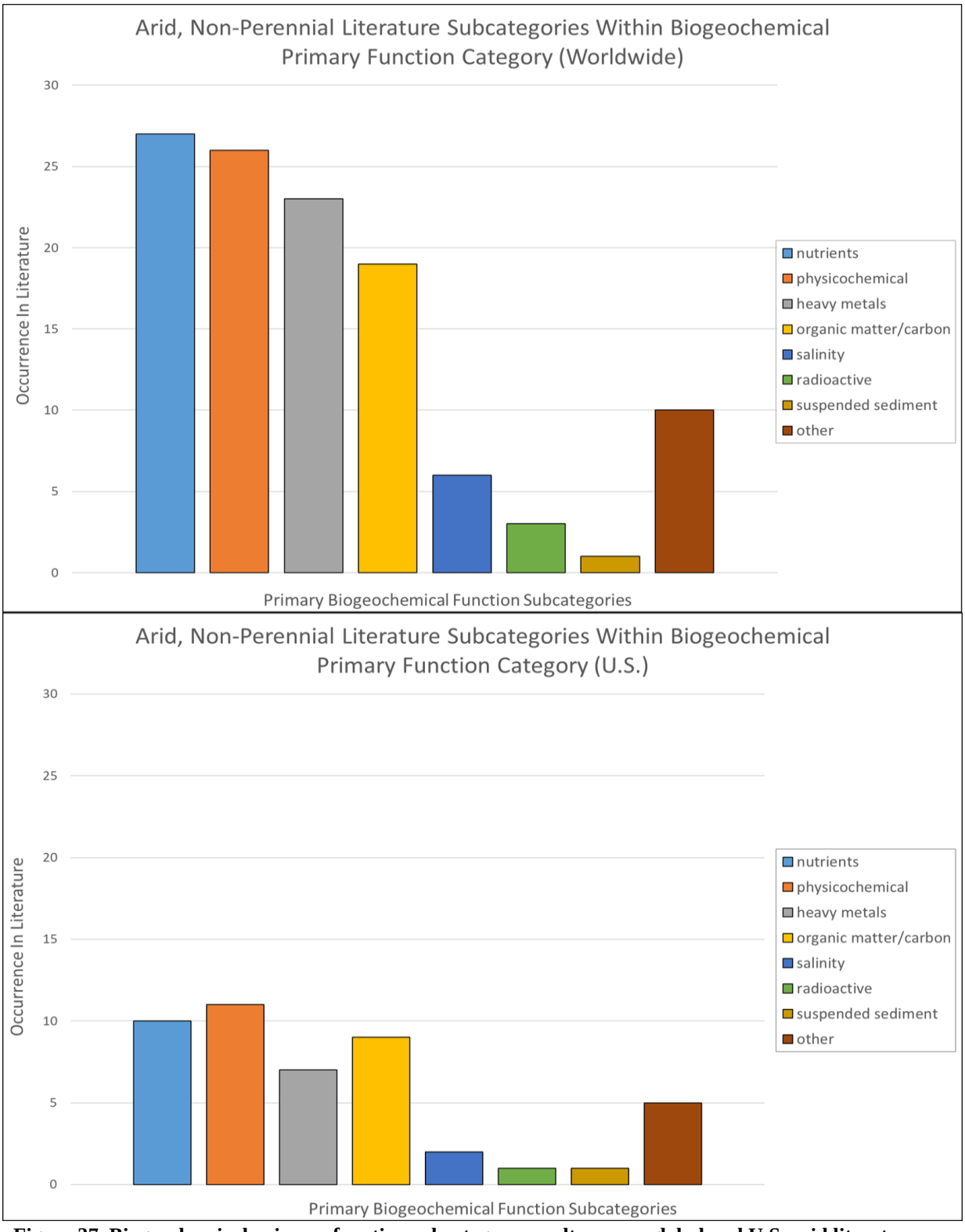


Figure 27. Biogeochemical primary function subcategory results across global and U.S. arid literature.

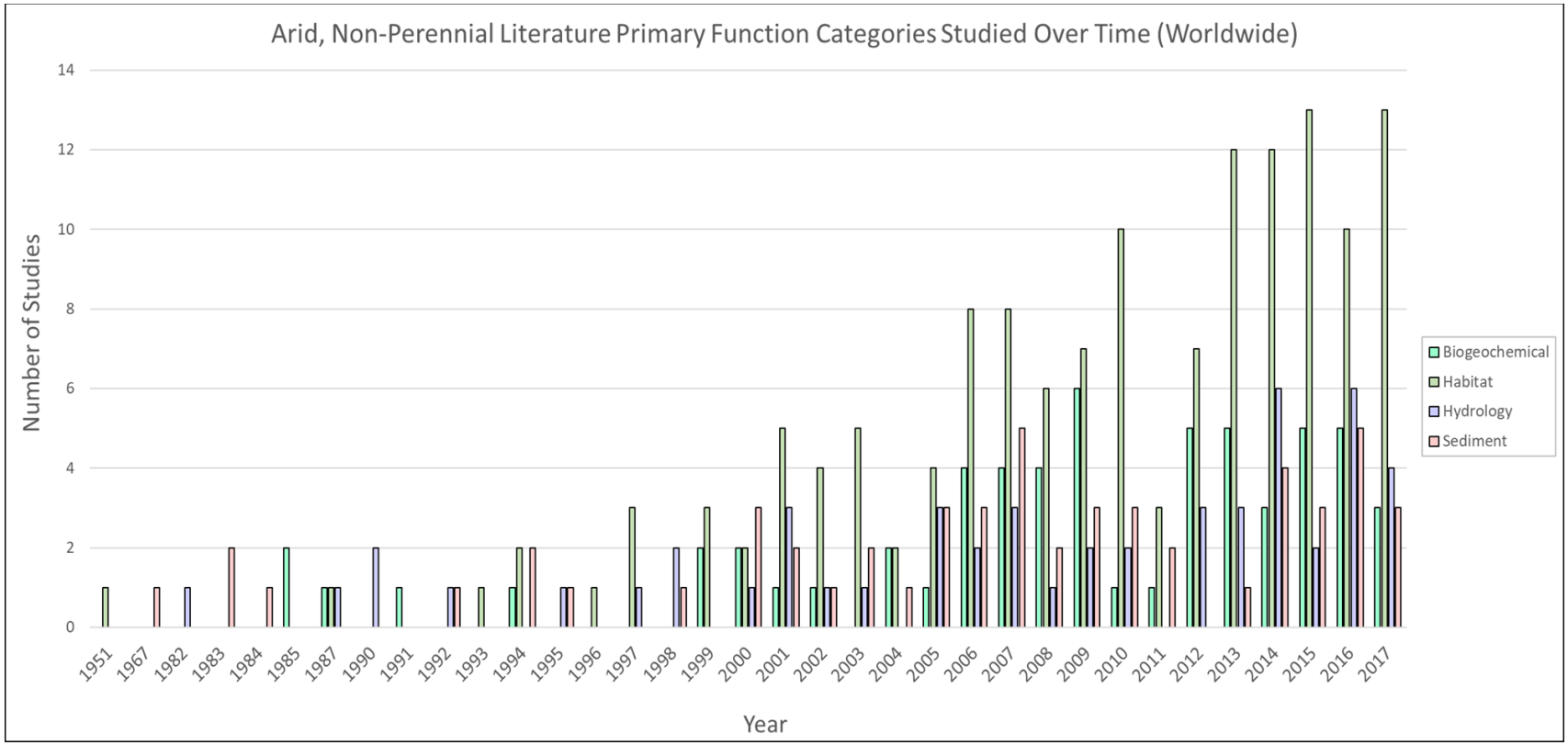


Figure 28. Occurrence of primary recorded broad function categories in non-perennial arid literature published over time, globally.

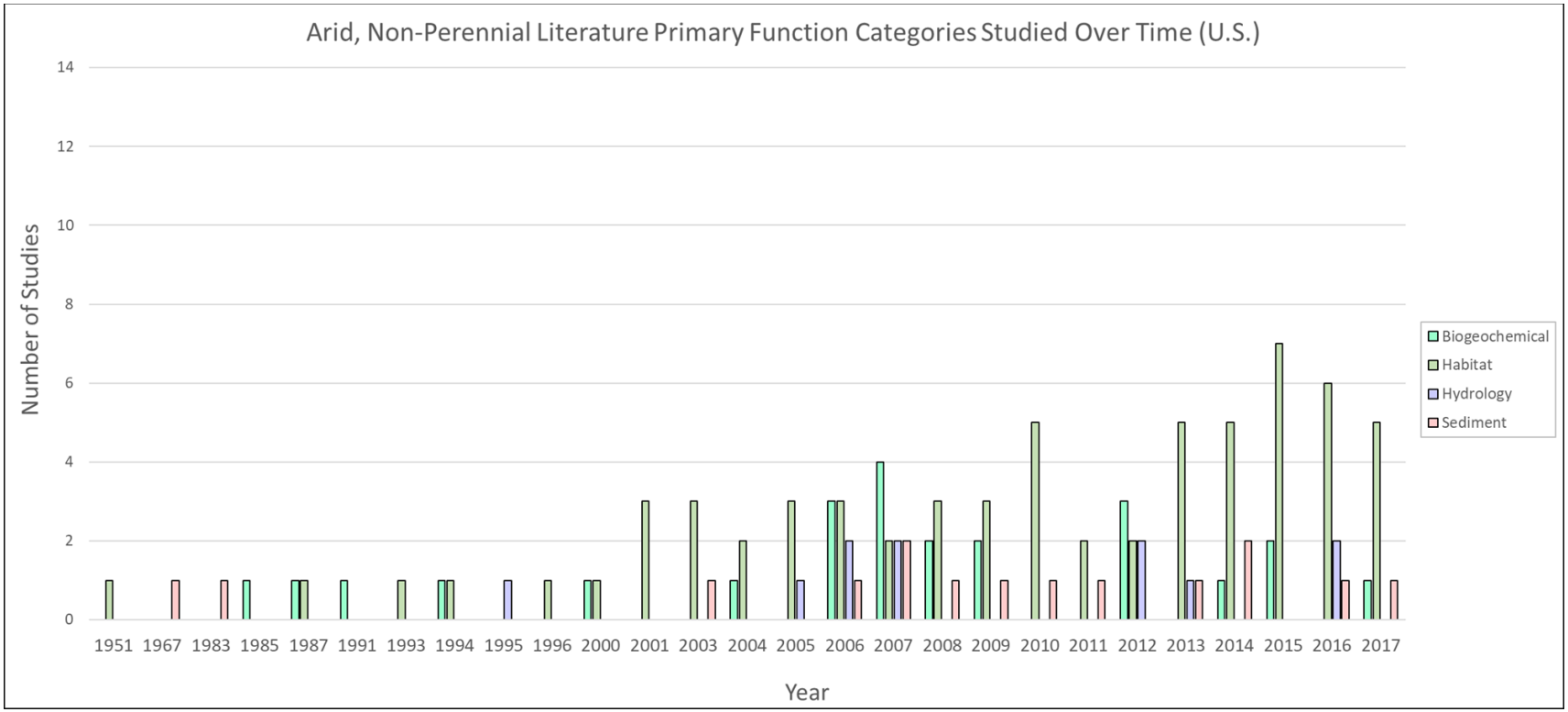


Figure 29. Occurrence of primary recorded broad function categories in non-perennial arid literature published over time, within the U.S.

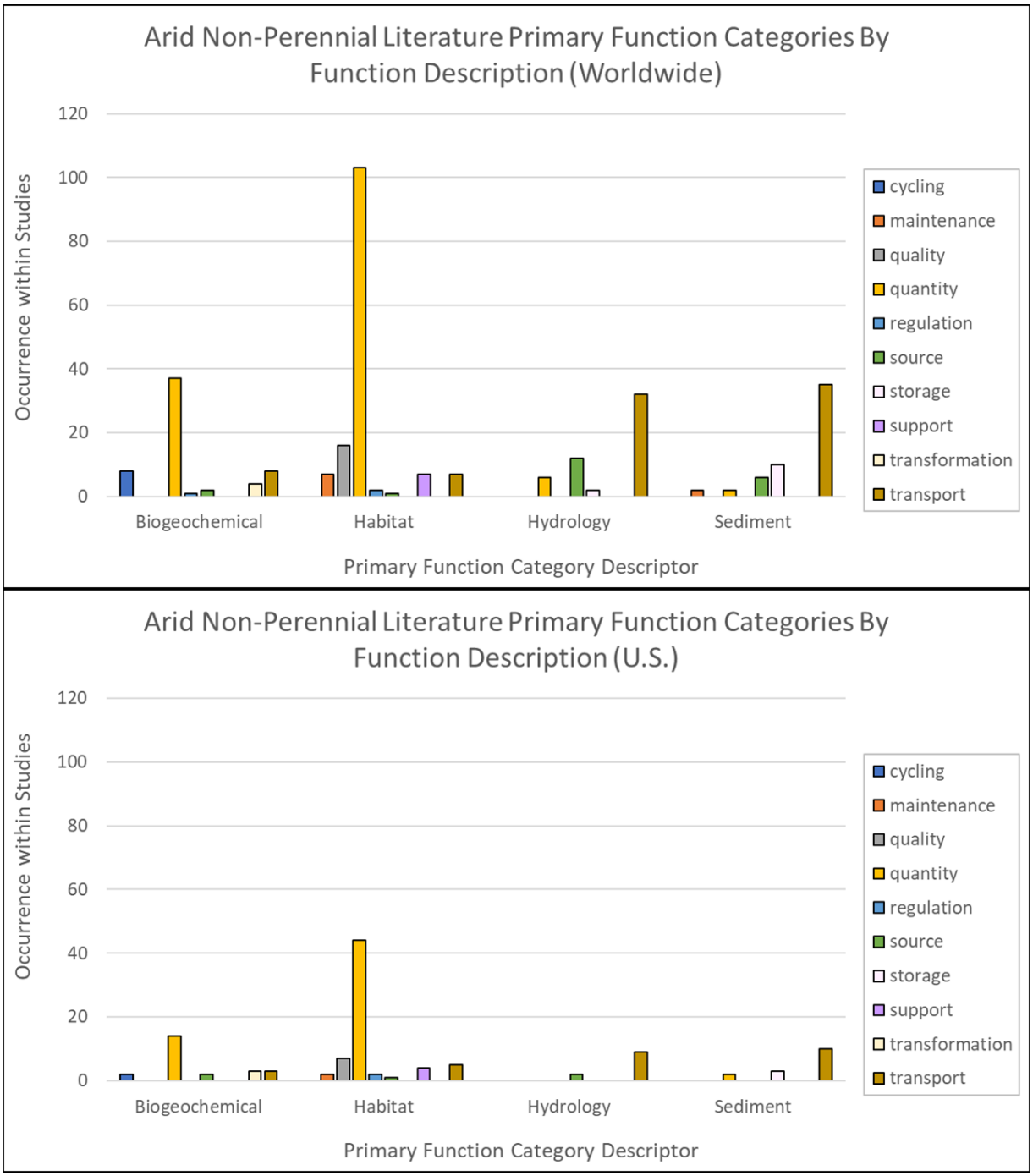


Figure 30. Function descriptions by primary function category within global and U.S. arid non-perennial literature.

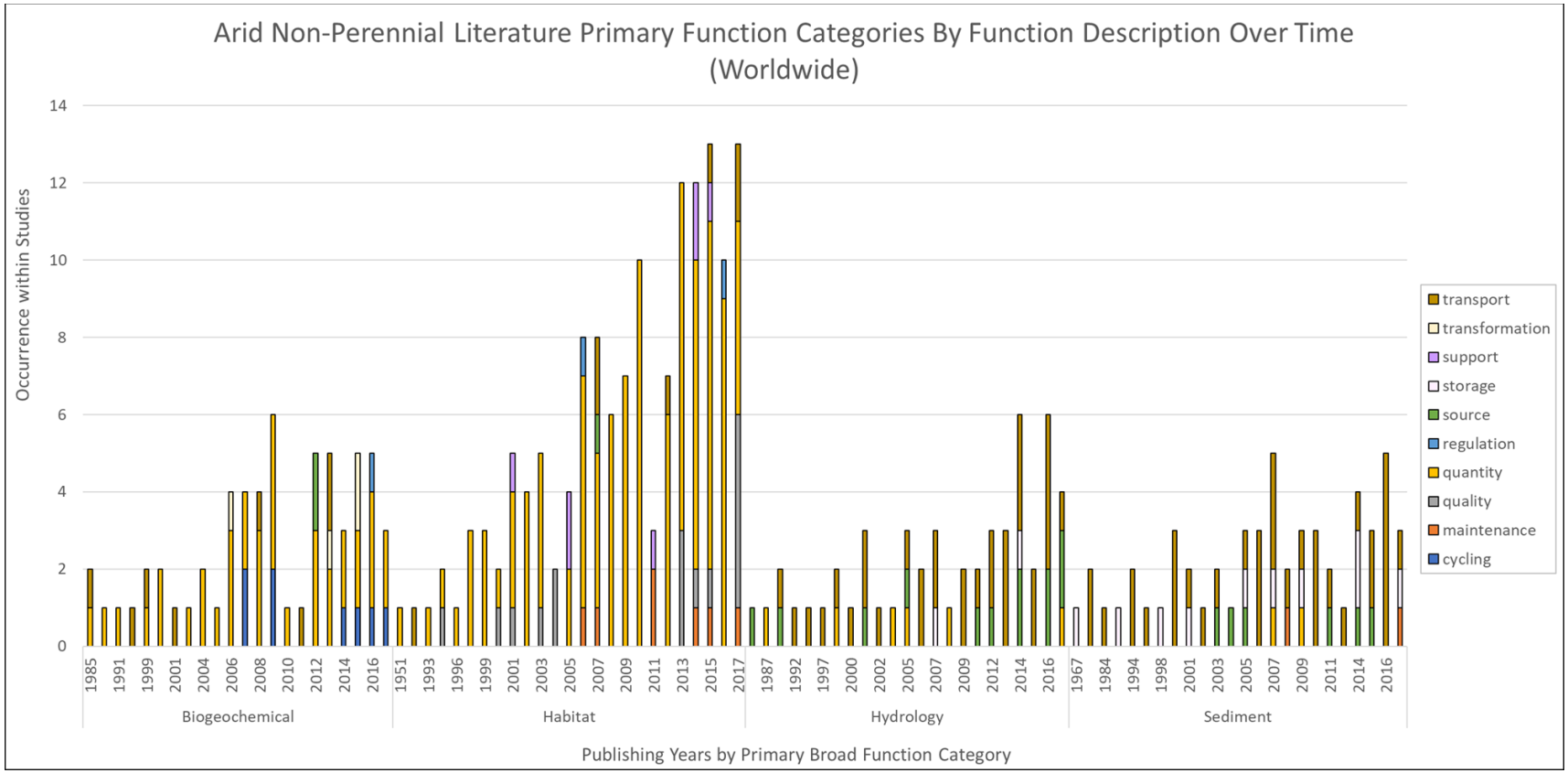


Figure 31. Occurrence of primary function descriptors, by primary function category, within global arid non-perennial literature published over time.

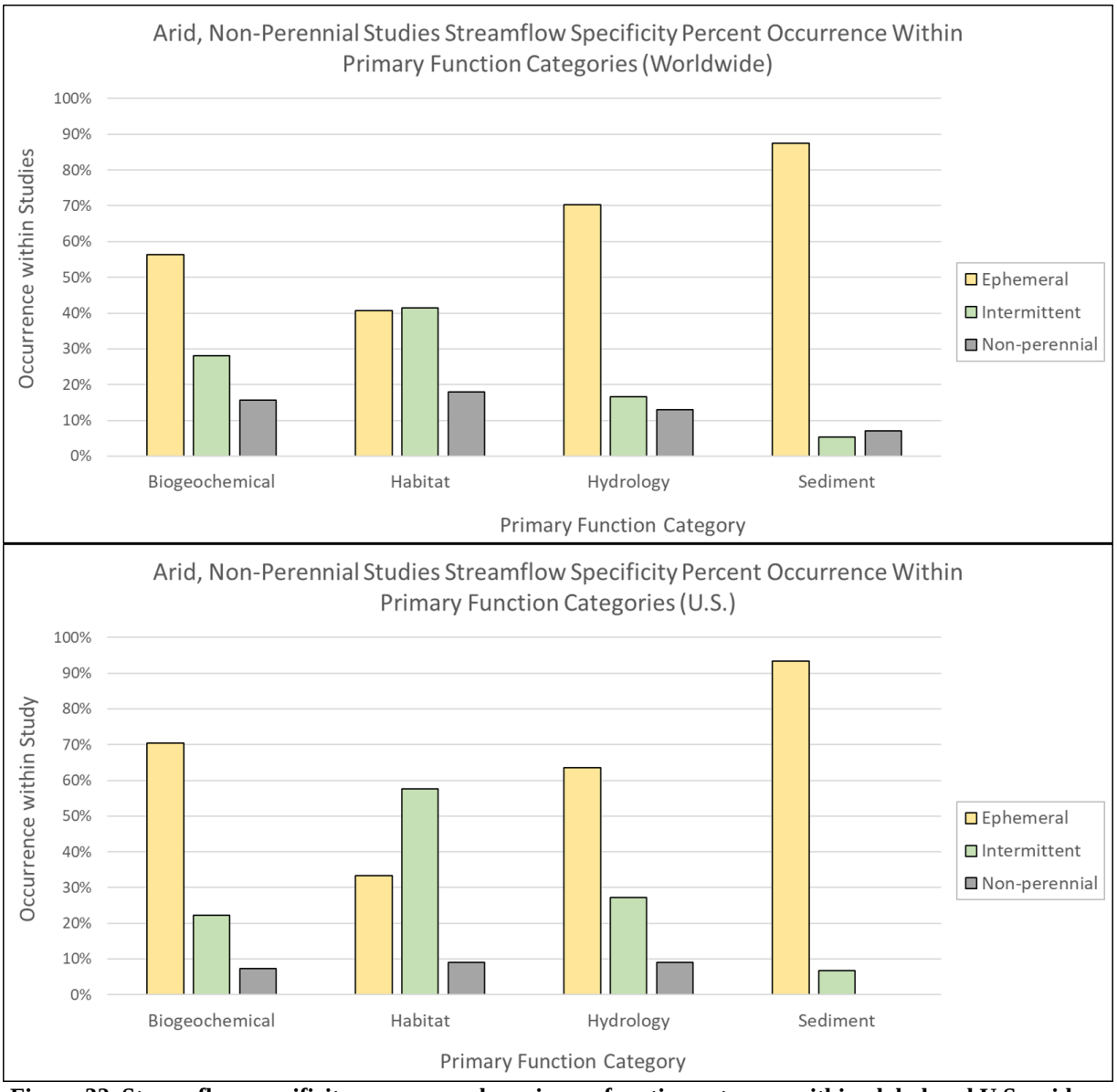


Figure 32. Streamflow specificity occurrence by primary function category within global and U.S. arid non-perennial literature.

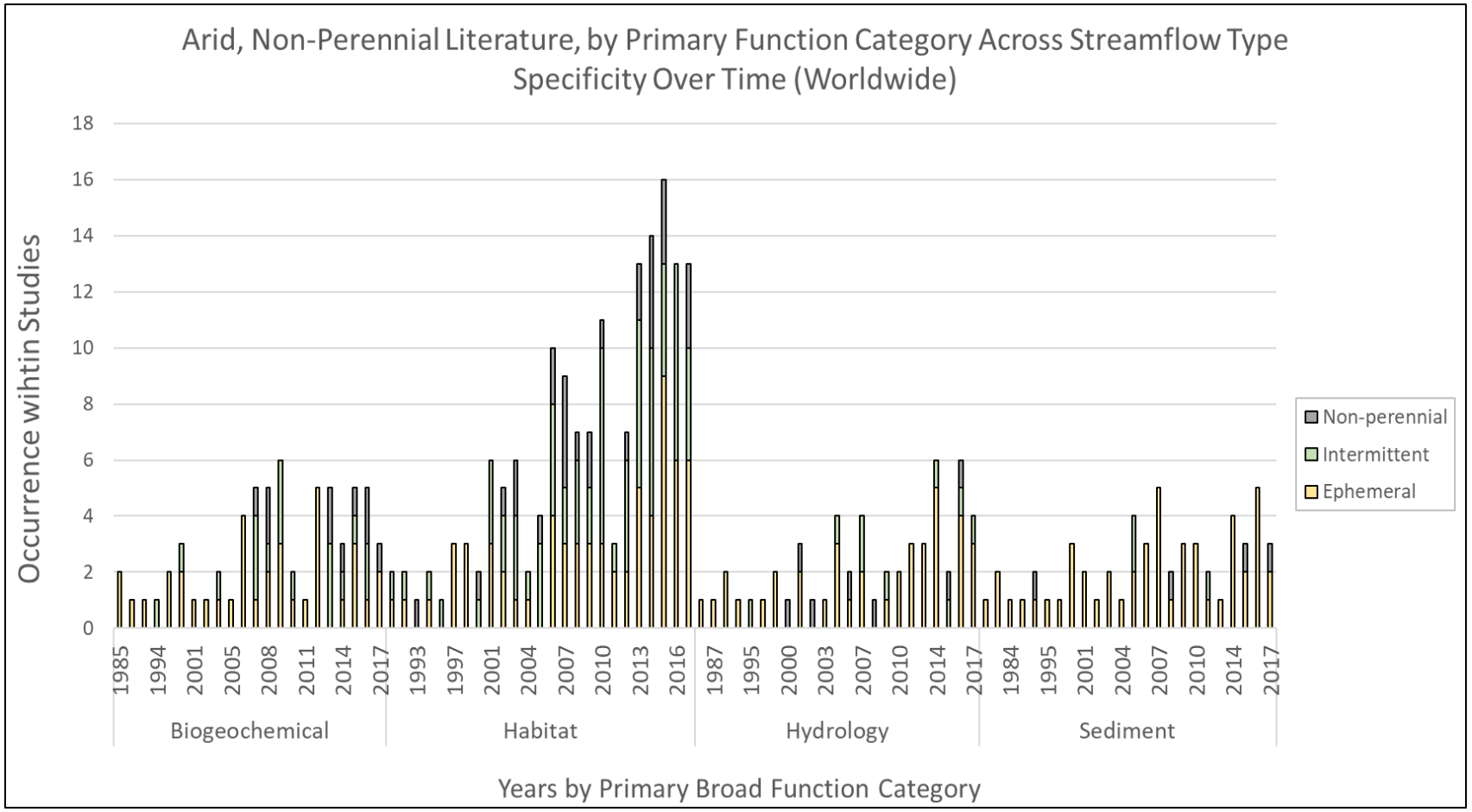


Figure 33. Occurrence of streamflow specificity by primary function category within global arid non-perennial literature over time.

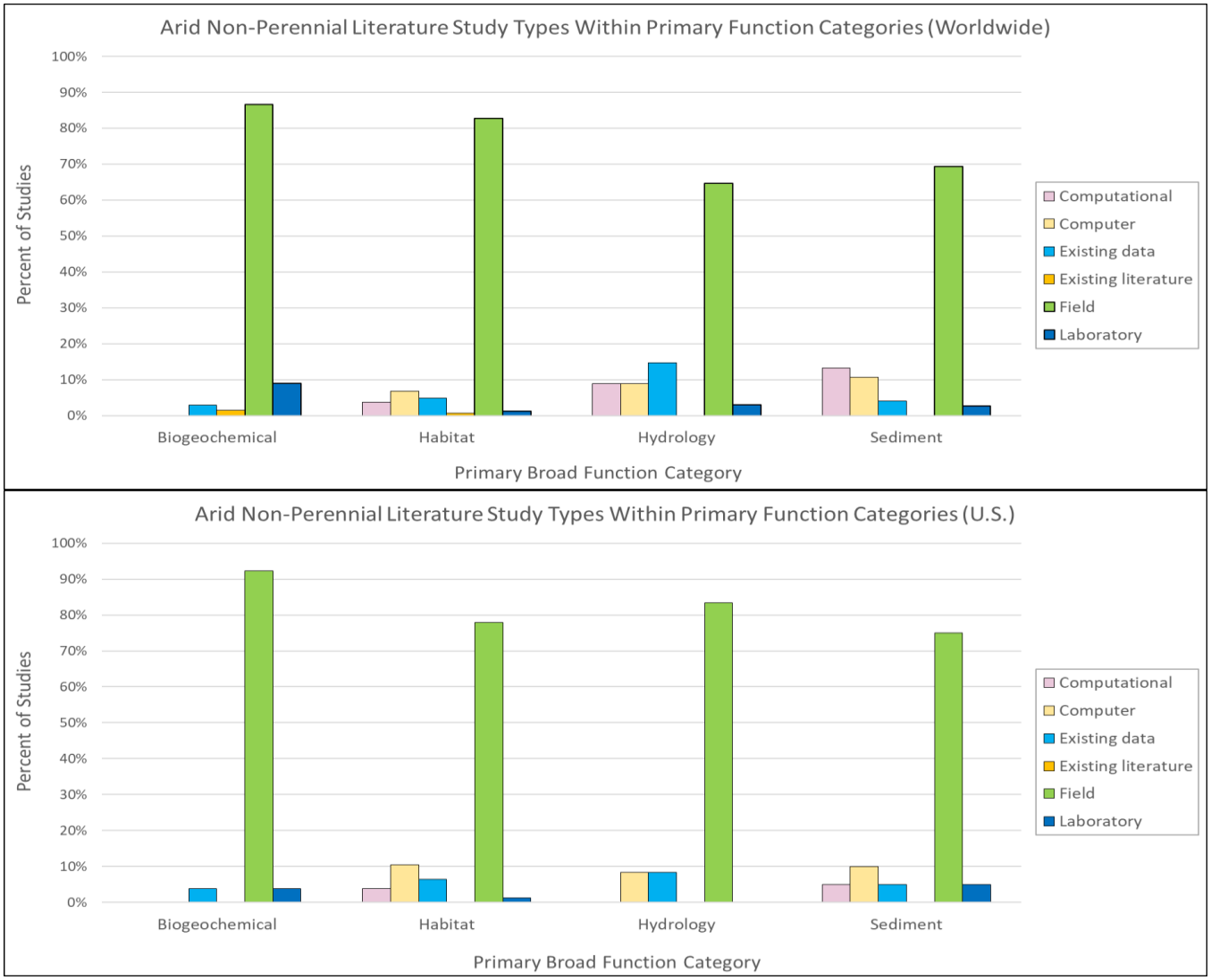


Figure 34. Occurrence of primary recorded broad function categories across non-perennial arid literature study types worldwide and in the U.S.

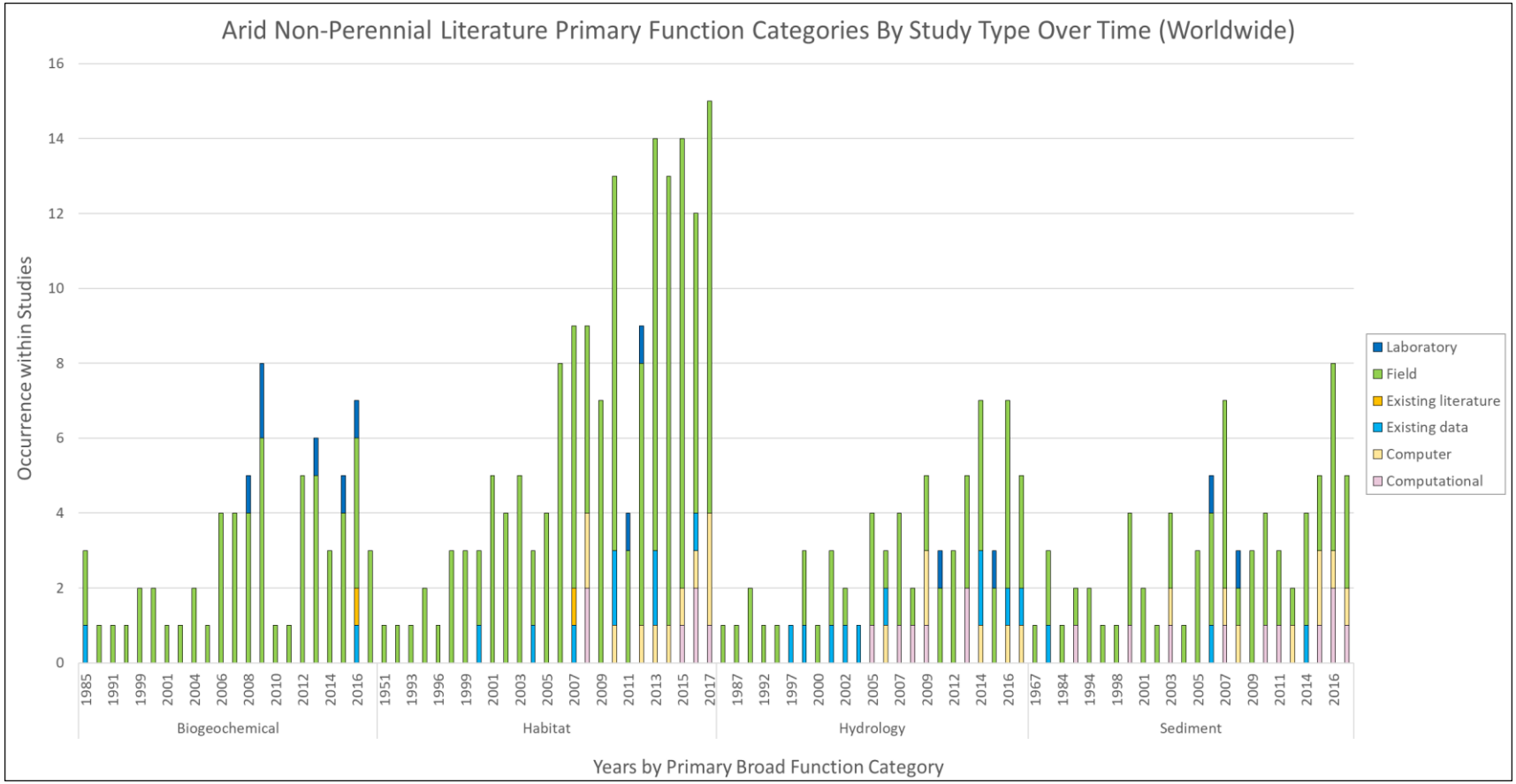


Figure 35. Occurrence of study type by primary function category within global arid non-perennial literature over time.

Functions and Climate

Climate has intrinsic importance as an ecosystem forcing function (Figure 4), and information on stream functions as they relate to various climate settings would be valuable in evaluating and improving assessment methods of non-perennial arid streams (David et al., 2021). The specific functions and level of functions a stream may provide are in context of climate, acting in concert with environmental settings as covered in the proceeding sections (Figure 36). Furthermore, the function categories are within their own hierarchy, whereby hydrologic processes and functions provide overall support and influence on the other subsequent broad function categories, and so on (Harman et al., 2012; Poff et al., 1997).

As hydrology plays a critical role in stream systems in addition to climate (Poff et al., 1997), the broad function categories of arid non-perennial studies were examined in terms of overall climate (e.g., subclimes) with and without hydrology components (precipitation types and streamflow regimes). Though streamflow regime is not entirely independent of the precipitation component of climate, there are several other factors that affect a channel's streamflow regime including geology and bed materials (J. Stromberg et al., 2015; J. C. Stromberg et al., 2007). Therefore, it is treated as a separate factor in addition precipitation with contributing to overall hydrology. The various climate and hydrology data breakouts are represented within Figure 37, along with the influence of each over the broad stream function categories (highlighted in blue). Though the separate attribute of temperature alone does influence some Biogeochemical and Habitat aspects, the hydrology components have a greater overriding control and influence (J. Stromberg et al., 2015; J. C. Stromberg et al., 2013).

Global and U.S. studies were recorded within all Koppen-Geiger arid subclimes, including hot and cold arid regions and steppe and desert arid precipitation types. Globally, the distribution of the primary functions across the Koppen-Geiger subclimes (temperature with precipitation) had similar patterns unequal of a predominance of over 30% occurring within the cold steppe subclime, followed by hot desert, hot steppe, and cold desert (Figure 38). An exception for the Hydrology function category was a dominant occurrence within hot desert. Globally, others have noted the highest percentage of earth's land area is within the hot desert subclime (Peel et al., 2007), but within the U.S. the majority of Koppen-Geiger arid climate land coverage is by cold steppe. With U.S. studies comprising most of the global studies set, it may be the influence of U.S. studies whereby coverage of most function categories are weighted toward the cold steppe subclime (Table 4). Though the Sediment and Biogeochemical function categories for U.S. studies followed the same overall global pattern, both the Habitat and Hydrology categories had hot steppe occurring more than hot desert. Across all functions in both U.S. and global literature, the function categories were least studied within the cold desert subclime. In terms of global and U.S. research of the primary functions within the subclimes over time, the overall patterns of increase for Biogeochemical and Habitat functions, with more of a steady state for Hydrology and Sediment function categories (Figure 39, Figure 40, Figure 41). Worldwide, the Biogeochemical, Habitat, and Hydrology functions were increasingly studied in all subclimes, with the greatest rates of increase for Habitat. The exception was hot steppe for Biogeochemical where research remained static. For the Sediment function category, research is only slowly increasing within hot steppe and cold desert subclimes, whereas there was a notable rate of increase within cold steppe and a decline within hot desert. In a similar

fashion, U.S. Habitat studies across all subclimes had the greatest upward trends, while Biogeochemical studies were either static or decreasing across all subclimes, except hot desert where there's a slight upward trend. Likewise, Hydrology and Sediment functions across all subclimes were either static or had a minimal increase. These differences indicate future global and U.S. research should place an emphasis on all functions within the cold desert, as well as generally more on stream function categories other than Habitat, which dominates not only by overall number but also increasing trends.

Similar to the above data analyses, the subclimes were subdivided into the temperature and precipitation components, which were also examined in terms of with and without streamflow regime types among the primary function categories (Figure 37). Global studies across all function categories were most prevalent within hot arid temperatures, while U.S. studies were split with Biogeochemical and Hydrology functions being most prevalently covered within hot arid areas, and Habitat and Sediment functions primarily being studied within cold arid areas (Figure 42). While U.S. studies are significant portion of overall hot and cold arid global studies for the Biogeochemical and Habitat function categories, they comprise only a small percentage of global studies covering the Hydrology and Sediment function categories (Table 4). Over time global studies have overall upward trends across both temperatures and all functions, except for Sediment functions within hot arid areas that had a slight downward pattern (Figure 43, Figure 44). Similarly. U.S. studies have an overall increasing trend in hot arid temperature across all functions, but interestingly have decreased over time for all but the Habitat function (Figure 45). Habitat by far has the highest rates of increase for global and U.S.

studies in both arid temperatures, though while that increase is fairly even for global studies there is a higher rate of increase in U.S. studies within cold arid temperatures.

In addressing the other collective subclime and hydrology component, or precipitation types, both global and U.S. studies across all function categories were most prevalent within the steppe precipitation type. Almost half of all studies occurring within steppe areas were situated within the U.S., while the contribution of U.S. studies to all global studies within desert precipitation areas was much less at 28%. U.S. studies also comprised almost half of all worldwide studies within the Biogeochemical and Habitat function categories, but much less so for Hydrology and Sediment function categories. Over time global studies have overall upward trends across both arid precipitation types and all functions (Figure 47, Figure 48). However, U.S. studies are generally decreasing across both precipitation types for the Biogeochemical and Hydrology function categories, and only slightly increasing across both for the Sediment function category (Figure 49). Like the arid temperature results, studies covering the Habitat function category have a high rate of increase across both precipitation types within the U.S. and worldwide literature.

The other key component of hydrology, streamflow regime, was also layered with the broad function categories of arid non-perennial studies in terms of overall climate (subclimes), as well as with the separate temperature and precipitation components (Figure 37). Overall patterns of occurrence of the subclimes among the primary function categories and streamflow regime specificity were similar in U.S. studies compared to all global studies (Figure 50) (Table 5). Studies with ephemeral streams made up most studies across all subclimes and function categories in both U.S. and global data sets, followed by intermittent streams. And though

occurrences within cold steppe subclime dominated each streamflow type across all function categories for U.S. studies, cold steppe was only predominant for intermittent and generic non-perennial streamflow types of global studies, with most global studies covering ephemeral streams across all functions were situated within hot desert. When layering temperature data with the streamflow regimes and function categories, most global studies occurred within hot arid temperatures while the opposite was true for U.S. studies (Figure 51). On closer examination U.S. studies by streamflow type mostly occurred within cold arid areas. However, global studies occurrence in hot and cold areas varied by the study streamflow type. Those global studies including ephemeral streams were situated within hot arid areas across all function categories, while studies with intermittent streams were evenly split across hot and cold arid areas, and those with generic non-perennial streams mostly fell within cold arid areas. Overall patterns of precipitation type occurrence among the primary function categories and streamflow regime specificity were the same in U.S. and global studies (Figure 52). Both as a whole across all streamflow types, as well as by individual streamflow type, steppe precipitation was dominant among U.S. and global studies. This difference between occurrences within steppe and desert precipitation was more pronounced among studies with intermittent streams compared to ephemeral streams. Across all data cuts of arid subclimes, temperatures, and precipitation types among all function categories with streamflow regimes, it bears mentioning that approximately a tenth of all U.S. and global studies had streams with flow regimes that were not discernable beyond the generic non-perennial flow assignment. With hydrology being a critical component of stream functions (J. Stromberg et al., 2015), future published studies should clearly include and define the stream types involved.

Tables

Table 4. Global and U.S. non-perennial stream primary broad function category occurrences by study countries within Koppen-Geiger broad hot and cold arid climates, with further subdivisions among temperature and seasonal precipitation types.

Primary Function Category	Study Locations	Hot Arid				Cold Arid				(U.S.%)
Biogeochemical	Worldwide	35				32				
	U.S.	15				13				42%
Habitat	Worldwide	89				84				
	U.S.	34				55				51%
Hydrology	Worldwide	41				20				
	U.S.	6				5				18%
Sediment	Worldwide	35				24				
	U.S.	5				10				25%
(U.S.%)		30%				52%				
		Desert	(U.S.%)	Steppe	(U.S.%)	Desert	(U.S.%)	Steppe	(U.S.%)	
Biogeochemical	Worldwide	19		16		9		23		
	U.S.	9	47%	6	38%	2	22%	11	48%	
Habitat	Worldwide	46		43		18		66		
	U.S.	15	33%	19	44%	8	44%	47	71%	
Hydrology	Worldwide	23		18		6		14		
	U.S.	2	9%	4	22%	0	0%	5	36%	
Sediment	Worldwide	22		13		2		22		
	U.S.	4	18%	1	8%	0	0%	10	45%	
(U.S.%)		27%		33%		29%		58%		

Table 5. Primary function categories of arid non-perennial literature study specificity by streamflow regime without and within all subclimates worldwide, including the U.S.

Primary Function Category	Study Location	Non-perennial				Ephemeral				Intermittent				(U.S.%)
Biogeochemical	Worldwide	10				36				18				42%
	U.S.	2				19				6				
Habitat	Worldwide	29				66				67				48%
	U.S.	7				26				45				
Hydrology	Worldwide	7				38				9				20%
	U.S.	1				7				3				
Sediment	Worldwide	4				49				3				27%
	U.S.	0				14				1				
(U.S.%)		20%				35%				57%				
		Hot Arid		Cold Arid		Hot Arid		Cold Arid		Hot Arid		Cold Arid		
		Desert	Steppe	Desert	Steppe	Desert	Steppe	Desert	Steppe	Desert	Steppe	Desert	Steppe	(U.S.%)
Biogeochemical	Worldwide	13	4	2	10	6	0	6	1	2	12	5	6	33%
	U.S.	7	2	0	5	1	0	2	0	0	9	0	2	
Habitat	Worldwide	31	8	7	19	17	7	4	5	9	24	30	12	50%
	U.S.	9	4	2	7	12	0	3	2	3	17	24	6	
Hydrology	Worldwide	16	3	3	12	3	3	5	0	1	11	1	2	50%
	U.S.	2	0	0	2	2	0	0	0	0	3	1	1	
Sediment	Worldwide	20	1	1	11	0	1	2	0	0	19	1	2	0%
	U.S.	4	0	0	1	0	0	0	0	0	9	1	0	
(U.S.%)		28%	38%	15%	29%	58%	0%	29%	33%	25%	58%	70%	41%	

Figures

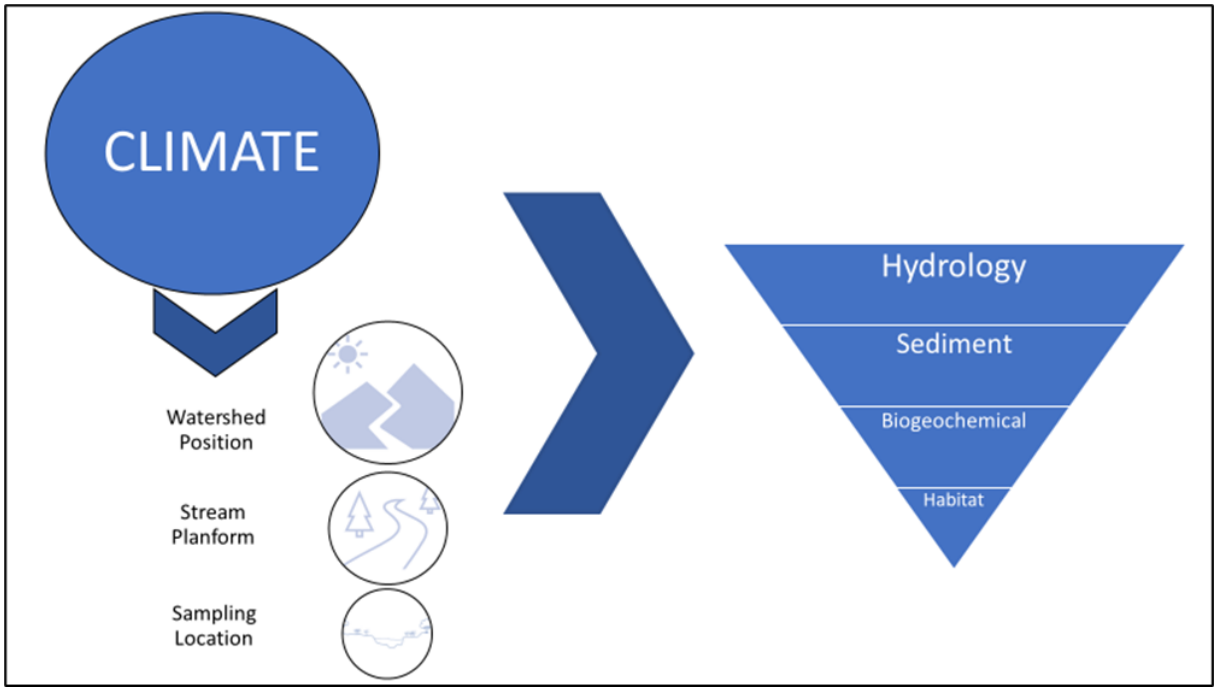


Figure 36. Conceptual relations and hierarchies of ecosystem forcing functions, regional to local environmental parameter controls, and broad stream function categories.

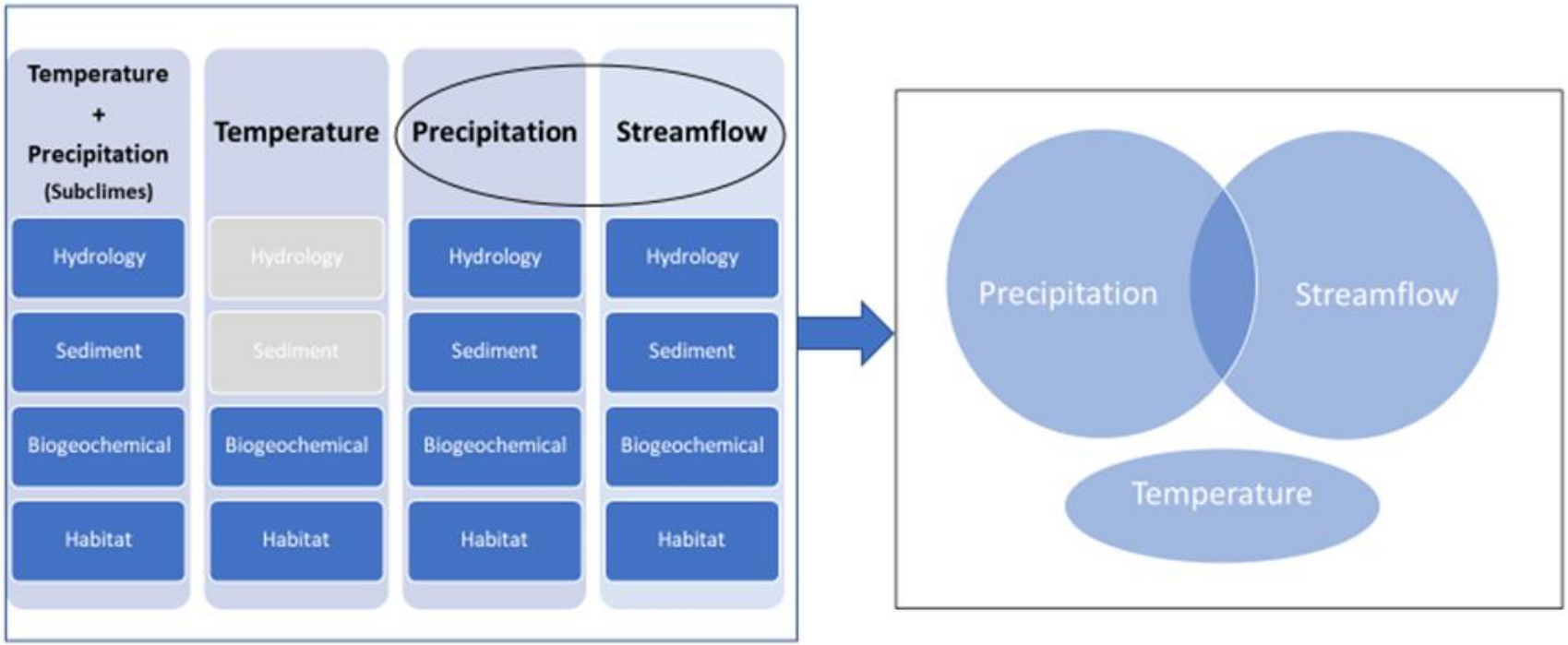


Figure 37. Conceptual relations and hierarchies of climate (subclimes, temperature, and precipitation) and hydrology (inherent precipitation and streamflow) factors and their influence on broad stream function categories.

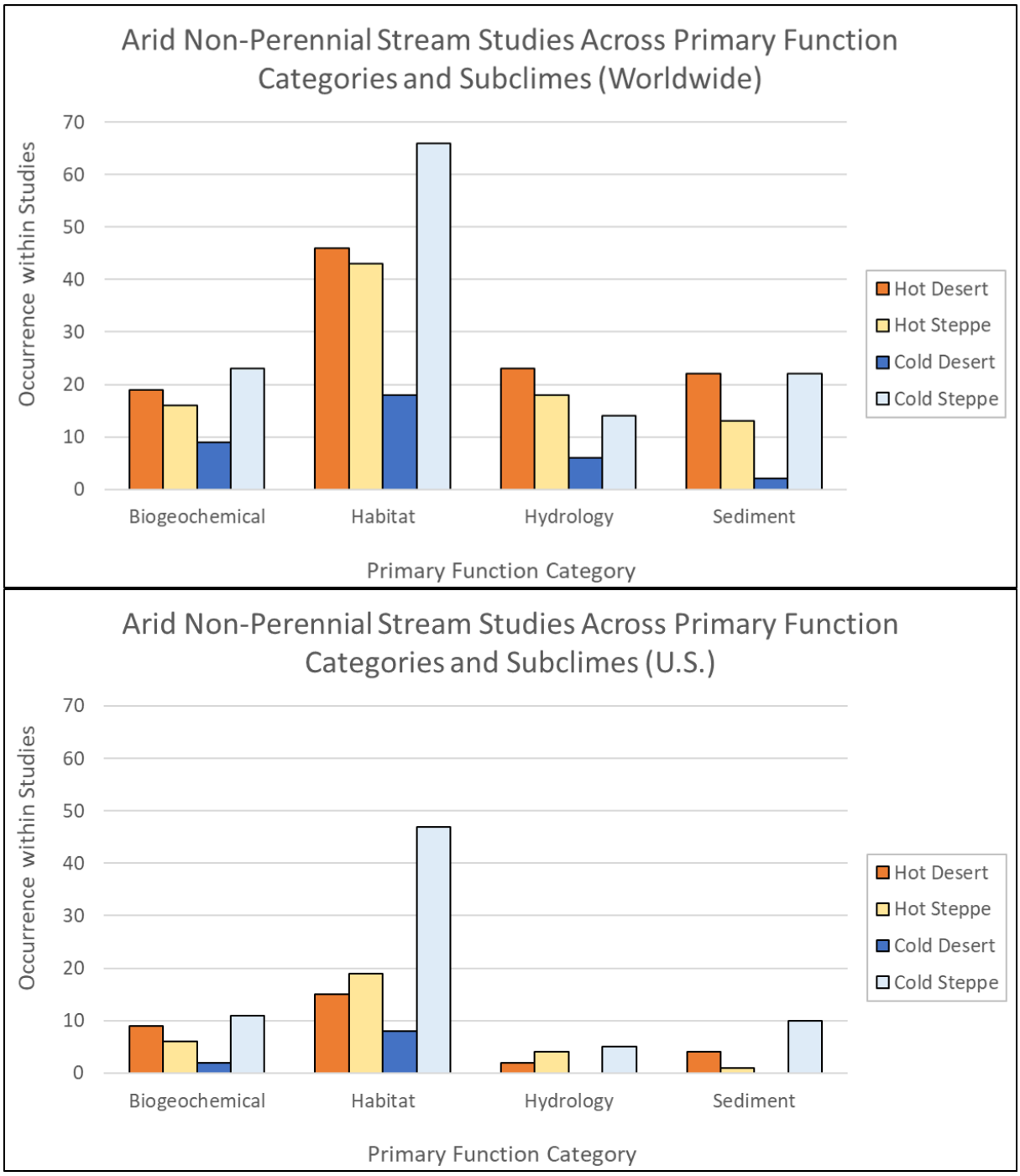


Figure 38. Koppen-Geiger arid subclimes by primary function category among global and U.S. arid non-perennial literature.

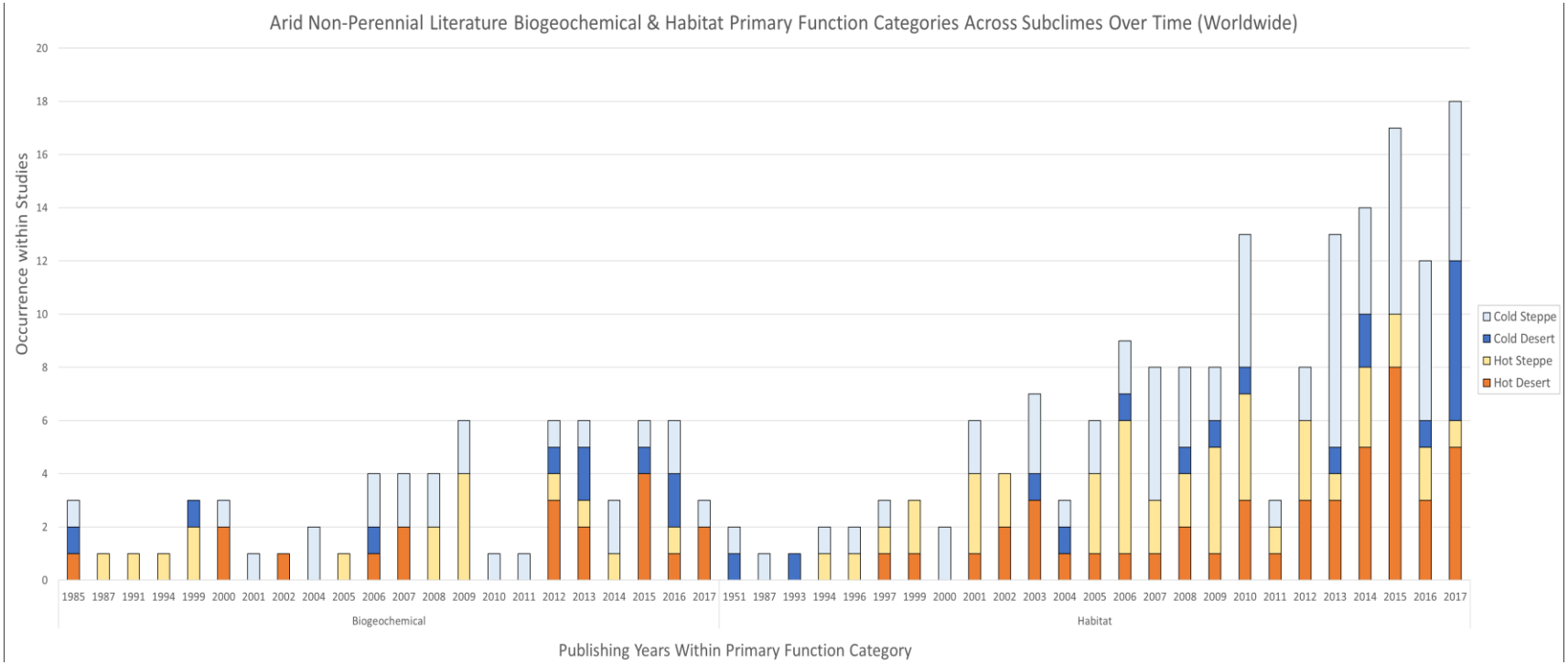


Figure 39. Occurrence of Koppen-Geiger subclimes by Biogeochemical and Habitat primary function categories, within global arid non-perennial literature published over time.

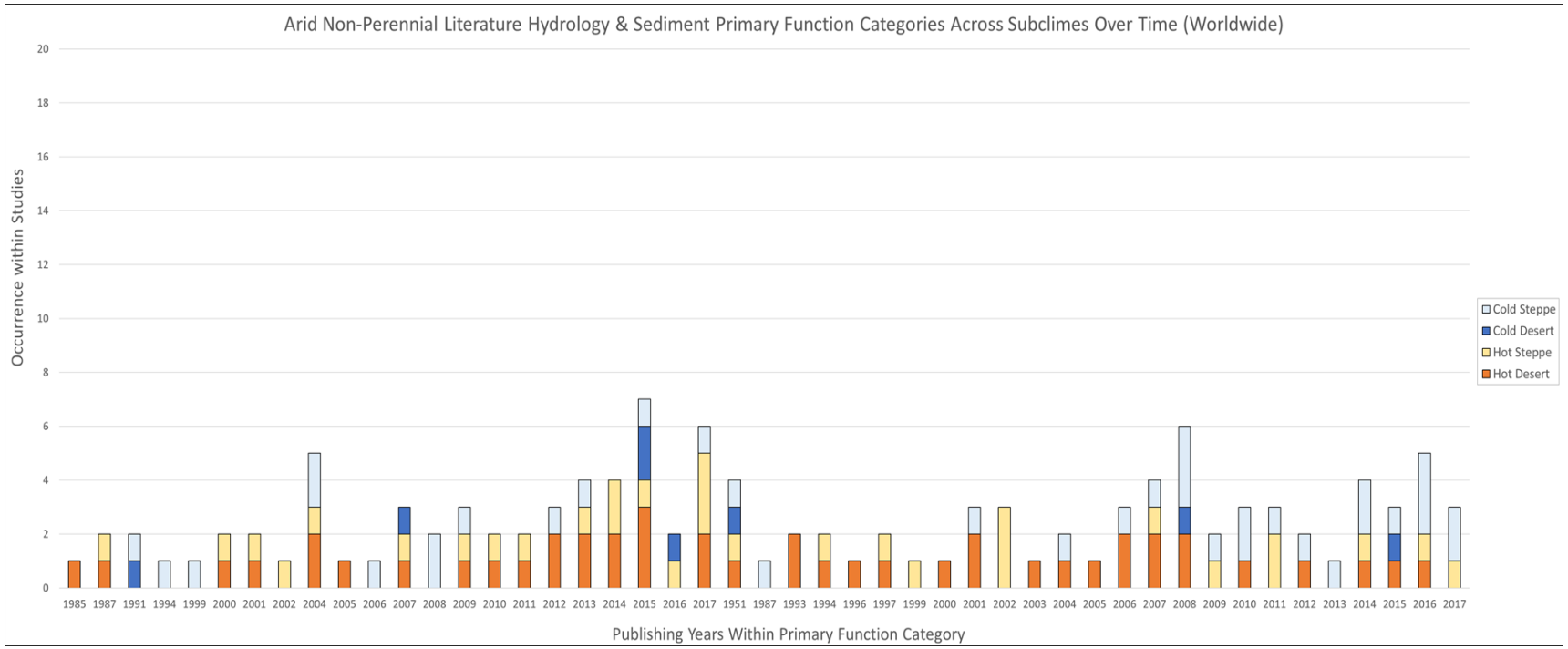


Figure 40. Occurrence of Koppen-Geiger subclimes by Hydrology and Sediment primary function categories, within global arid non-perennial literature published over time.

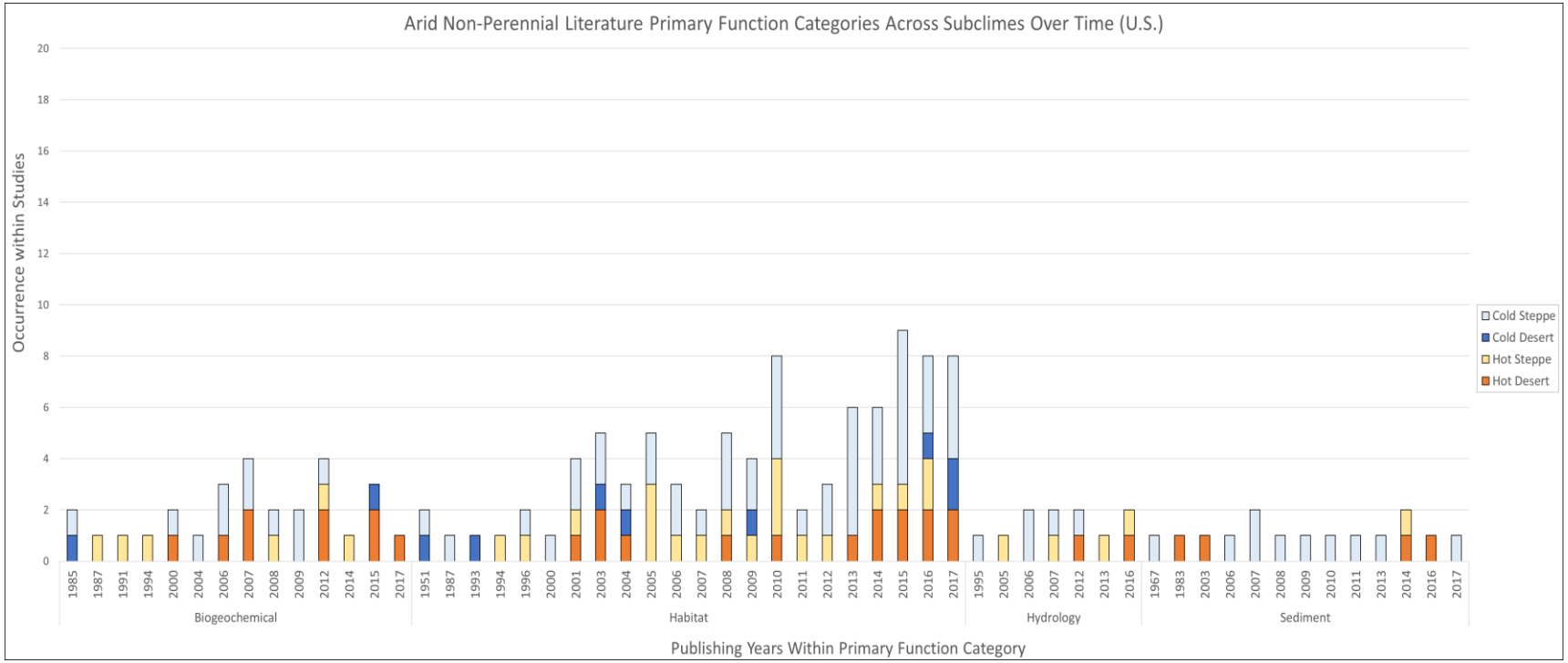


Figure 41. Occurrence of Koppen-Geiger subclimes by primary function category, within U.S. arid non-perennial literature published over time.

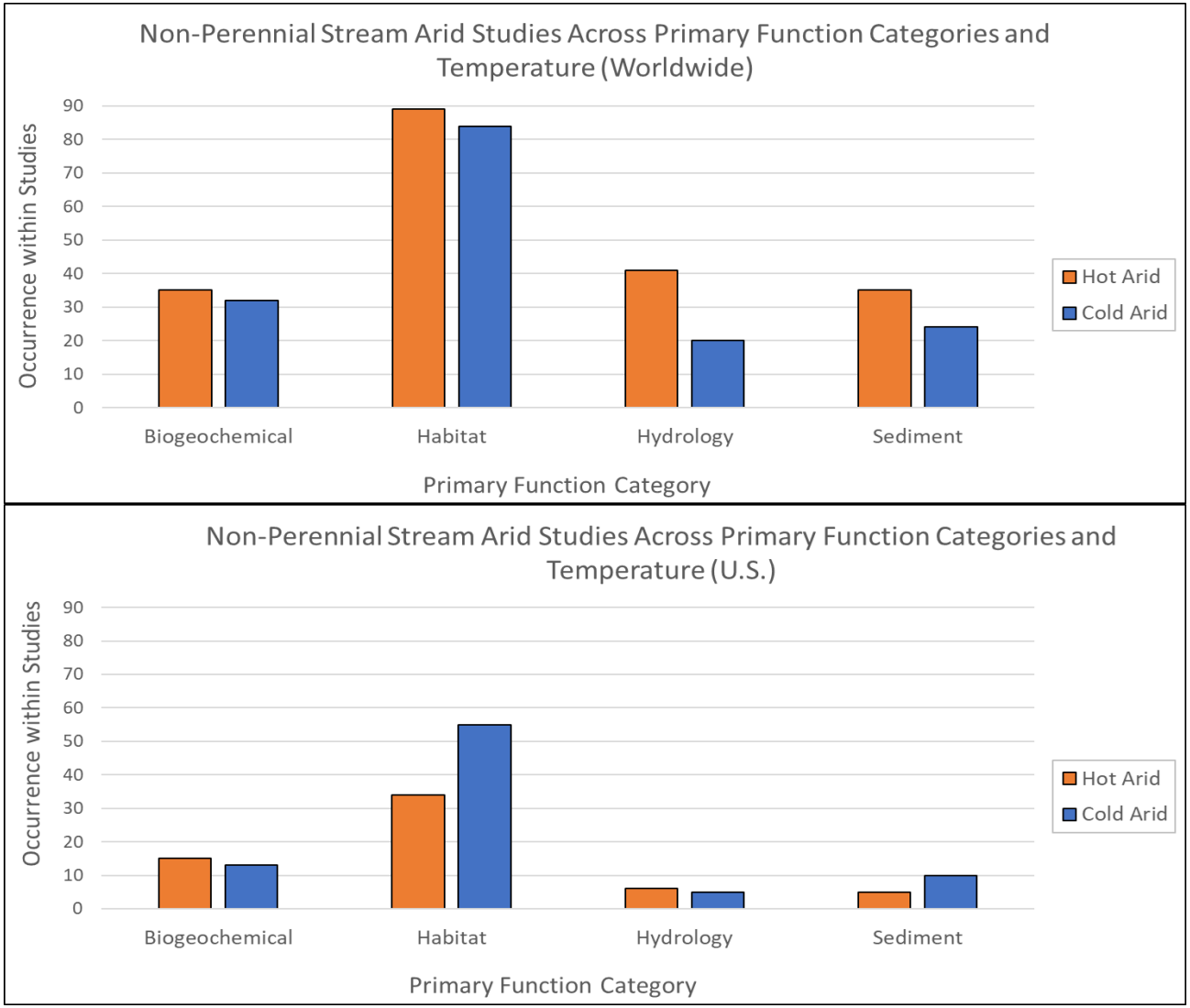


Figure 42. Koppen-Geiger arid temperature sub-climates by primary function category among global and U.S. arid non-perennial literature.

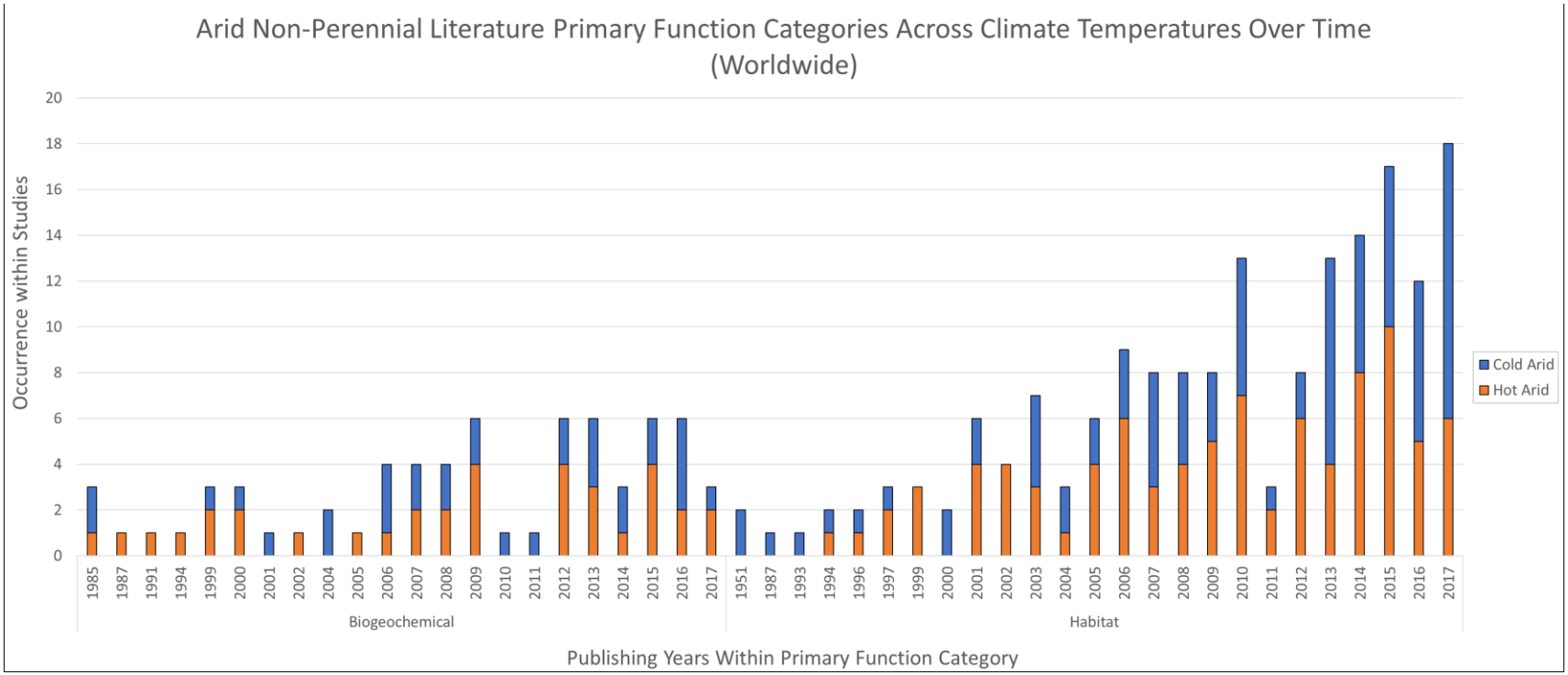


Figure 43. Occurrence of Koppen-Geiger temperature sub-climates by Biogeochemical and Habitat primary function categories, within global arid non-perennial literature published over time.

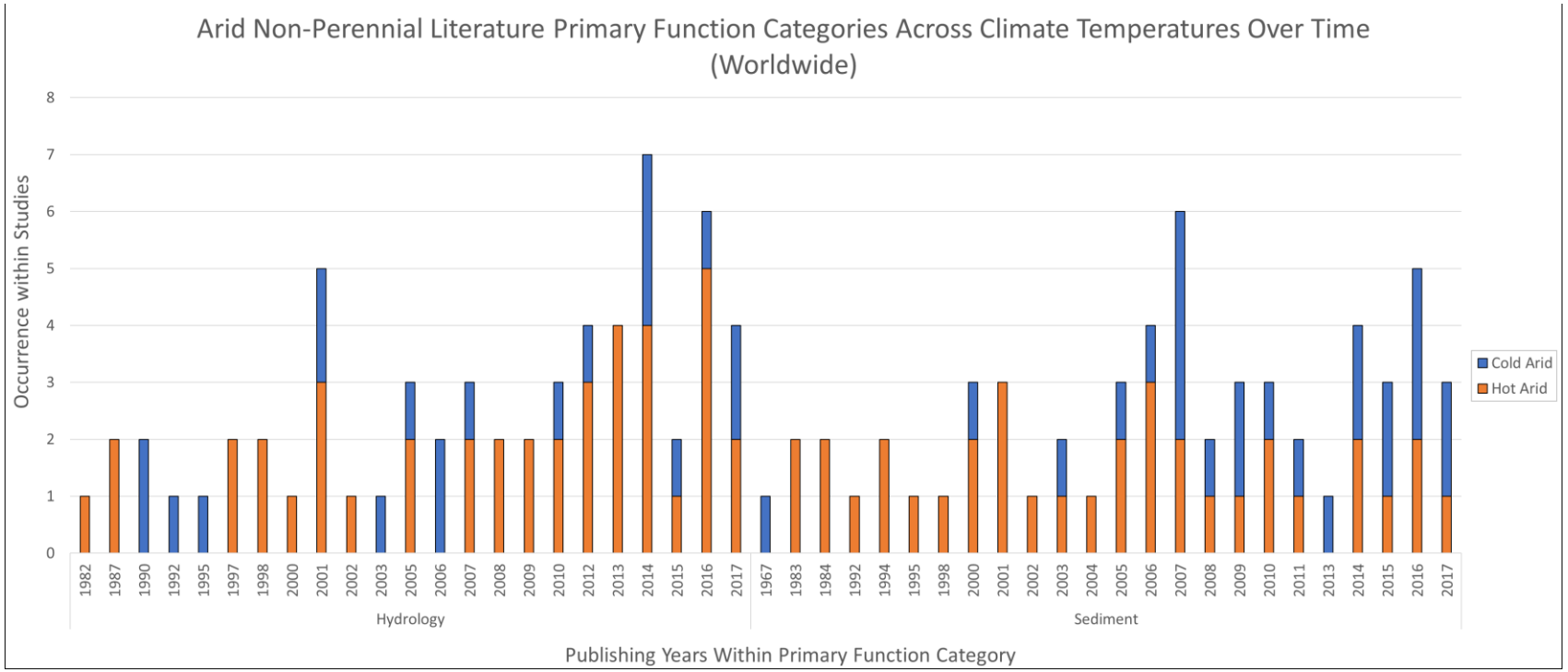


Figure 44. Occurrence of Koppen-Geiger temperature sub-climates by Hydrology & Sediment primary function categories, within global arid non-perennial literature published over time.

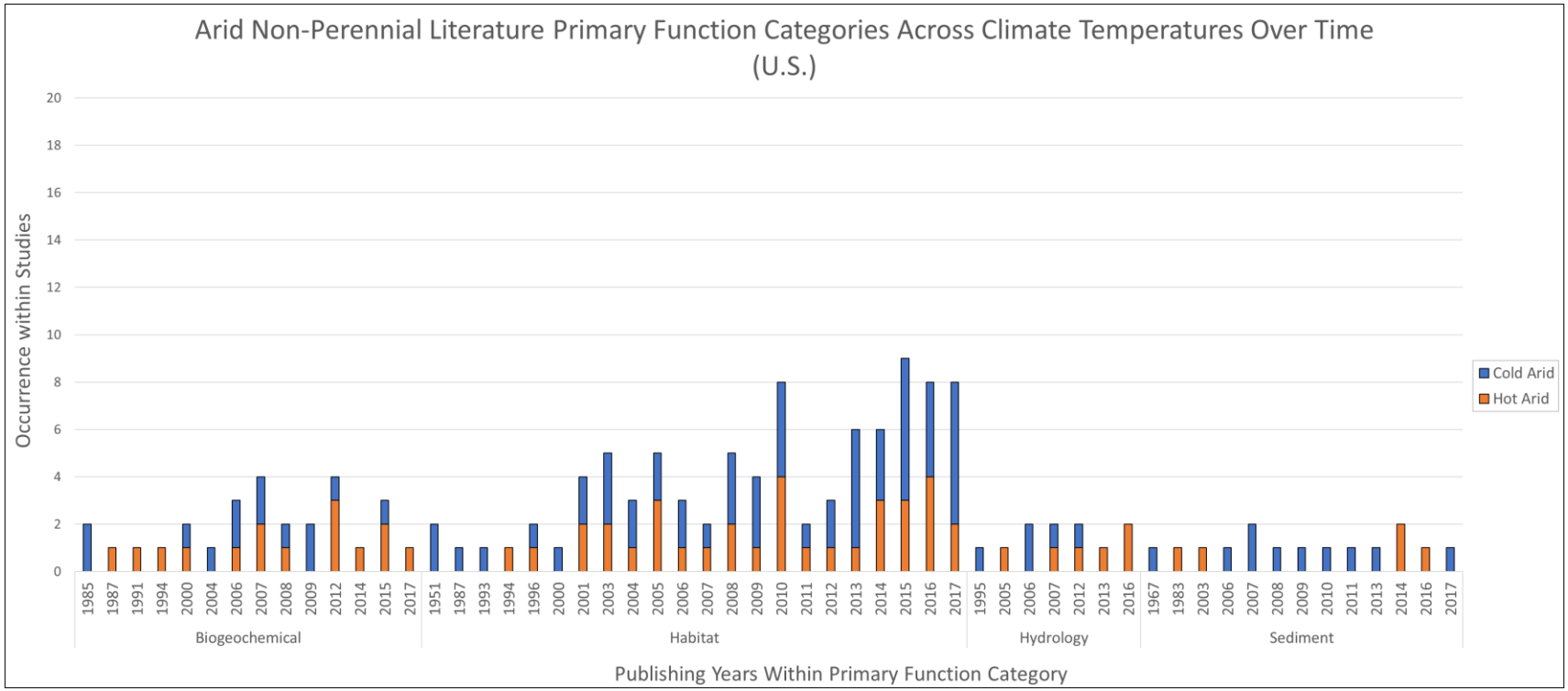


Figure 45. Occurrence of Koppen-Geiger temperature sub-climates by primary function category, within U.S. arid non-perennial literature published over time.

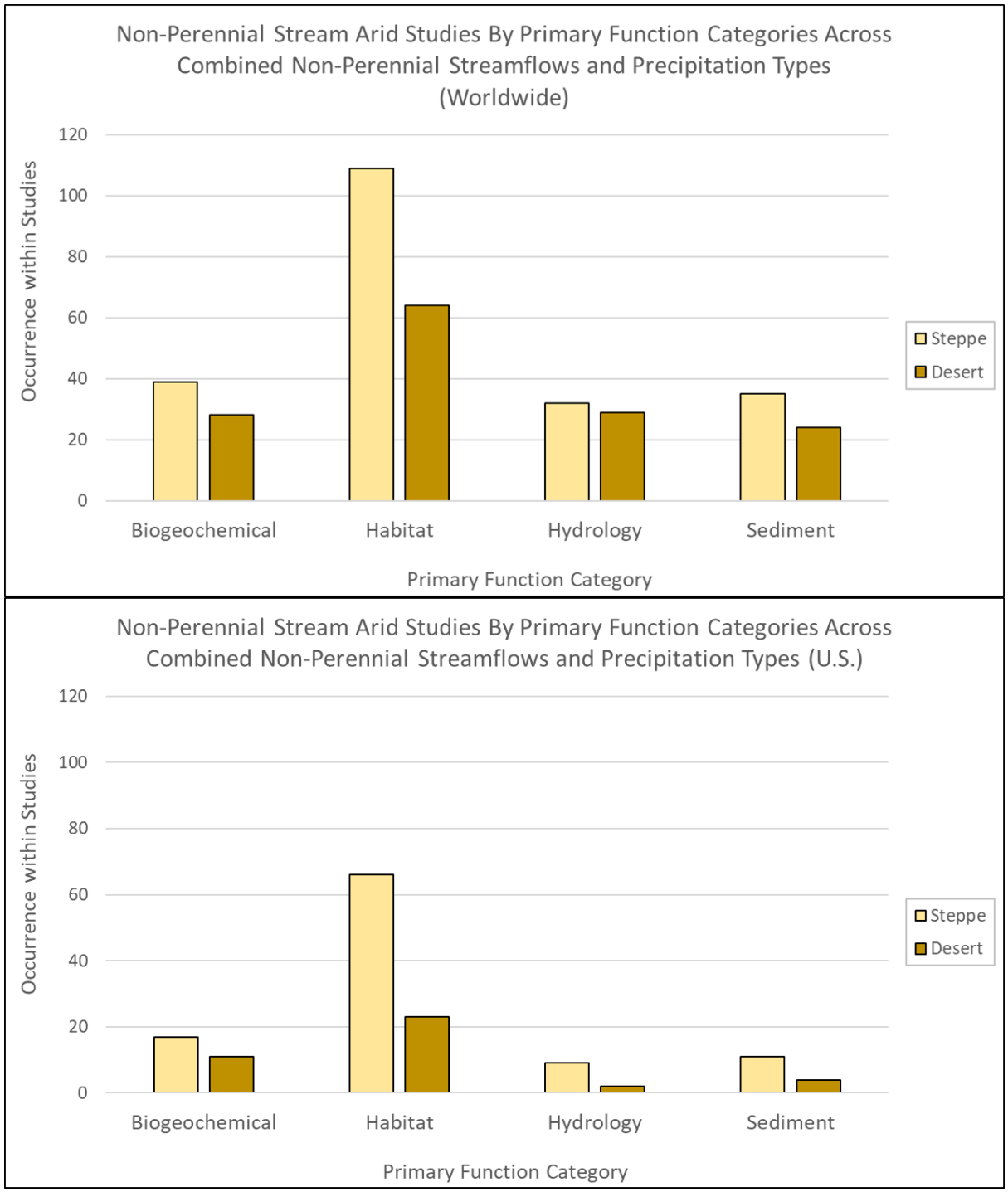


Figure 46. Koppen-Geiger arid precipitation sub-climates by primary function category among global and U.S. arid non-perennial literature.

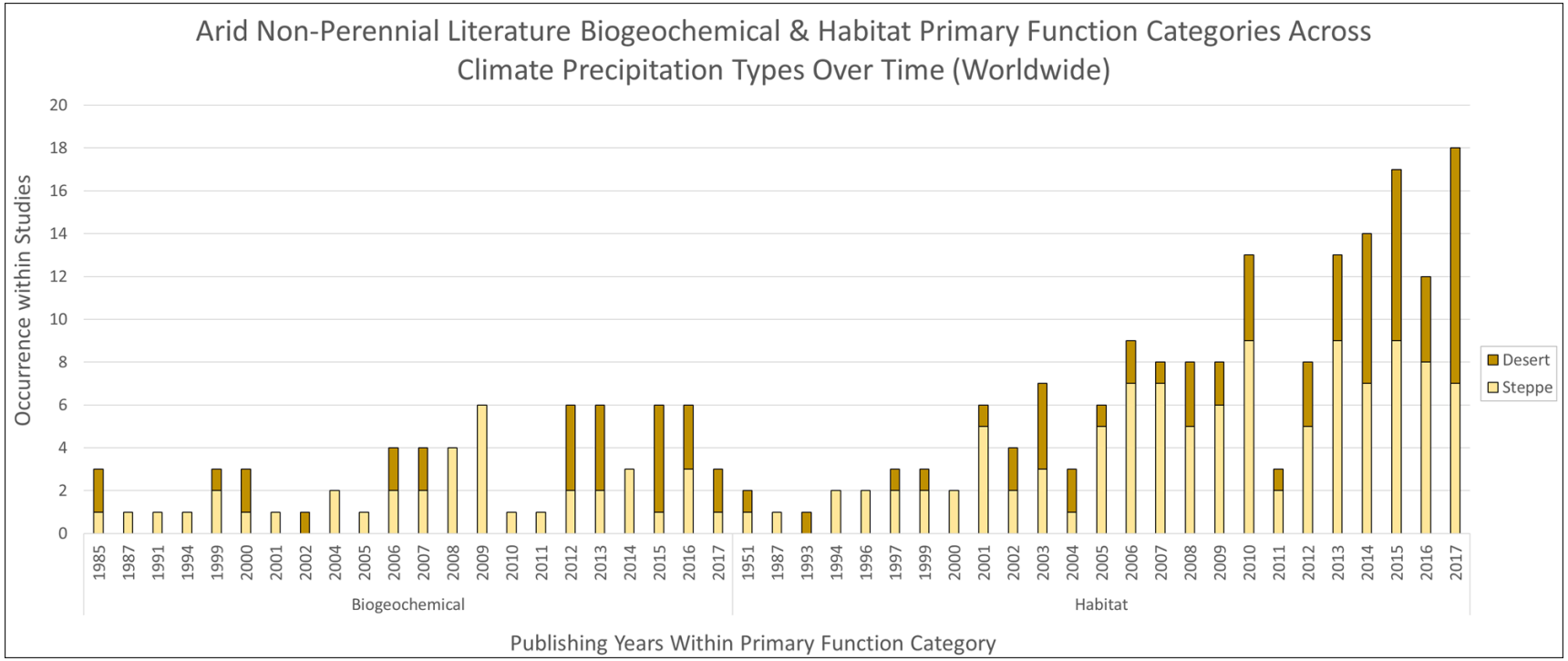


Figure 47. Occurrence of Koppen-Geiger precipitation sub-climates by Biogeochemical and Habitat primary function categories, within global arid non-perennial literature published over time.

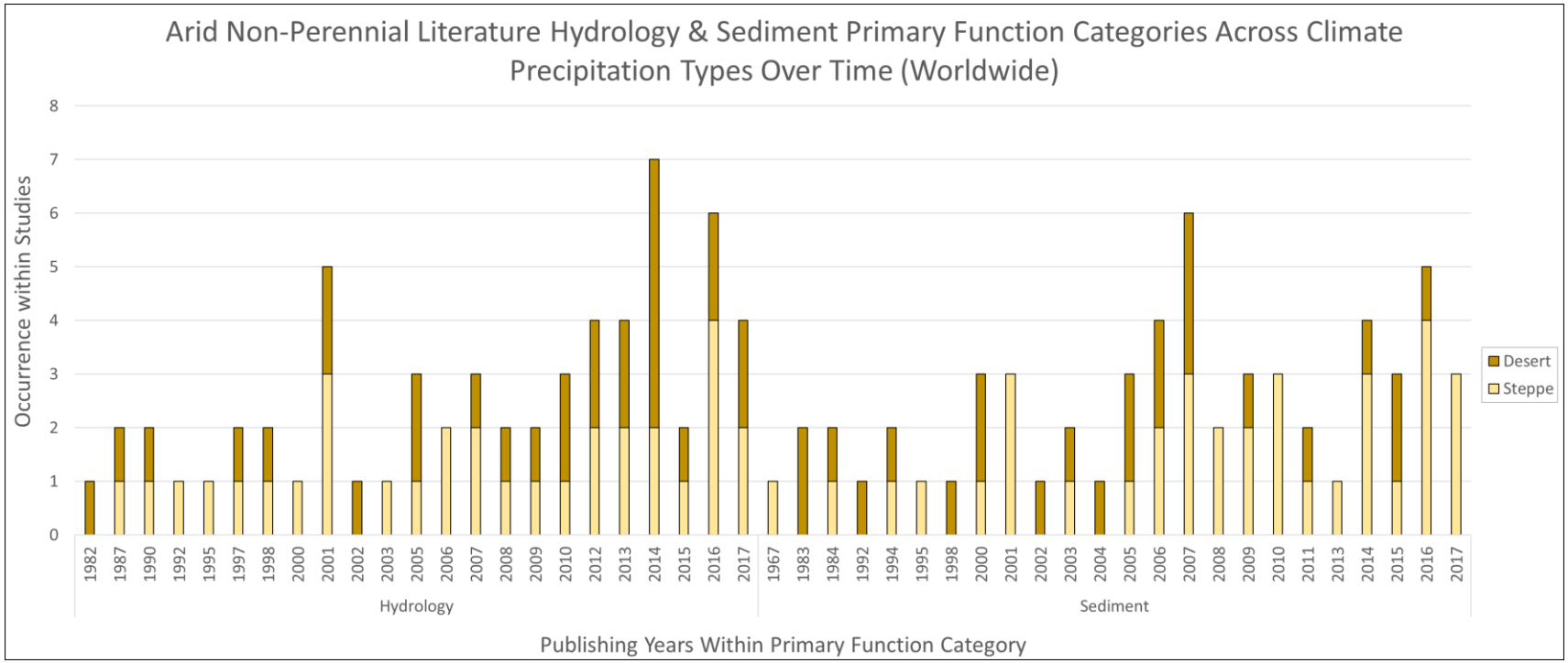


Figure 48. Occurrence of Koppen-Geiger precipitation sub-climates by Hydrology and Sediment primary function categories, within global arid non-perennial literature published over time.

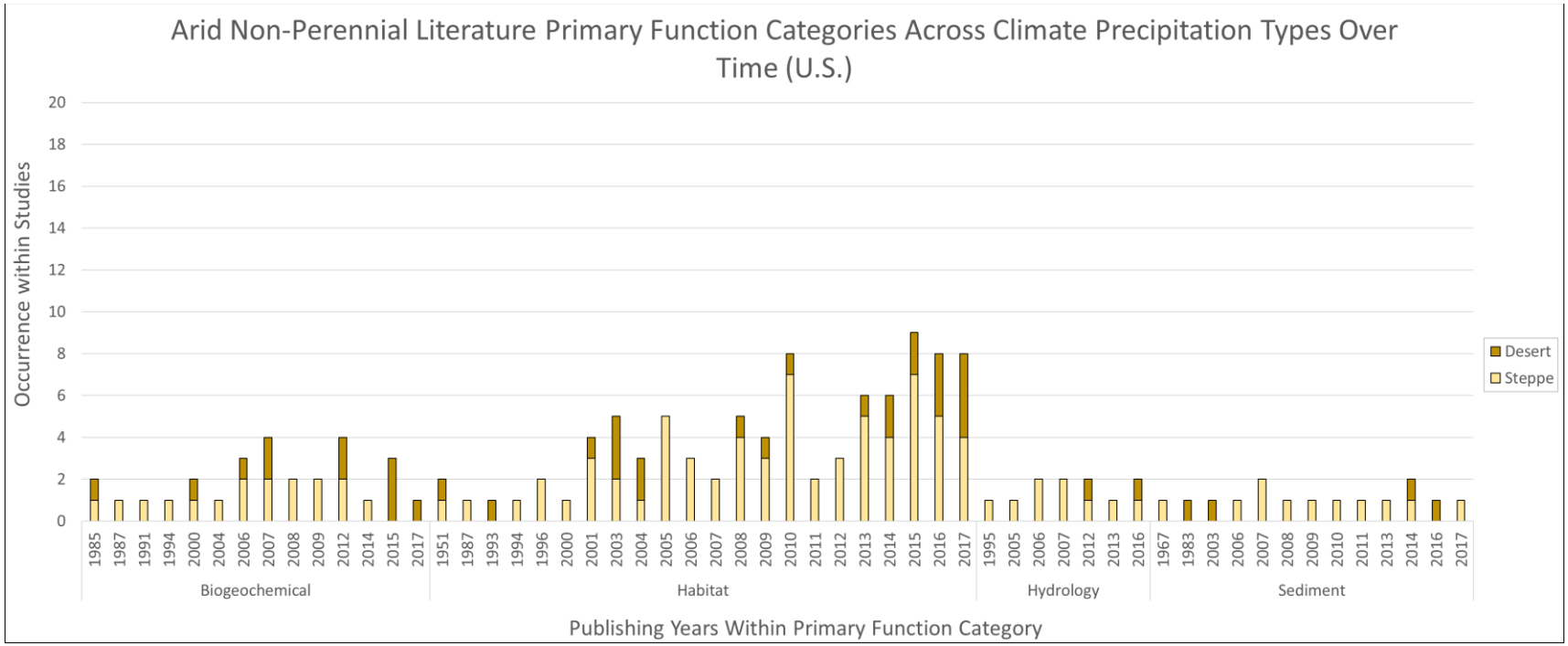


Figure 49. Occurrence of Koppen-Geiger precipitation sub-climates by primary function category, within U.S. arid non-perennial literature published over time.

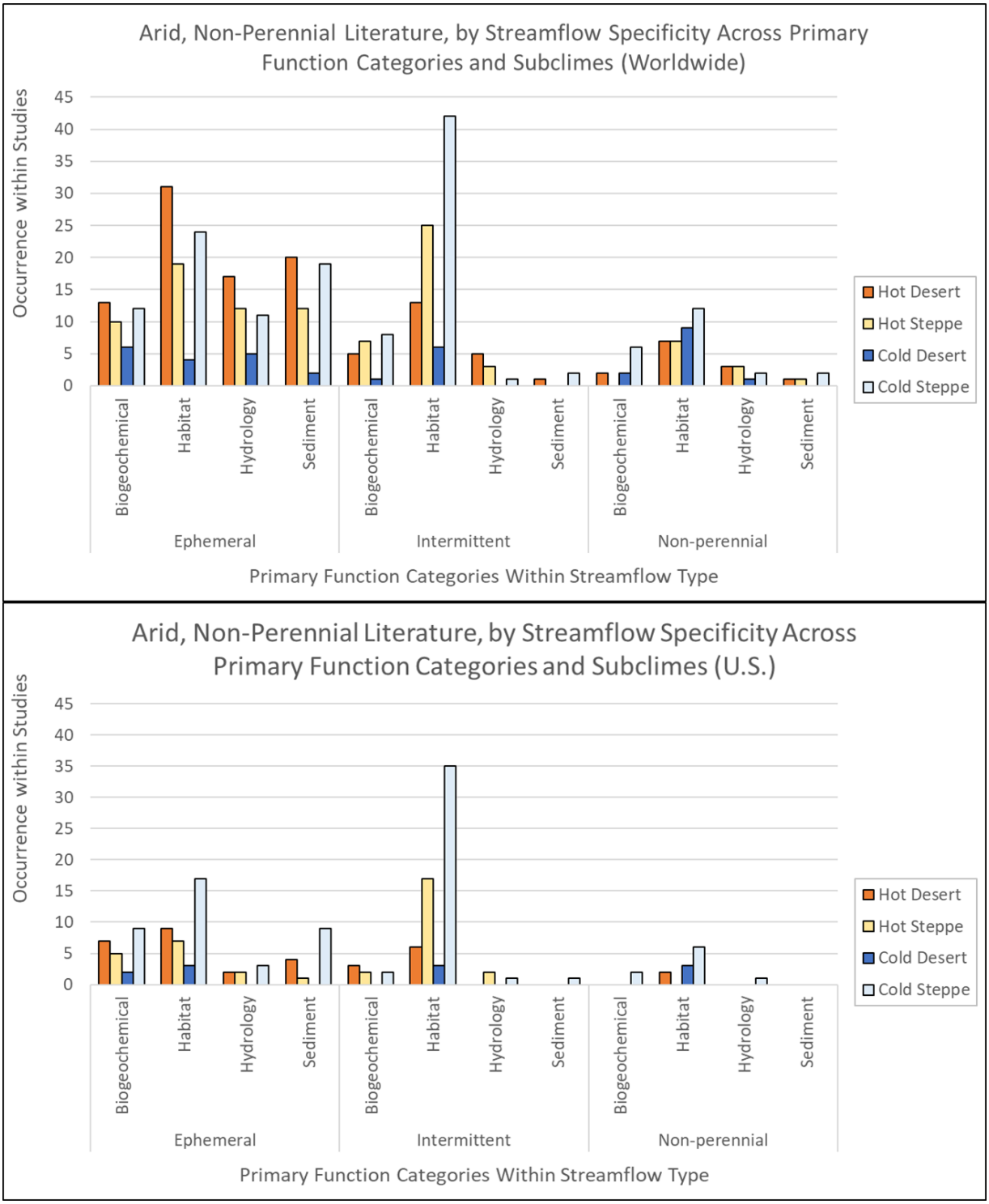


Figure 50. Koppen-Geiger arid subclimes by primary function category and streamflow specificity among global and U.S. arid non-perennial literature.

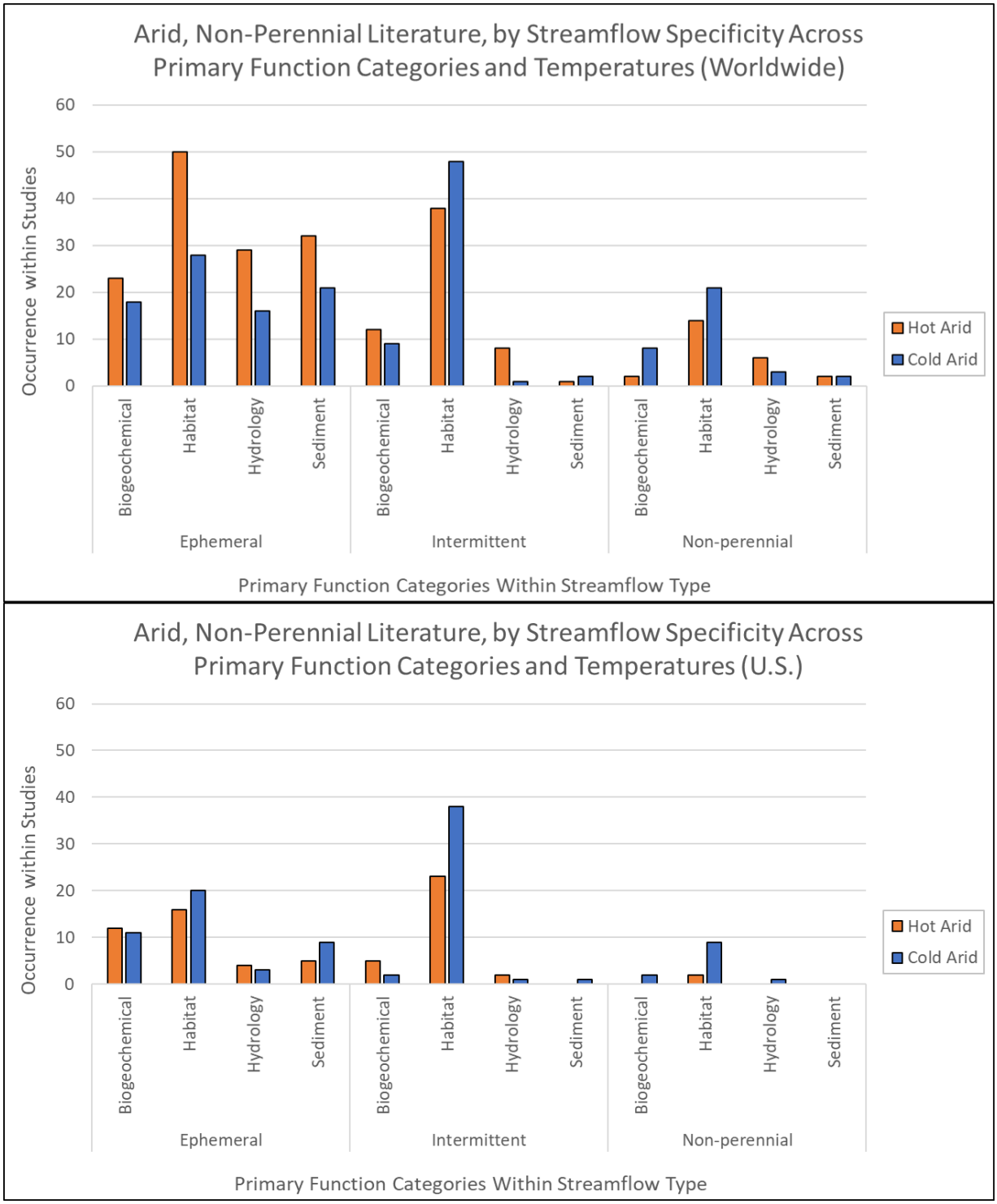


Figure 51. Koppen-Geiger arid temperatures by primary function category and streamflow specificity among global and U.S. arid non-perennial literature.

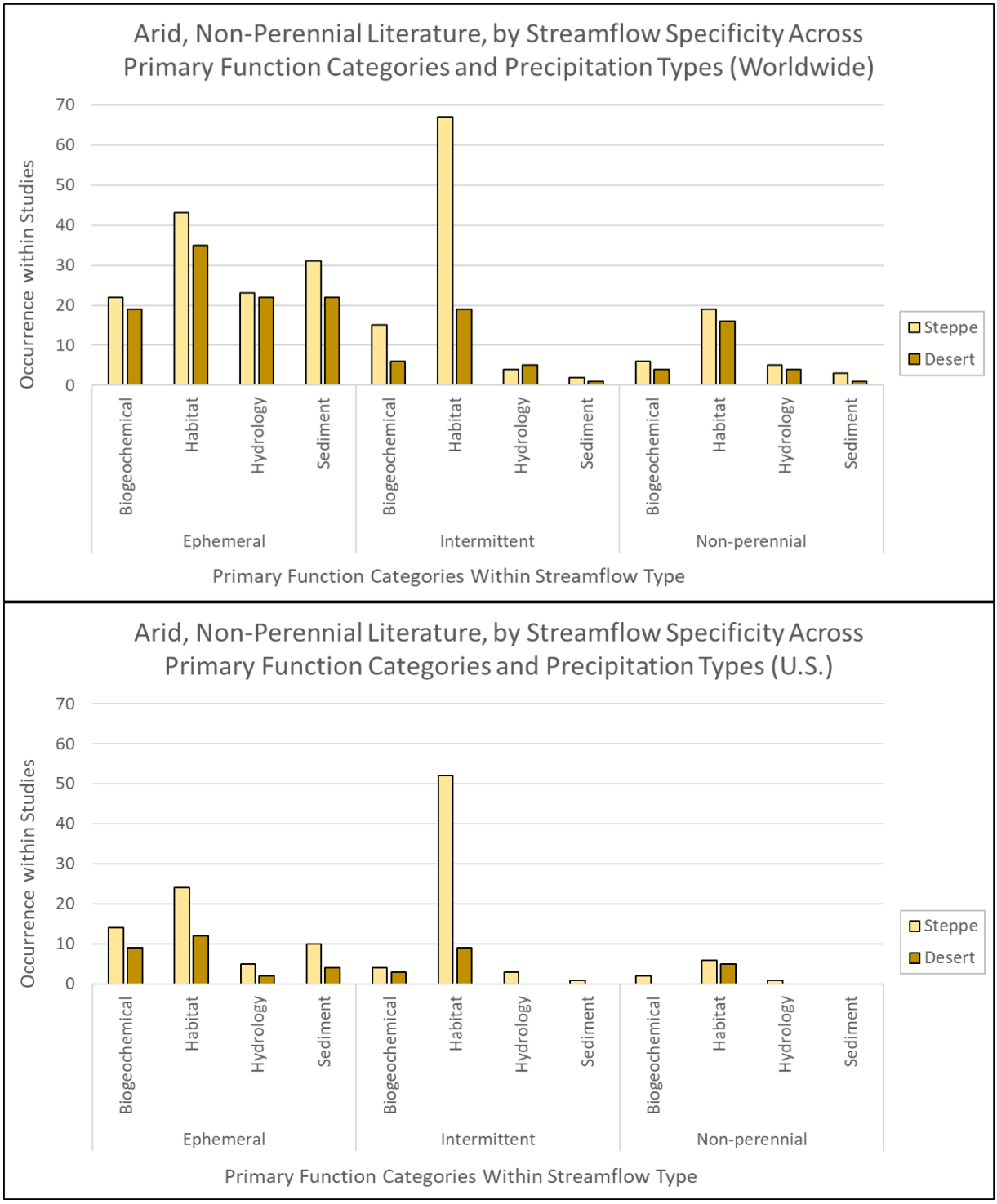


Figure 52. Koppen-Geiger arid precipitation types by primary function category and streamflow specificity among global and U.S. arid non-perennial literature.

Functions and Summary Trends

As touched upon in the previous section, the arid non-perennial stream literature data is organized and presented in the manner of Figure 36 and Figure 37 conceptual diagrams, providing context of stream primary function categories in relation to three conceptual overlapping hierarchies. From Figure 36, the first fundamental element is the overarching influence and control of climate on stream ecosystem functions (Wohl et al., 2016). This is represented within Figure 37 in the first three columns, as both climate categories as a whole (e.g., Koppen-Geiger subclimes) and subsequently the subclime components separated out (temperature and precipitation). The stream function categories primarily affected by these climate components, as first indicated on the right side of Figure 36, are highlighted in blue below each listed component of Figure 37. The overall hydrology of aquatic systems, another key factor influencing aquatic functions, is represented by the circled precipitation and streamflow columns. As part of the overall hydrology in aquatic systems, streamflow regime is an important factor significantly influencing hydrological and other stream functions (Harman et al., 2012). This lower hierarchy of functions, nestled within overarching climate influences, is reflected on the right side of Figure 36 and is included within Figure 37 as the fourth abiotic component within which stream functions information was analyzed. Another conceptual theme outlined on the right side of Figure 37 is the dominance of overall and separate system hydrology components over most arid stream functions, in comparison to the separate temperature component of climate. Therefore, the four columns of factors influencing the stream primary

function categories data were additionally analyzed in the contexts of with and without hydrology components.

Following the systematic analyses and data layering described above, overall and sub-trends of the arid, non-perennial stream primary function categories emerged for both U.S. and global literature sets. Beginning first with the basic distribution of primary function categories, the pattern was the same for global and U.S. studies where Habitat function studies dominated all primary functions coverage, followed in decreasing order by Biogeochemical, Sediment, and Hydrology functions (Table 6). When looking at the occurrence of the primary function categories within the arid climate subareas (e.g., subclimes), both U.S. and global studies had the same basic trend of occurring mostly within the cold steppe subclime, followed in decreasing order by hot desert, hot steppe, and cold desert subclimes (Table 7). However, while most global studies followed this same large pattern when compared alongside the primary functions, Hydrology studies deviated with a predominance within the hot desert subclime and a shift of cold steppe occurrences to just above the least well represented cold desert subclime. For studies within the U.S., there was a distinct split of Biogeochemical and Sediment studies following the overall occurrence trend within subclimes, and though the highest and lowest number of Habitat and Hydrology studies had a middle subclime range shift between hot desert and hot steppe predominant occurrences. Even with these slight deviations from standard, the cold desert subclime was consistently least represented among all studies. Next, the primary function categories of global and U.S. studies were evaluated by the separate subclime components of temperature (Table 8) and precipitation type (Table 9). As a whole, global arid non-perennial stream studies within and across all function categories consistently dominated within hot arid

areas, while U.S. studies overall were predominantly within cold arid areas. As with the subclimes, but in a different manner, U.S. studies were split with Habitat and Sediment studies following the larger U.S. trend yet Biogeochemical and Hydrology studies were predominant within hot arid areas. There was more consistency in overall patterns across both U.S. and global studies for representation of the primary function categories across the overall hydrology components of precipitation type (Table 9) and streamflow regime (Table 10). For all studies, across and by individual stream function categories, occurrences within steppe precipitation areas clearly dominated over desert areas. Similarly, all studies across all function categories predominantly researched streams with ephemeral vs intermittent flow. The only deviation of this larger pattern occurred for Habitat studies, where both U.S. and global research predominantly occurred within intermittent streams. The last overall trends for all arid non-perennial stream studies incorporated the layering of the overall and separate climate components along with streamflow regime across primary function categories. In terms of the stream functions among subclimes, there were only two clear trends across U.S. and global studies (Table 11). The first was a lack of study occurrences within cold desert areas across all streamflow regimes and studies. The second was a pattern only within ephemeral stream studies across all function categories, where the highest representation was within the hot desert subclime (deviating from the larger subclimes pattern) for global studies and global studies followed the larger subclimes occurrence pattern. In again looking at the separate subclime components of temperature (Table 12) and precipitation (Table 13), global and U.S. studies were fairly consistent in following trends for their respective data sets. For hot and cold arid areas, only intermittent stream Habitat and Sediment studies deviated with a dominance within cold

areas, and likewise only intermittent stream Hydrology studies occurred more predominantly within desert precipitation areas. The deviation pattern for U.S. studies within cold and hot arid areas for Biogeochemical and Hydrology functions was still consistent across both ephemeral and intermittent stream studies, and all U.S. studies by all stream function categories and streamflow regimes were consistently dominant in steppe precipitation areas.

Lastly, in addition to the two conceptual hierarchies mentioned above, the third intermediate conceptual hierarchy consists of large to small scale factors, or environmental parameters, acting on different landscape scales (Figure 36). The first, and largest scale parameter is watershed position, followed by stream planform types and then within-site stream sampling locations. The following sections separately cover analyses of each of these environmental parameters among the associated stream primary function categories, along with other data layers in a similar systematic fashion as described above. Following the basic presentation of arid non-perennial stream studies distribution among subcategories of the individual environmental parameter and along with the primary function categories, the results are organized by most to least data layerings of climate and hydrology components. The data are also presented in context of the overall function summary trends of this section, as deviations from larger overall patterns would be significant. The results are presented in the same manner organized within the conceptual diagrams of Figure 36 and Figure 37, and as such these figures are repeated throughout the presentation of data (with relevant highlights) as visual map guides though the results subsections.

Tables

Table 6. Overall occurrence trends of the primary function categories within global and U.S. arid non-perennial stream literature. The relative representation between the function categories is noted as slight (>), moderate (>>), or significant (>>>).

Overall	**Global**						
	Habitat	>>	Biogeochemical	>	Sediment	>	Hydrology
	U.S.						
	Habitat	>>	Biogeochemical	>>	Sediment	>	Hydrology

Table 7. Overall occurrence trends of the primary function categories among Koppen-Geiger subclimes within global and U.S. arid non-perennial stream literature. The relative representation between the function categories is noted as slight (>), moderate (>>), or significant (>>>). Data layer trends that mirror overall study trends are denoted as "*".

Global							
Overall	Cold Steppe	>	Hot Desert	>	Hot Steppe	>>	Cold Desert
Biogeochemical	*	>	*	>	*	>>	*
Habitat	*	>>	*	>	*	>>	*
Hydrology	Hot Desert	>	Hot Steppe	>	Cold Steppe	>>	Cold Desert
Sediment	*	>	*	>	*	>>>	*
U.S.							
Overall	Cold Steppe	>>	Hot Desert	>	Hot Steppe	>>	Cold Desert
Biogeochemical	*	>	*	>	*	>>	*
Habitat	Cold Steppe	>>>	Hot Steppe	>	Hot Desert	>>	Cold Desert
Hydrology	Cold Steppe	>	Hot Steppe	>	Hot Desert	>	Cold Desert
Sediment	*	>>	*	>>	*	>	*

Table 8. Overall occurrence trends of the primary function categories among hot and cold temperatures within global and U.S. arid non-perennial stream literature. The relative representation between the function categories is noted as slight (>), moderate (>>), or significant (>>>). Data layer trends that mirror overall study trends are denoted as "*".

Global			
Overall	**Hot arid**	**>**	**Cold arid**
Biogeochemical	*	>	*
Habitat	*	>	*
Hydrology	*	>>	*
Sediment	*	>	*
U.S.			
Overall	**Cold arid**	**>**	**Hot arid**
Biogeochemical	Hot arid	>	Cold arid
Habitat	*	>>	*
Hydrology	Hot arid	>	Cold arid
Sediment	*	>>	*

Table 9. Overall occurrence trends of the primary function categories among arid precipitation types within global and U.S. arid non-perennial stream literature. The relative representation between the function categories is noted as slight (>), moderate (>>), or significant (>>>). Data layer trends that mirror overall study trends are denoted as "*".

Global			
Overall	**Steppe**	**>**	**Desert**
Biogeochemical	*	>	*
Habitat	*	>>	*
Hydrology	*	>	*
Sediment	*	>	*
U.S.			
Overall	**Steppe**	**>>**	**Desert**
Biogeochemical	*	>	*
Habitat	*	>>	*
Hydrology	*	>>>	*
Sediment	*	>>	*

Table 10. Overall occurrence trends of the primary function categories among streamflow regimes within global and U.S. arid non-perennial stream literature. The relative representation between the function categories is noted as slight (>), moderate (>>), or significant (>>>). Data layer trends that mirror overall study trends are denoted as "*".

Global			
Overall	**Ephemeral**	**>>**	**Intermittent**
Biogeochemical	*	>>	*
Habitat	Intermittent	>	Ephemeral
Hydrology	*	>>>	*
Sediment	*	>>>	*
U.S.			
Overall	**Ephemeral**	**>**	**Intermittent**
Biogeochemical	*	>>>	*
Habitat	Intermittent	>>	Ephemeral
Hydrology	*	>>	*
Sediment	*	>>>	*

Table 11. Overall occurrence trends of the primary function categories among Koppen-Geiger subclimes and streamflow regimes within global and U.S. arid non-perennial stream literature. The relative representation between the function categories is noted as slight (>), moderate (>>), or significant (>>>). Data layer trends that mirror overall study trends are denoted as "*".

Global								
Overall		Cold Steppe	>	Hot Desert	>	Hot Steppe	>>	Cold Desert
By Function	Biogeochemical	*	>	*	>	*	>>	*
	Habitat	*	>>	*	>	*	>>	*
	Hydrology	Hot Desert	>	Hot Steppe	>	Cold Steppe	>>	Cold Desert
	Sediment	*	>	*	>	*	>>>	*
By Ephemeral flow	Biogeochemical	Hot Desert	>	Cold Steppe	>	Hot Steppe	>	Cold Desert
	Habitat	Hot Desert	>	Cold Steppe	>	Hot Steppe	>>>	Cold Desert
	Hydrology	Hot Desert	>	Hot Steppe	>	Cold Steppe	>>	Cold Desert
	Sediment	Hot Desert	>	Cold Steppe	>>	Hot Steppe	>>>	Cold Desert
By Intermittent flow	Biogeochemical	Cold Steppe	>	Hot Steppe	>	Hot Desert	>>>	Cold Desert
	Habitat	Cold Steppe	>>	Hot Steppe	>>	Hot Desert	>>	Cold Desert
	Hydrology	Hot Desert	>>	Hot Steppe	>>>	Cold Steppe		NA
	Sediment	*	>	*		NA		NA

U.S.								
Overall		Cold Steppe	>>	Hot Desert	>	Hot Steppe	>>	Cold Desert
By Function	Biogeochemical	*	>	*	>	*	>>	*
	Habitat	Cold Steppe	>>>	Hot Steppe	>	Hot Desert	>>	Cold Desert
	Hydrology	Cold Steppe	>	Hot Steppe	>	Hot Desert	>	Cold Desert
	Sediment	*	>>	*	>>	*	>	*
By Ephemeral flow	Biogeochemical	*	>	*	>	*	>>	*
	Habitat	*	>>	*	>	*	>>	*
	Hydrology	*	>	*	>	*		NA
	Sediment	*	>>	*	>>	*		NA
By Intermittent flow	Biogeochemical	Hot Desert	>	Hot Steppe	>	Cold Steppe		NA
	Habitat	Cold Steppe	>>	Hot Steppe	>>>	Hot Desert	>	Cold Desert
	Hydrology	Hot Steppe	>	Cold Steppe		NA		NA
	Sediment	Cold Steppe		NA		NA		NA

Table 12. Overall occurrence trends of the primary function categories among hot and cold temperatures and streamflow regimes within global and U.S. arid non-perennial stream literature. The relative representation between the function categories is noted as slight (>), moderate (>>), or significant (>>>). Data layer trends that mirror overall study trends are denoted as "*".

Global				
Overall		Hot arid	>	Cold arid
By Function	Biogeochemical	*	>	*
	Habitat	*	>	*
	Hydrology	*	>>	*
	Sediment	*	>	*
By Ephemeral flow	Biogeochemical	*	>	*
	Habitat	*	>>	*
	Hydrology	*	>>	*
	Sediment	*	>>	*
By Intermittent flow	Biogeochemical	*	>	*
	Habitat	Cold arid	>	Hot arid
	Hydrology	*	>>>	*
	Sediment	Cold arid	>>	Hot arid
U.S.				
Overall		Cold arid	>	Hot arid
By Function	Biogeochemical	Hot arid	>	Cold arid
	Habitat	*	>>	*
	Hydrology	Hot arid	>	Cold arid
	Sediment	*	>>	*
By Ephemeral flow	Biogeochemical	Hot arid	>	Cold arid
	Habitat	*	>	*
	Hydrology	Hot arid	>	Cold arid
	Sediment	*	>>	*
By Intermittent flow	Biogeochemical	Hot arid	>>	Cold arid
	Habitat	*	>>	*
	Hydrology	Hot arid	>	Cold arid
	Sediment	*	>	*

Table 13. Overall occurrence trends of the primary function categories among arid precipitation types and streamflow regimes within global and U.S. arid non-perennial stream literature. The relative representation between the function categories is noted as slight (>), moderate (>>), or significant (>>>). Data layer trends that mirror overall study trends are denoted as "*".

Global				
Overall		Steppe	>	Desert
By Function	Biogeochemical	*	>	*
	Habitat	*	>>	*
	Hydrology	*	>	*
	Sediment	*	>	*
By Ephemeral flow	Biogeochemical	*	>	*
	Habitat	*	>	*
	Hydrology	*	>	*
	Sediment	*	>	*
By Intermittent flow	Biogeochemical	*	>>	*
	Habitat	*	>>>	*
	Hydrology	Desert	>	Steppe
	Sediment	*	>	*
U.S.				
Overall		Steppe	>>	Desert
By Function	Biogeochemical	*	>	*
	Habitat	*	>>	*
	Hydrology	*	>>>	*
	Sediment	*	>>	*
By Ephemeral flow	Biogeochemical	*	>	*
	Habitat	*	>>	*
	Hydrology	*	>>	*
	Sediment	*	>>	*
By Intermittent flow	Biogeochemical	*	>	*
	Habitat	*	>>>	*
	Hydrology	*	>>>	*
	Sediment	*	>>>	*

Functions and Watershed Position Parameter

The specific functions and level of functions a stream may provide are in context of the environmental settings, including separate consideration of the watershed position within which the stream site situated (Figure 53). Watershed position commonly is utilized as a proxy for slope or gradient, system energy, stream power, differences in hydrology and sediment inputs (Detenbeck, 2002), and it can also be used as a rough categorical estimation of elevation. Therefore, as an important abiotic environmental factor watershed position has been used by a number of various other stream studies for data partitioning and analysis (Bogan, 2013; Bonada et al., 2007; Bonada et al., 2005; Brinson et al., 1995; Lefebvre, Lichvar, Curtis, et al., 2013; Noble et al., 2010), in addition to differences in streamflow regime and climate.

Watershed position was only listed or discernable for 79% of global studies and 80% of U.S. studies. Moreover, as U.S. studies comprised roughly half of all watershed position studies, both U.S. and global literature data sets were analyzed. Both the U.S. and global literature sets exhibit similar trends on where in the watershed the studies were conducted, with lower watershed position dominating across all Biogeochemical, Habitat, Hydrology and Sediment function categories, followed by the upper watershed and closely then by middle watershed position (Figure 54)(Table 15). As practical matter, this generally could be a result of greater site accessibility within lower watershed areas. There was only a slight difference with Biogeochemical and Habitat functions within U.S. studies having a small majority within upper watershed sampling areas. However, overall differences in the data collection areas were not drastic, and the studies had adequately sampled across the three subcategories. In terms of the opposite perspective, focusing on each of the three watershed position subcategories and the

coverage of all stream function categories within each (Figure 55), the overall global and U.S. study patterns covered the Habitat function category the most, followed by the Biogeochemical, Sediment, and Hydrology function categories. These consistent patterns across all watershed position subcategories likely reflects the influence of the overall coverage of the primary function categories across all studies (Figure 23).

The next steps of data layering included all climate and hydrology aspects, in addition to that of the primary function categories with watershed position subcategories (Figure 56). As detailed within Figure 57, the broad function categories of arid non-perennial studies were examined in terms of overall climate (e.g., subclimes) with hydrology components (inherent precipitation types and specific streamflow regimes). This data layering represented the most influence on the function categories, as it combined both system hydrology components along with temperature. Globally, the distribution of the primary functions across the Koppen-Geiger subclimes, all watershed position subcategories, and combined ephemeral and intermittent streamflow regimes is a predominance (>35%) within the cold steppe subclime, followed by hot desert, hot steppe, and cold desert (Figure 38) (Table 16). Though this larger pattern holds across each watershed position for intermittent stream studies, it somewhat shifts for ephemeral stream studies within lower and middle watershed sampling positions occurring primarily within the hot desert sublime (Figure 58). In contrast to global studies, U.S. studies were consistent with the same larger pattern with all streamflow regimes across all watershed positions occurring predominantly within the cold steppe subclime (Figure 59, Figure 60). Though this could likely be due to U.S. studies comprising a significant portion of global studies (Table 14). In terms of the opposite perspective, focusing on the percent contribution of studies covering a specific

watershed position, subclime and streamflow regime type across all function categories, Biogeochemical and Habitat functions were mainly addressed within both global and U.S. studies (Figure 61, Figure 62). However, the percentage coverage of the U.S. studies was notably higher than all global studies, and there was a distinct lack of the Sediment functions category coverage across intermittent streams studies in general for all watershed positions, as well as for Sediment function studies occurring within the cold desert subclime. Moreover, ephemeral stream studies had a notable lack of the Hydrology functions coverage appearing as dominant across all watershed positions, within both U.S. and global studies (Figure 63, Figure 64).

Similar to the above data analyses, the subclimes were subdivided into the temperature and precipitation components, which were also examined in terms of with specific streamflow regime types among the primary function categories and watershed position subcategories (Figure 65) (Table 17). Figure 66 and Figure 67 depict this data layering with the global and U.S. studies data side-by-side, in terms of each primary function category, while Figure 68 and Figure 69 provide a similar data set comparison in terms of each watershed position. Likely influenced by general streamflow regime studies coverage (Figure 32), overall global and U.S. patterns have greater study coverage of ephemeral vs intermittent streams. It's interesting this pattern still generally held for the Habitat function category across most temperature and precipitation divisions, as the overall U.S. and global studies coverage was greater across studies involving intermittent streams and the Habitat function category. Similarly, though overall global studies were typically as a whole located within hot arid and steppe precipitation areas, and (Figure 42), those patterns were not as evident with global ephemeral stream studies of Habitat and Sediment function categories, including across all watershed positions. On the other hand, U.S. studies

held fairly consistent to the general patterns. In terms of the opposite perspective, focusing on the percent contribution of studies covering a specific watershed position, temperature, arid precipitation type, and streamflow regime type across all function categories, the Biogeochemical and Habitat functions were mainly addressed within both global and U.S. studies across both intermittent and ephemeral streamflow regimes (Figure 70, Figure 71). There was also a tendency across arid temperatures and precipitation types and watershed positions for ephemeral studies to focus on the Biogeochemical function category while intermittent streams focused on Habitat functions, which was slightly more pronounced when presenting the data by watershed position (Figure 72, Figure 73).

Separating out the partial hydrology effects without the inclusion of streamflow regime, the primary functions categories were layered with subclimes (temperature and inherent precipitation) and watershed position subcategories (Figure 74). Within both global and U.S. studies, across all watershed positions, the overall trends are similar with cold desert subclime being least represented while the cold steppe subclime is most heavily represented (Figure 75, Figure 76) (Table 18). Except for the Biogeochemical function that was split between global study occurrences within hot desert and cold steppe, across all watershed positions sampling was dominated within the cold steppe subclime for Habitat and Sediment function categories, while the hot desert steppe was most sampled within for the Hydrology function category. Though the U.S. study occurrences of Habitat and Sediment function category were also dominated by cold steppe subclime across all watershed positions sampling, the Biogeochemical functions trended toward the hot desert subclime. And for the U.S. Hydrology function studies, there was more of a difference by watershed position with hot steppe, hot desert, and cold steppe being predominant

for lower, middle, and upper watershed positions, respectively. In terms of the opposite perspective, focusing on the percent contribution of studies covering a specific watershed position and subclime type across all function categories, the Biogeochemical and Habitat functions were chiefly addressed within both global and U.S. studies, typically with higher percentages within U.S. studies (Figure 77). Moreover, most functions were covered across all global studies among all subclimes and watershed positions. There was also a tendency for global Biogeochemical function studies to be best represented across the cold desert subclime across all watersheds, and similarly for global Hydrology studies within the hot desert subclime. Yet the global Habitat and Sediment studies were inconsistently represented across the watershed positions and subclimes in mixed occurrences. U.S. studies function occurrences also had inconsistences across both subclimes and watershed locations, though most functions were addressed within hot desert and cold steppe subclimes across all watershed positions. Moreover, the cold desert subclime covered only Habitat and Biogeochemical functions across all watershed positions, and there was a trend for Sediment studies to be absent from hot steppe and cold desert subclimes across all watersheds (Figure 78, Figure 79).

Similar to the above data analyses, the subclimes were further subdivided into the temperature (Figure 80) and then precipitation (Figure 85) components among the function categories they primarily influence and among watershed positions, in the absence of streamflow regime contributions. Whereas all global studies had exhibited a general pattern of predominance within hot arid areas (Figure 42), which was mirrored within all watershed positions for Biogeochemical studies, there was a pronounced shift in global Habitat studies with greater sampling within cold arid areas of middle and upper watershed positions (Figure 81) (Table 19).

U.S. studies for Biogeochemical and Habitat functions followed that of general hot and cold arid predominance patterns, and as well as generally mirrored the patterns of global studies (Figure 82). In terms of the opposite perspective, focusing on the percent contribution of studies covering a specific watershed position and temperature across the Biogeochemical and Habitat function categories, global studies had a strong pattern of Habitat studies outpacing Biogeochemical studies across all watershed positions and hot and cold arid temperatures (Figure 83). U.S. studies had a different pattern consistent across all watershed positions, where sampling was greater in Biogeochemical functions in hot arid areas and Habitat Functions were significantly greater within cold arid areas (Figure 84). When subsequently examining the other component of subclimes, precipitation type, among the function categories watershed positions in the absence of streamflow regime (Figure 85), for the most part both U.S. and global studies exhibited the general pattern of predominance (Figure 46) within steppe precipitation areas (Figure 86) (Table 20). However, for global Hydrology studies within middle and upper watershed positions, there was a notable increase in desert precipitation locations over steppe (Figure 87). Though in general, across all function categories and watershed positions, there is a lack of study occurrences within desert locations and future research in those locales would thus be beneficial. In terms of the opposite perspective, focusing on the percent contribution of studies covering a specific watershed position and precipitation type, there was coverage of all functions across all watershed positions and precipitation types in both U.S. and global studies (Figure 88). U.S. and global study patterns were similar across all watershed positions within steppe precipitation areas, consisting of the general larger pattern (Figure 46) of greatest Habitat functions coverage, followed by Biogeochemical, Sediment, and Hydrology functions (Figure 89). However, the

global desert studies had a more even coverage of all functions, while for U.S. desert studies the general trend was a predominance of Biogeochemical functions followed by Habitat, Sediment and Hydrology studies within lower and upper watershed positions. Moreover, U.S. and global desert studies within middle watershed locations also had a notable dominance of Sediment functions coverage, deviating from the larger pattern where Sediment function studies typically lag behind both Biogeochemical and Habitat studies.

In a similar fashion to the above sections, in terms of regarding individual contributions of precipitation and temperature, the individual contribution of streamflow regimes absent any other hydrology and climate components was examined in concert with the function categories and watershed position (Figure 90). The general pattern of a predominance of ephemeral stream coverage over intermittent streams (Figure 32) carried through all watershed positions for U.S. and global Biogeochemical, Hydrology, and Sediment studies (Figure 91) (Table 21). Nonetheless, there was a noted alteration from that general pattern for global Habitat studies, where there continued to be a predominance of ephemeral over intermittent stream studies for lower (26% difference) and upper watershed (8% difference) positions, while the streamflow regimes were equally represented within studies located within the middle watershed position (Figure 92). Similar to precipitation types, as overall hydrology is a critical factor in arid water-limited stream systems influencing the spectrum of primary function categories, it would be beneficial for future studies to provide an increase focus on arid intermittent stream studies. In terms of the opposite perspective, focusing on the percent contribution of studies covering a specific watershed position and streamflow type, there was coverage of most functions across all watershed positions and streamflow regimes in both U.S. and global studies. The exceptions

were a complete lack of Sediment function studies within upper watersheds for intermittent streams across both U.S. and global studies, as well as very little to no Sediment function studies within lower and middle watersheds for intermittent streams (Figure 93). The intermittent streamflow regime study patterns were similar across both watershed positions and U.S. and global studies, with Habitat and then Biogeochemical functions dominating all studies in all watershed positions. Yet for U.S. ephemeral stream studies there was a predominance of Biogeochemical functions coverage across watershed positions, while global ephemeral stream studies were trending with Sediment function as most dominant (Figure 94).

The last, and arguably most overall influential ecosystem control for arid stream systems addressed herein are the combined overall hydrology components, precipitation and streamflow regime, in concert with the watershed positions among the primary function categories (Figure 95). The general overarching patterns of a predominance of ephemeral stream studies and steppe precipitation studies carried through most U.S. and global literature sets, across all watershed positions and function categories (Figure 96) (Table 22). Also, U.S. and global study patterns largely were very similar, with the largest percent dominance of ephemeral compared to intermittent streams within Sediment function studies (Figure 97, Figure 99). The noted difference was for global Habitat studies, where intermittent stream coverage did not dominate for both precipitation types within the lower watershed position, as well as for upper watershed studies within desert precipitation areas (Figure 97). Additionally, there was a notable increase in desert precipitation locations over steppe for global Hydrology studies within middle and upper watershed positions (Figure 100). Lastly, in terms of the opposite perspective, focusing on the percent contribution of studies covering a specific watershed position, precipitation, and

streamflow type, there was coverage of most functions across all watershed positions, precipitation types and streamflow regimes in both U.S. and global studies. The exceptions were a complete lack of Sediment function studies within upper watersheds for intermittent streams across both precipitation types and both U.S. and global studies, as well as for U.S. desert and steppe intermittent stream studies within lower watersheds and global steppe intermittent stream studies within lower watersheds (Figure 101). Patterns within the U.S. and within the global literature sets were similar across all watersheds, streamflow and precipitation types, including a noticeable lack of Sediment and Hydrology function studies within U.S. intermittent stream studies in desert precipitation areas; and an overall cross-pattern of the dominance of global intermittent stream Habitat studies within steppe precipitation areas (Figure 102). Overall, the lack of even coverage across the primary function categories, including differences in coverage among watershed positions, streamflow and precipitation types, could be benefitted by future studies concentrating more in these key areas.

Tables

Table 14. Primary function categories of arid non-perennial literature by streamflow regime and watershed sampling position without and within all subclimates worldwide, including the U.S. (LW= lower watershed, MW = middle watershed, UW = upper watershed).

	Primary Function Category	Study Location	Non-perennial			SubTotal (U.S.%)	Ephemeral			SubTotal (U.S.%)	Intermittent			SubTotal (U.S.%)	TOTAL (U.S.%)
			LW	MW	UW		LW	MW	UW		LW	MW	UW		
	Biogeochemical	Worldwide	5	7	6		26	15	23		8	7	8		
		U.S.	0	1	1	11%	13	8	14	55%	2	3	2	30%	42%
	Habitat	Worldwide	17	10	15		36	20	26		21	20	22		
		U.S.	3	2	7	29%	12	8	10	37%	14	16	16	73%	47%
	Hydrology	Worldwide	5	4	5		27	14	17		6	4	4		
		U.S.	0	0	1	7%	6	3	5	24%	3	2	2	50%	26%
	Sediment	Worldwide	4	4	4		34	25	26		1	1	0		
		U.S.	0	0	0	0%	10	9	8	32%	0	1	0	50%	28%
		(U.S.%)	10%	12%	30%	**17%**	33%	38%	40%	**37%**	53%	69%	59%	**60%**	**38%**
Primary Function Category	**Watershed Position**	**Study Location**	Hot Arid		Cold Arid		Hot Arid		Cold Arid		Hot Arid		Cold Arid		
			Desert	Steppe	Desert	Steppe	Desert	Steppe	Desert	Steppe	Desert	Steppe	Desert	Steppe	(U.S.%)
Biogeochemical	LW	Worldwide	2	0	1	2	8	7	5	6	2	2	1	3	
		U.S.	0	0	0	0	3	5	1	4	2	0	0	0	38%
	MW	Worldwide	2	0	1	4	4	4	3	4	2	2	1	2	
		U.S.	0	0	0	1	2	3	1	2	2	1	0	0	41%
	UW	Worldwide	2	0	1	3	7	5	2	9	2	2	1	3	
		U.S.	0	0	0	1	5	2	1	6	2	0	0	0	46%
Habitat	LW	Worldwide	2	3	6	6	15	7	2	12	2	7	3	9	
		U.S.	0	0	1	2	1	2	1	8	2	5	1	6	39%
	MW	Worldwide	3	1	1	5	7	3	0	10	1	7	1	11	
		U.S.	0	0	1	1	0	1	0	7	0	5	1	10	52%
	UW	Worldwide	3	2	2	8	11	2	0	13	2	7	1	12	
		U.S.	1	0	1	5	0	1	0	9	2	4	1	9	52%
Hydrology	LW	Worldwide	1	3	1	0	11	6	2	8	3	2	0	1	
		U.S.	0	0	0	0	2	2	0	2	0	2	0	1	24%
	MW	Worldwide	2	2	0	0	7	2	2	3	2	1	0	1	
		U.S.	0	0	0	0	2	0	0	1	0	1	0	1	23%
	UW	Worldwide	2	2	0	1	8	3	1	5	2	1	0	1	
		U.S.	0	0	0	1	2	1	0	2	0	1	0	1	31%
Sediment	LW	Worldwide	1	1	0	2	14	4	0	16	1	0	0	0	
		U.S.	0	0	0	0	3	0	0	7	0	0	0	0	26%
	MW	Worldwide	1	1	0	2	12	0	1	12	0	0	0	1	
		U.S.	0	0	0	0	4	0	0	5	0	0	0	1	33%
	UW	Worldwide	1	1	0	2	11	3	0	12	0	0	0	0	
		U.S.	0	0	0	0	3	1	0	4	0	0	0	0	27%
		(U.S.%)	5%	0%	23%	31%	23%	39%	22%	52%	53%	61%	38%	66%	**38%**

Table 15. Overall occurrence trends of the primary function categories among watershed positions within global and U.S. arid non-perennial stream literature. The relative representation between the function categories is noted as slight (>), moderate (>>), or significant (>>>). Data layer trends that mirror overall study trends are denoted as "*".

Global							
Overall	**Habitat**	**>>**	**Biogeochemical**	**>**	**Sediment**	**>**	**Hydrology**
Watershed position	*	>	*	>	*	>	*
Lower	Habitat	>>	Sediment	>	Biogeochemical	>	Hydrology
Upper	*	>>	*	>	*	>	*
Middle	*	>>	*	>	*	>	*

U.S.							
Overall	**Habitat**	**>>**	**Biogeochemical**	**>>**	**Sediment**	**>**	**Hydrology**
Watershed position	*	>	*	>	*	>	*
Lower	*	>>	*	>	*	>	*
Upper	*	>	*	>>	*	>	*
Middle	*	>	*	>	*	>	*

Table 16. Overall occurrence trends of the primary function categories among watershed positions, Koppen-Geiger subclimes, and streamflow regimes within global and U.S. arid non-perennial stream literature. The relative representation between the function categories is noted as slight (>), moderate (>>), or significant (>>>). Data layer trends that mirror overall study trends are denoted as "*".

Global								
Overall		Cold Steppe	>	Hot Desert	>	Hot Steppe	>>	Cold Desert
By Function	Biogeochemical	*	>	*	>	*	>>	*
	Habitat	*	>>	*	>	*	>>	*
	Hydrology	Hot Desert	>	Hot Steppe	>	Cold Steppe	>>	Cold Desert
	Sediment	*	>	*	>	*	>>>	*
By Ephemeral flow	Biogeochemical	Hot Desert	>	Cold Steppe	>	Hot Steppe	>	Cold Desert
	Habitat	Hot Desert	>	Cold Steppe	>	Hot Steppe	>>>	Cold Desert
	Hydrology	Hot Desert	>	Hot Steppe	>	Cold Steppe	>>	Cold Desert
	Sediment	Hot Desert	>	Cold Steppe	>>	Hot Steppe	>>>	Cold Desert
By Intermittent flow	Biogeochemical	Cold Steppe	>	Hot Steppe	>	Hot Desert	>>>	Cold Desert
	Habitat	Cold Steppe	>>	Hot Steppe	>>	Hot Desert	>>	Cold Desert
	Hydrology	Hot Desert	>>	Hot Steppe	>>>	Cold Steppe		NA
	Sediment	*	>	*		NA		NA
Watershed position		*	>	*	>>	*	>>	*
By Function	Biogeochemical	*	>	*	>	*	>>	*
	Habitat	*	>>	*	>	*	>>>	*
	Hydrology	Hot Desert	>>	Cold Steppe	>>>	Hot Steppe	>>>	Cold Desert
	Sediment	*	>	*	>>>	*	>>>	*
By Ephemeral flow	Biogeochemical	*	>	*	>	*	>	*
	Habitat	*	>	*	>>>	*	>>>	*
	Hydrology	Hot Desert	>	Cold Steppe	>>>	Hot Steppe	>>>	Cold Desert
	Sediment	*	>	*	>>>	*	>>>	*
By Intermittent flow	Biogeochemical	*	>	*	>	*	>>	*
	Habitat	Cold Steppe	>	Hot Steppe	>>	Hot Desert	>	Cold Desert
	Hydrology	Hot Desert	>>	Hot Steppe	>	Cold Steppe		NA
	Sediment	*	>	*		NA		NA

U.S.								
Overall		Cold Steppe	>>	Hot Desert	>	Hot Steppe	>>	Cold Desert
By Function	Biogeochemical	*	>	*	>	*	>>	*
	Habitat	Cold Steppe	>>>	Hot Steppe	>	Hot Desert	>>	Cold Desert
	Hydrology	Cold Steppe	>	Hot Steppe	>	Hot Desert	>	Cold Desert
	Sediment	*	>>	*	>>	*	>	*
By Ephemeral flow	Biogeochemical	*	>	*	>	*	>>	*
	Habitat	*	>>	*	>	*	>>	*
	Hydrology	*	>	*	>	*		NA
	Sediment	*	>>	*	>>	*		NA
By Intermittent flow	Biogeochemical	Hot Desert	>	Hot Steppe	>	Cold Steppe		NA
	Habitat	Cold Steppe	>>	Hot Steppe	>>>	Hot Desert	>	Cold Desert
	Hydrology	Hot Steppe	>	Cold Steppe		NA		NA
	Sediment	Cold Steppe		NA		NA		NA
Watershed position		*	>	*	>>	*	>>	*
By Function	Biogeochemical	Hot Desert	>	Cold Steppe	>	Hot Steppe	>>	Cold Desert
	Habitat	Cold Steppe	>>>	Hot Steppe	>>>	Hot Desert	>	Cold Desert
	Hydrology	Cold Steppe	>	Hot Steppe	>	Hot Desert		NA
	Sediment	*	>>	*	>	*		NA
By Ephemeral flow	Biogeochemical	*	>	*	>	*	>>>	*
	Habitat	Cold Steppe	>>>	Hot Steppe	>>>	Hot Desert	>	Cold Desert
	Hydrology	Hot Desert	>	Cold Steppe	>	Hot Steppe		NA
	Sediment	*	>	*	>>>	*		NA
By Intermittent flow	Biogeochemical	Hot Steppe	>>>	Hot Desert		NA		NA
	Habitat	Cold Steppe	>>	Hot Steppe	>>>	Hot Desert	>	Cold Desert
	Hydrology	Hot Steppe		Cold Steppe		NA		NA
	Sediment	*		NA		NA		NA

Table 17. Overall occurrence trends of the primary function categories among watershed positions, hot and cold temperatures, and streamflow regimes within global and U.S. arid non-perennial stream literature. The relative representation between the function categories is noted as slight (>), moderate (>>), or significant (>>>). Data layer trends that mirror overall study trends are denoted as "*".

Global				
Overall		Hot arid	>	Cold arid
By Function	Biogeochemical	*	>	*
	Habitat	*	>	*
	Hydrology	*	>>	*
	Sediment	*	>	*
By Ephemeral flow	Biogeochemical	*	>	*
	Habitat	*	>>	*
	Hydrology	*	>>	*
	Sediment	*	>>	*
By Intermittent flow	Biogeochemical	*	>	*
	Habitat	Cold arid	>	Hot arid
	Hydrology	*	>>>	*
	Sediment	Cold arid	>>	Hot arid
Watershed position		*	>>	*
By Function	Biogeochemical	*	>	*
	Habitat	Cold arid	>	Hot arid
	Hydrology	*	>>	*
	Sediment	*	>	*
By Ephemeral flow	Biogeochemical	*	>	*
	Habitat	*	>	*
	Hydrology	*	>>	*
	Sediment	*	>	*
By Intermittent flow	Biogeochemical	*	>	*
	Habitat	Cold arid	>	Hot arid
	Hydrology	*	>>>	*
	Sediment	*	=	*

U.S.				
Overall		Cold arid	>	Hot arid
By Function	Biogeochemical	Hot arid	>	Cold arid
	Habitat	*	>>	*
	Hydrology	Hot arid	>	Cold arid
	Sediment	*	>>	*
By Ephemeral flow	Biogeochemical	Hot arid	>	Cold arid
	Habitat	*	>	*
	Hydrology	Hot arid	>	Cold arid
	Sediment	*	>>	*
By Intermittent flow	Biogeochemical	Hot arid	>>	Cold arid
	Habitat	*	>>	*
	Hydrology	Hot arid	>	Cold arid
	Sediment	*	>	*
Watershed position		*	>	*
By Function	Biogeochemical	Hot arid	>>	Cold arid
	Habitat	*	>>	*
	Hydrology	Hot arid	>	Cold arid
	Sediment	*	>	*
By Ephemeral flow	Biogeochemical	Hot arid	>	Cold arid
	Habitat	*	>>>	*
	Hydrology	Hot arid	>>	Cold arid
	Sediment	*	>	*
By Intermittent flow	Biogeochemical	Hot arid		NA
	Habitat	*	>	*
	Hydrology	Hot arid	>	Cold arid
	Sediment	*		NA

Table 18. Overall occurrence trends of the primary function categories among watershed positions and Koppen-Geiger subclimes within global and U.S. arid non-perennial stream literature. The relative representation between the function categories is noted as slight (>), moderate (>>), or significant (>>>). Data layer trends that mirror overall study trends are denoted as "*".

Global							
Overall	Cold Steppe	>	Hot Desert	>	Hot Steppe	>>	Cold Desert
Biogeochemical	*	>	*	>	*	>>	*
Habitat	*	>>	*	>	*	>>	*
Hydrology	Hot Desert	>	Hot Steppe	>	Cold Steppe	>>	Cold Desert
Sediment	*	>	*	>	*	>>>	*
Watershed position	*	>	*	>>	*	>>	*
Biogeochemical	*	>	*	>	*	>>	*
Habitat	*	>>	*	>	*	>>>	*
Hydrology	Hot Desert	>>	Cold Steppe	>>>	Hot Steppe	>>>	Cold Desert
Sediment	*	>	*	>>>	*	>>>	*

U.S.							
Overall	Cold Steppe	>>	Hot Desert	>	Hot Steppe	>>	Cold Desert
Biogeochemical	*	>	*	>	*	>>	*
Habitat	Cold Steppe	>>>	Hot Steppe	>	Hot Desert	>>	Cold Desert
Hydrology	Cold Steppe	>	Hot Steppe	>	Hot Desert	>	Cold Desert
Sediment	*	>>	*	>>	*	>	*
Watershed position	*	>	*	>>	*	>>	*
Biogeochemical	Hot Desert	>	Cold Steppe	>	Hot Steppe	>>	Cold Desert
Habitat	Cold Steppe	>>>	Hot Steppe	>>>	Hot Desert	>	Cold Desert
Hydrology	Cold Steppe	>	Hot Steppe	>	Hot Desert		NA
Sediment	*	>>	*	>	*		NA

Table 19. Overall occurrence trends of the primary function categories among watershed positions and hot and cold temperatures within global and U.S. arid non-perennial stream literature. The relative representation between the function categories is noted as slight (>), moderate (>>), or significant (>>>). Data layer trends that mirror overall study trends are denoted as "*".

Global			
Overall	Hot arid	>	Cold arid
Biogeochemical	*	>	*
Habitat	*	>	*
Hydrology	*	>>	*
Sediment	*	>	*
Watershed position	*	>>	*
Biogeochemical	*	>	*
Habitat	Cold arid	>	Hot arid
Hydrology	*	>>	*
Sediment	*	>	*

U.S.			
Overall	Cold arid	>	Hot arid
Biogeochemical	Hot arid	>	Cold arid
Habitat	*	>>	*
Hydrology	Hot arid	>	Cold arid
Sediment	*	>>	*
Watershed position	*	>	*
Biogeochemical	Hot arid	>>	Cold arid
Habitat	*	>>	*
Hydrology	Hot arid	>	Cold arid
Sediment	*	>	*

Table 20. Overall occurrence trends of the primary function categories among watershed positions and arid precipitation types within global and U.S. arid non-perennial stream literature. The relative representation between the function categories is noted as slight (>), moderate (>>), or significant (>>>). Data layer trends that mirror overall study trends are denoted as "*".

Global			
Overall	**Steppe**	**>**	**Desert**
Biogeochemical	*	>	*
Habitat	*	>>	*
Hydrology	*	>	*
Sediment	*	>	*
Watershed position	*	>	*
Biogeochemical	*	>	*
Habitat	*	>>	*
Hydrology	Desert	>	Steppe
Sediment	*	>	*

U.S.			
Overall	**Steppe**	**>>**	**Desert**
Biogeochemical	*	>	*
Habitat	*	>>	*
Hydrology	*	>>>	*
Sediment	*	>>	*
Watershed position	*	>>	*
Biogeochemical	*	>	*
Habitat	*	>>>	*
Hydrology	*	>>	*
Sediment	*	>>	*

Table 21. Overall occurrence trends of the primary function categories among watershed positions and streamflow regimes within global and U.S. arid non-perennial stream literature. The relative representation between the function categories is noted as slight (>), moderate (>>), or significant (>>>). Data layer trends that mirror overall study trends are denoted as "*".

Global			
Overall	**Ephemeral**	**>>**	**Intermittent**
Biogeochemical	*	>>	*
Habitat	Intermittent	>	Ephemeral
Hydrology	*	>>>	*
Sediment	*	>>>	*
Watershed position	*	>>>	*
Biogeochemical	*	>>>	*
Habitat	*	>	*
Hydrology	*	>>>	*
Sediment	*	>>>	*

U.S.			
Overall	**Ephemeral**	**>**	**Intermittent**
Biogeochemical	*	>>>	*
Habitat	Intermittent	>>	Ephemeral
Hydrology	*	>>	*
Sediment	*	>>>	*
Watershed position	*	>>>	*
Biogeochemical	*	>>>	*
Habitat	*	>	*
Hydrology	*	>>>	*
Sediment	*	>>>	*

Table 22. Overall occurrence trends of the primary function categories among watershed positions, arid precipitation types, and streamflow regimes within global and U.S. arid non-perennial stream literature. The relative representation between the function categories is noted as slight (>), moderate (>>), or significant (>>>). Data layer trends that mirror overall study trends are denoted as "*".

Global				
Overall		Steppe	>	Desert
By Function	Biogeochemical	*	>	*
	Habitat	*	>>	*
	Hydrology	*	>	*
	Sediment	*	>	*
By Ephemeral flow	Biogeochemical	*	>	*
	Habitat	*	>	*
	Hydrology	*	>	*
	Sediment	*	>	*
By Intermittent flow	Biogeochemical	*	>>	*
	Habitat	*	>>>	*
	Hydrology	Desert	>	Steppe
	Sediment	*	>	*
Watershed position		*	>	*
By Function	Biogeochemical	*	>	*
	Habitat	*	>>	*
	Hydrology	Desert	>	Steppe
	Sediment	*	>	*
By Ephemeral flow	Biogeochemical	*	>	*
	Habitat	*	>	*
	Hydrology	Desert	>	Steppe
	Sediment	*	>	*
By Intermittent flow	Biogeochemical	*	>	*
	Habitat	*	>>>	*
	Hydrology	*	=	*
	Sediment	*	=	*

U.S.				
Overall		Steppe	>>	Desert
By Function	Biogeochemical	*	>	*
	Habitat	*	>>	*
	Hydrology	*	>>>	*
	Sediment	*	>>	*
By Ephemeral flow	Biogeochemical	*	>	*
	Habitat	*	>>	*
	Hydrology	*	>>	*
	Sediment	*	>>	*
By Intermittent flow	Biogeochemical	*	>	*
	Habitat	*	>>>	*
	Hydrology	*	>>>	*
	Sediment	*	>>>	*
Watershed position		*	>>	*
By Function	Biogeochemical	*	>	*
	Habitat	*	>>>	*
	Hydrology	*	>>	*
	Sediment	*	>>	*
By Ephemeral flow	Biogeochemical	*	>	*
	Habitat	*	>>>	*
	Hydrology	*	>	*
	Sediment	*	>	*
By Intermittent flow	Biogeochemical	Desert	>>	Steppe
	Habitat	*	>>>	*
	Hydrology	*		NA
	Sediment	*		NA

Figures

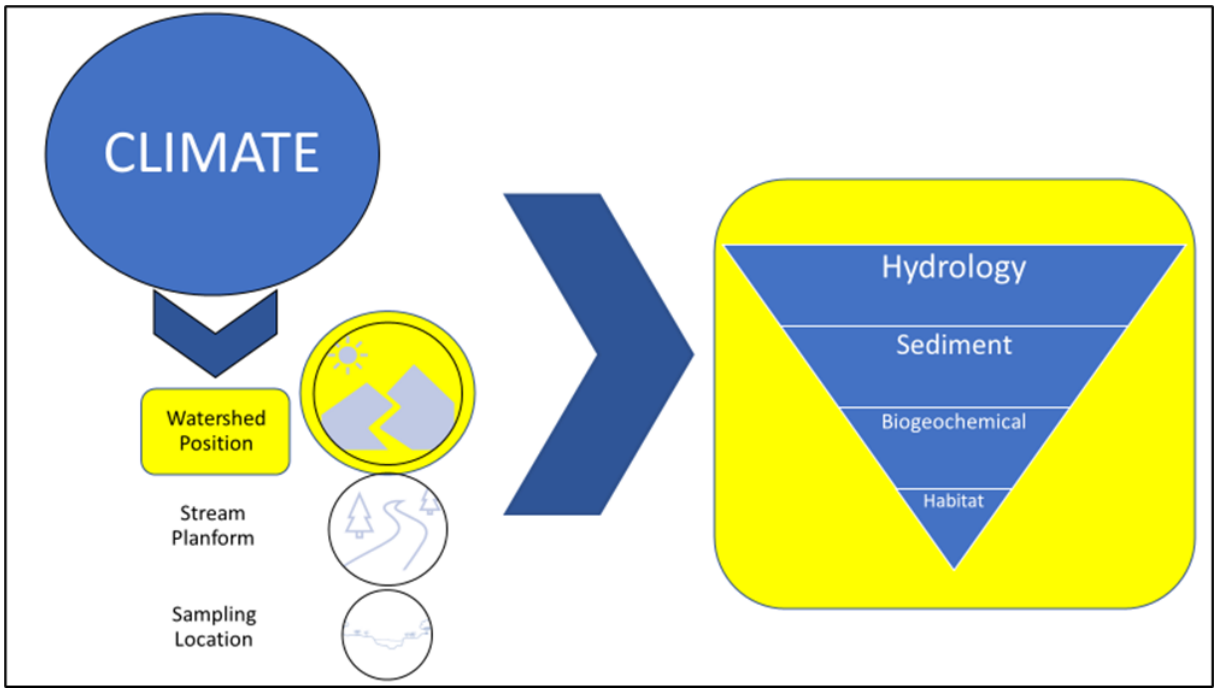


Figure 53. The conceptual relation of watershed position type (environmental parameter) to the hierarchy of broad stream function categories.

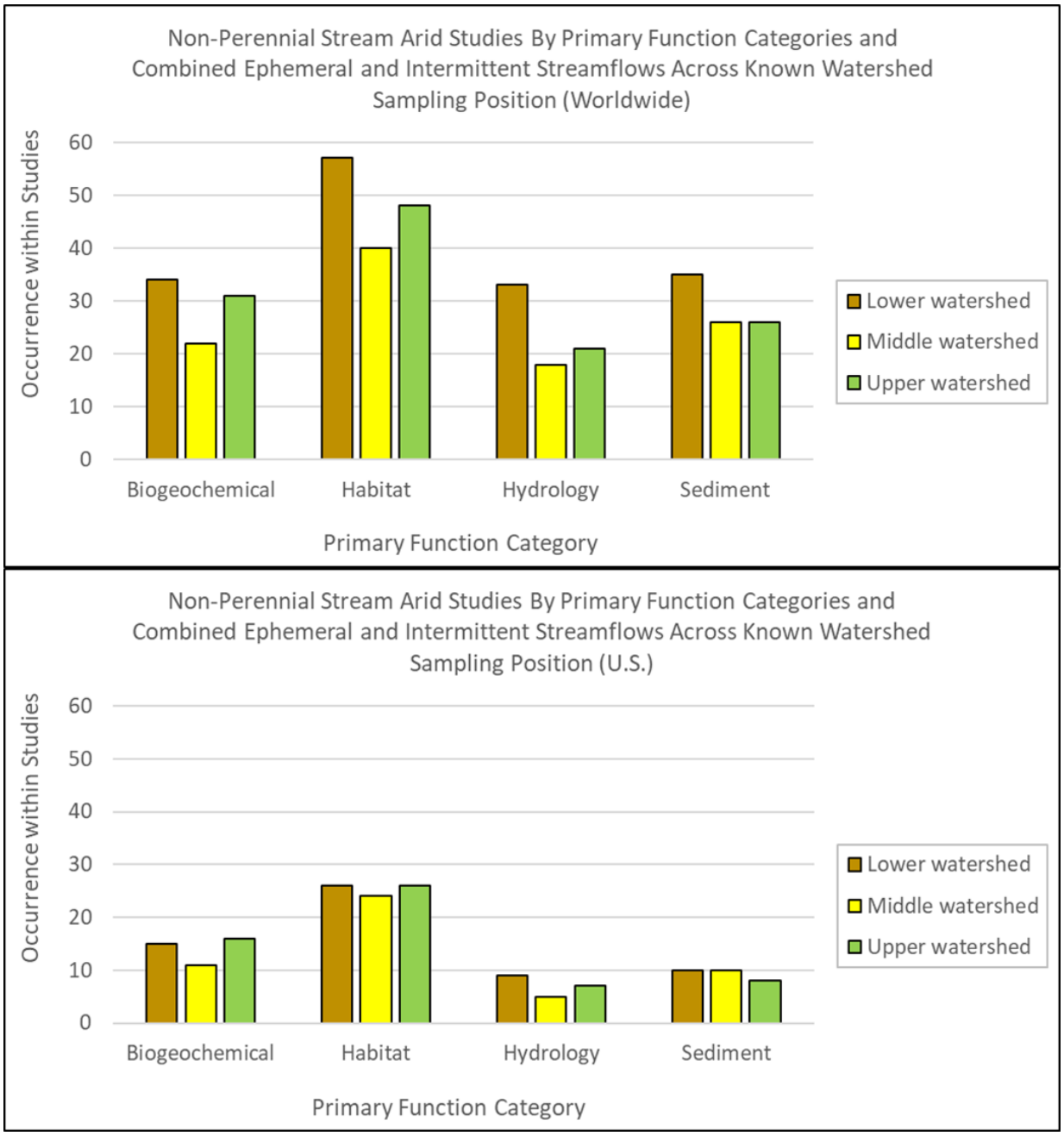


Figure 54. Sampling of primary broad function categories across known watershed positions and streamflow types, within global and U.S. arid non-perennial stream literature.

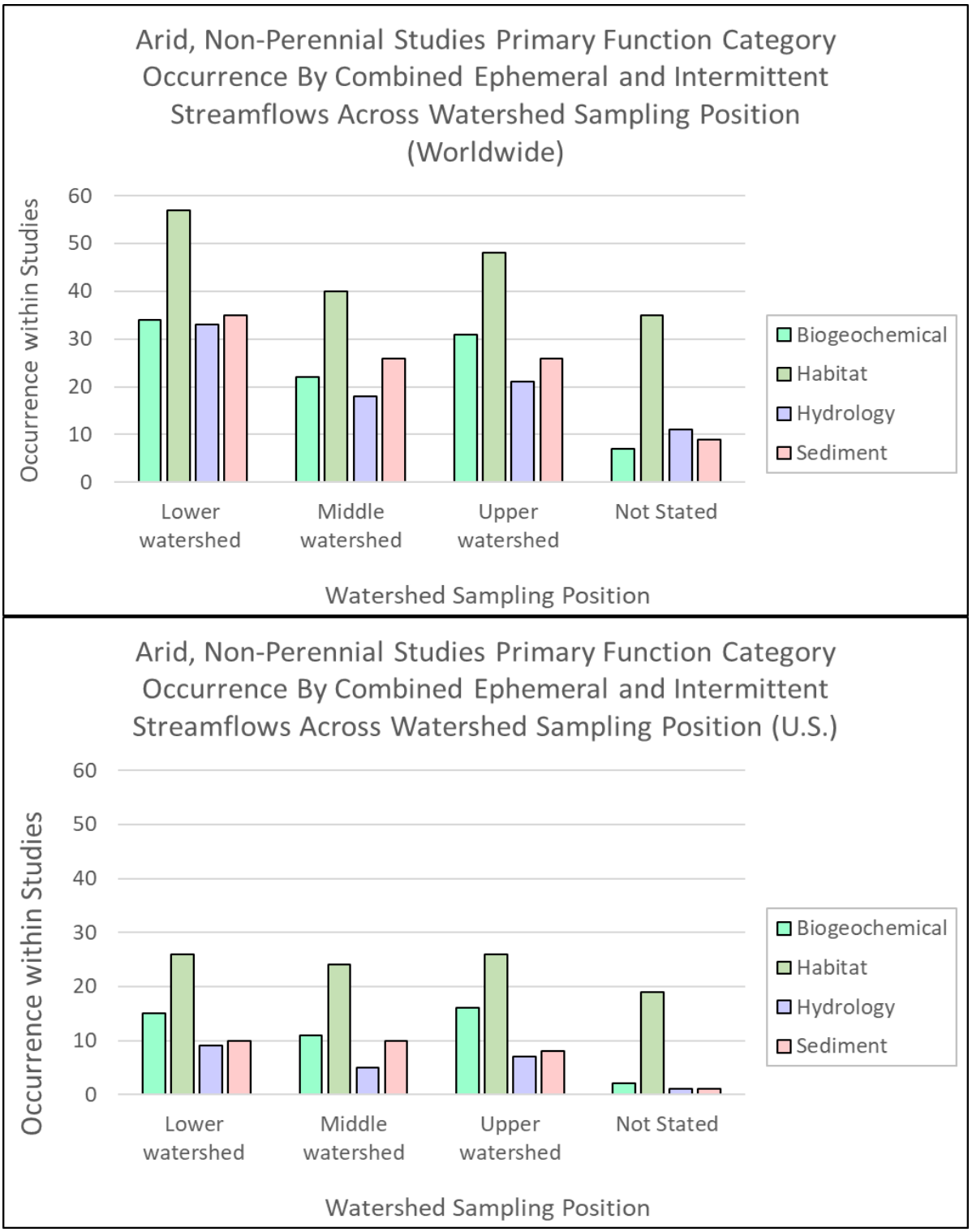


Figure 55. Sampling of known watershed positions across primary broad function categories and combined streamflow types, within global and U.S. arid non-perennial stream literature.

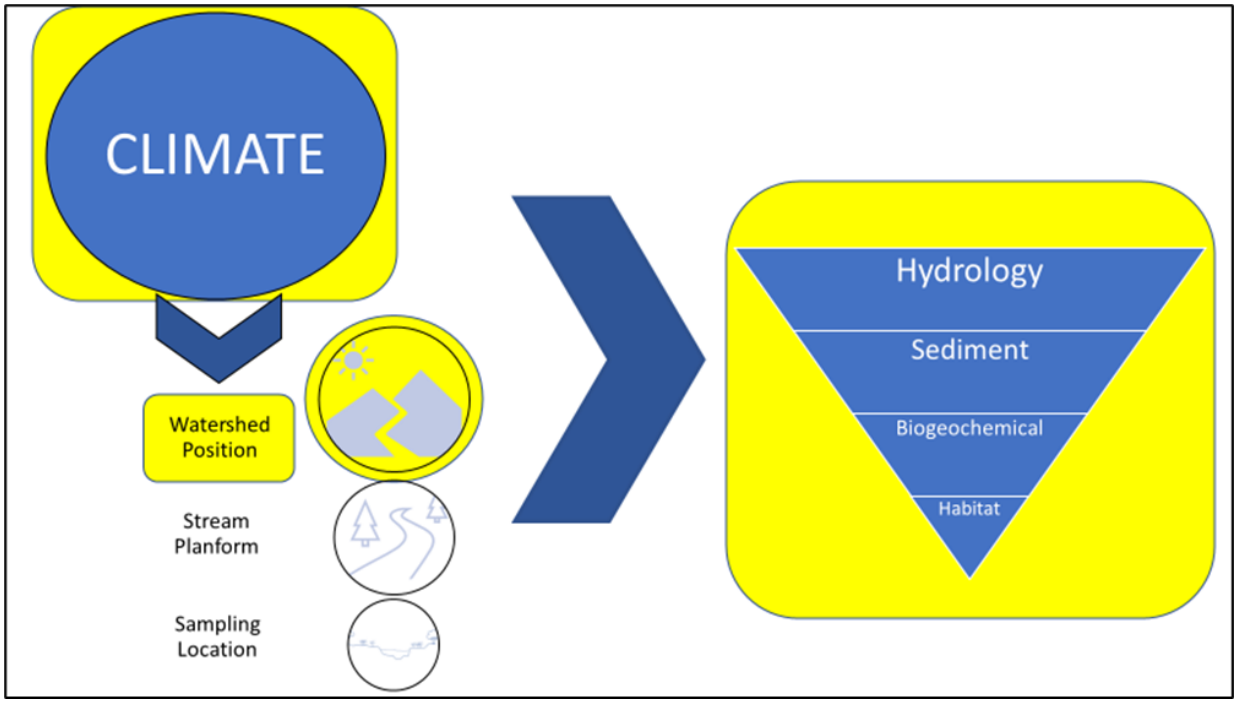


Figure 56. The conceptual relations of climate and watershed position type (environmental parameter) to the hierarchy of broad stream function categories.

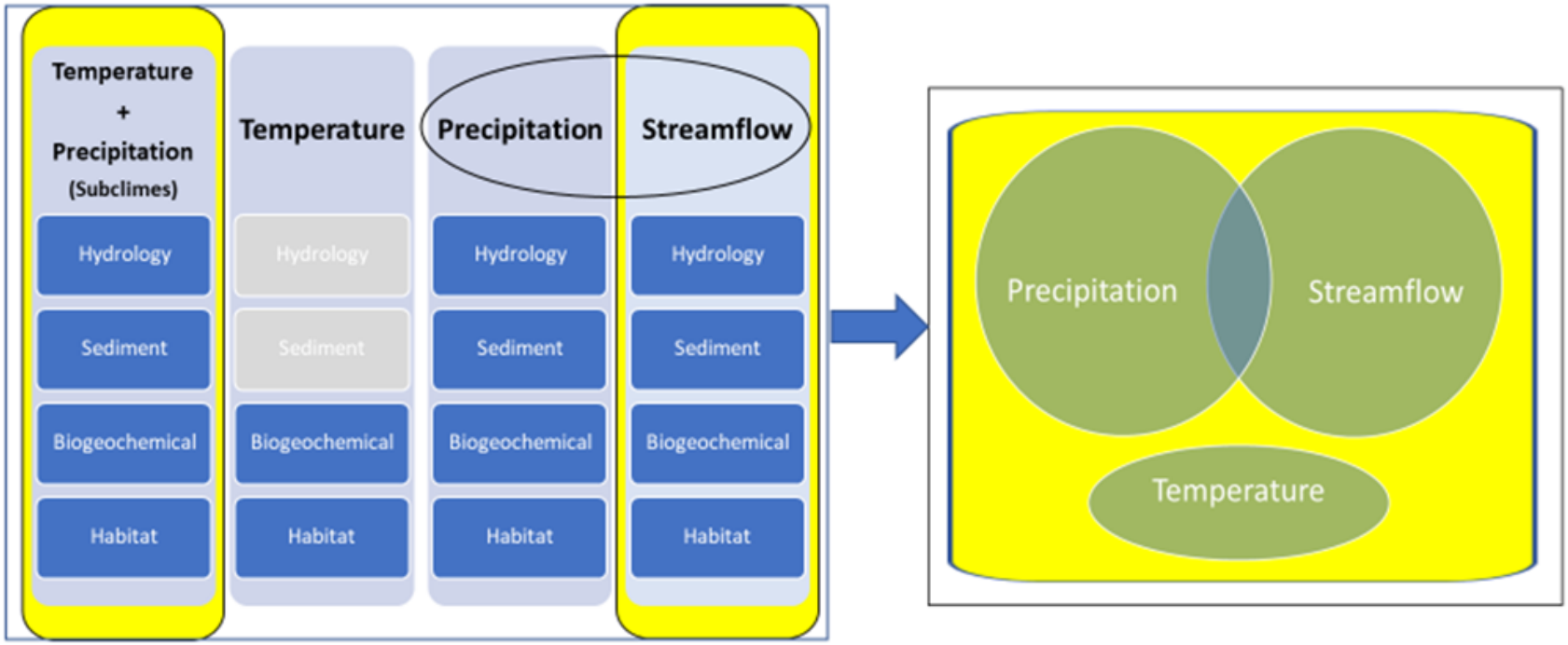


Figure 57. The conceptual relations and hierarchies of subclimes (combined temperature and precipitation types) and hydrology (inherent precipitation and streamflow types) factors and their influence on broad stream function categories.

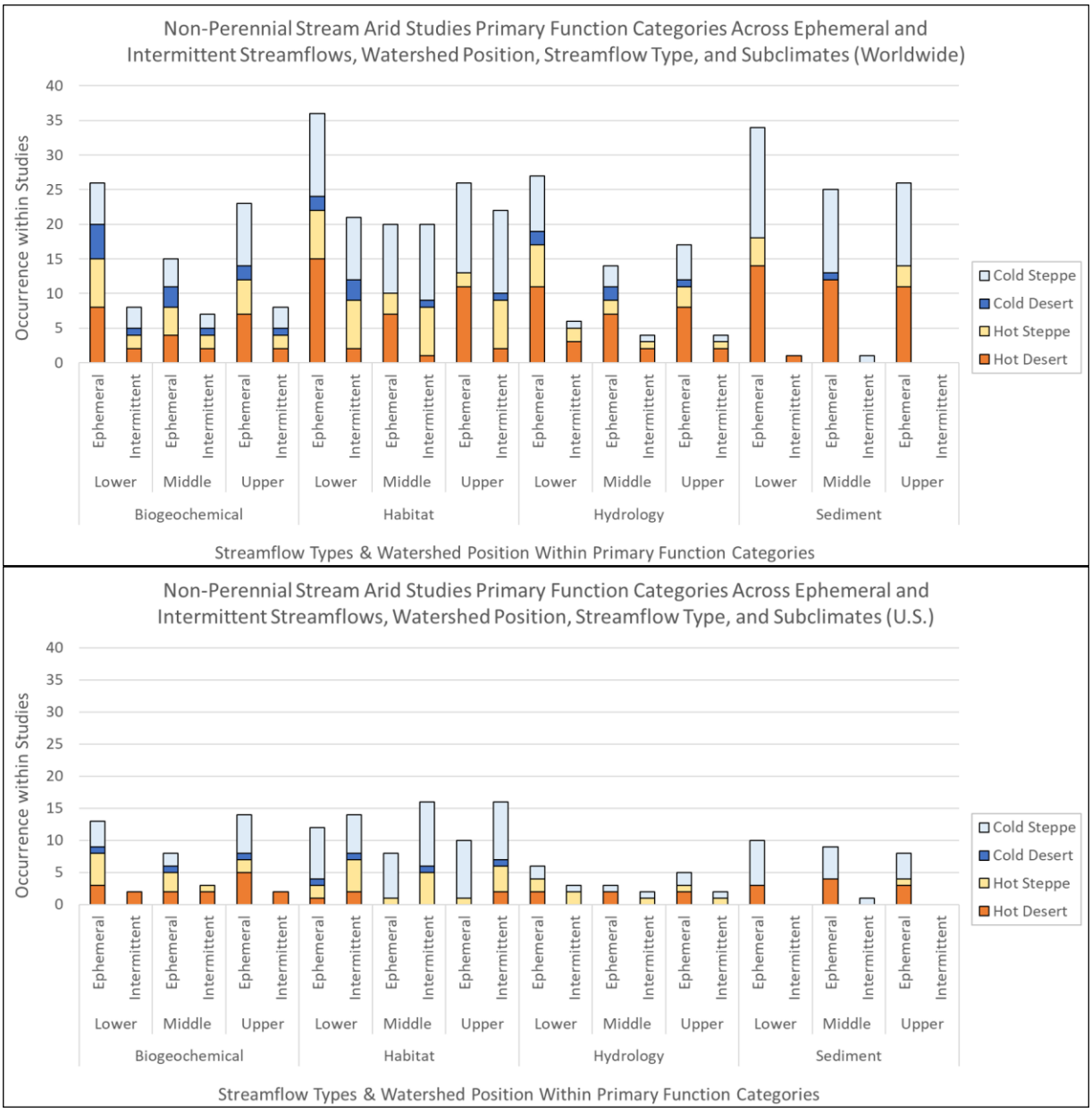


Figure 58. Sampling of primary broad function categories across known watershed positions and subclimes by known streamflow types, within global and U.S. arid non-perennial stream literature.

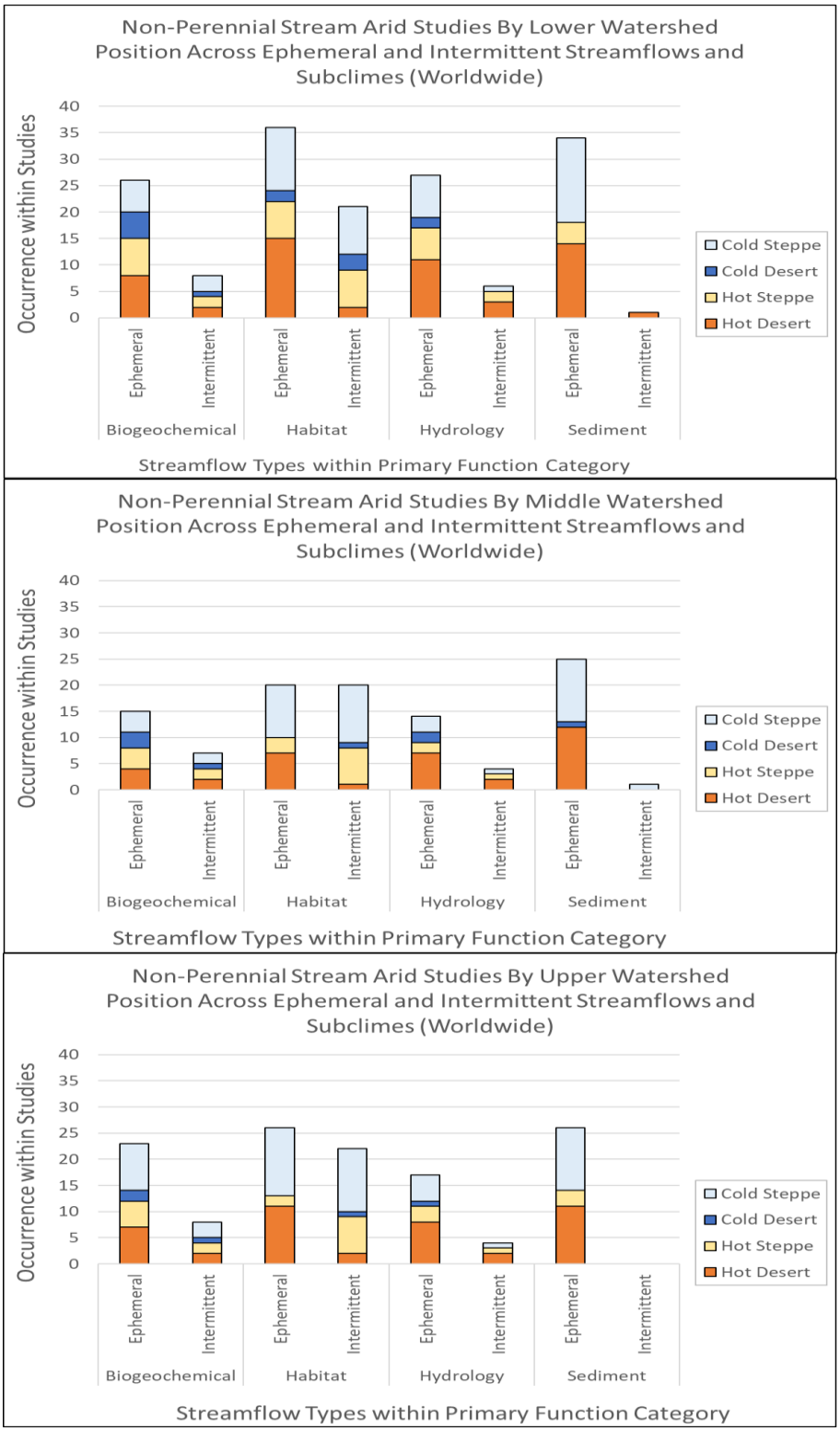


Figure 59. Sampling of each watershed position type across primary broad function categories and subclimes, by ephemeral and intermittent streamflow, within global arid non-perennial stream literature.

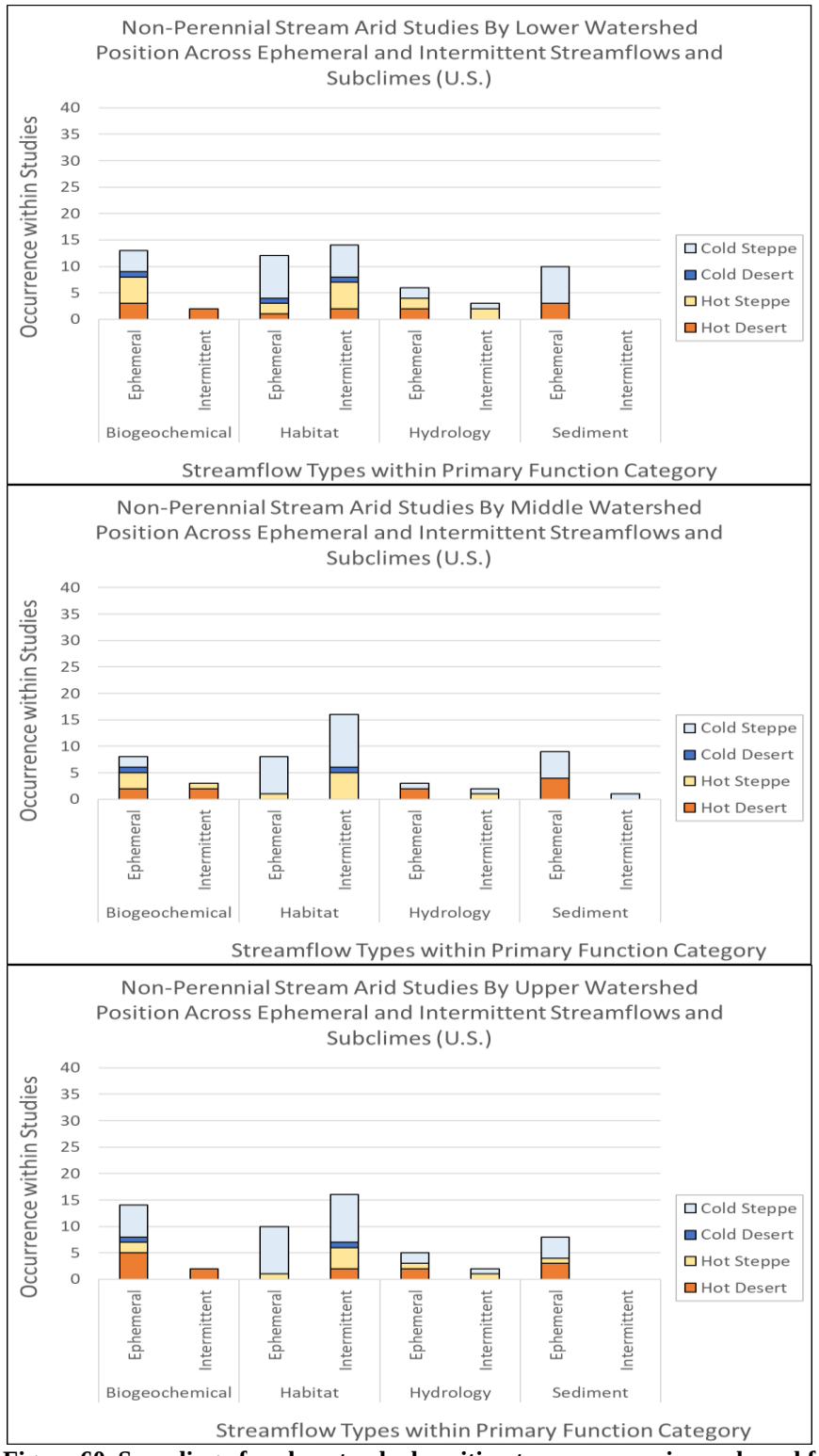


Figure 60. Sampling of each watershed position type across primary broad function categories and subclimes, by ephemeral and intermittent streamflow, within U.S. arid non-perennial stream literature.

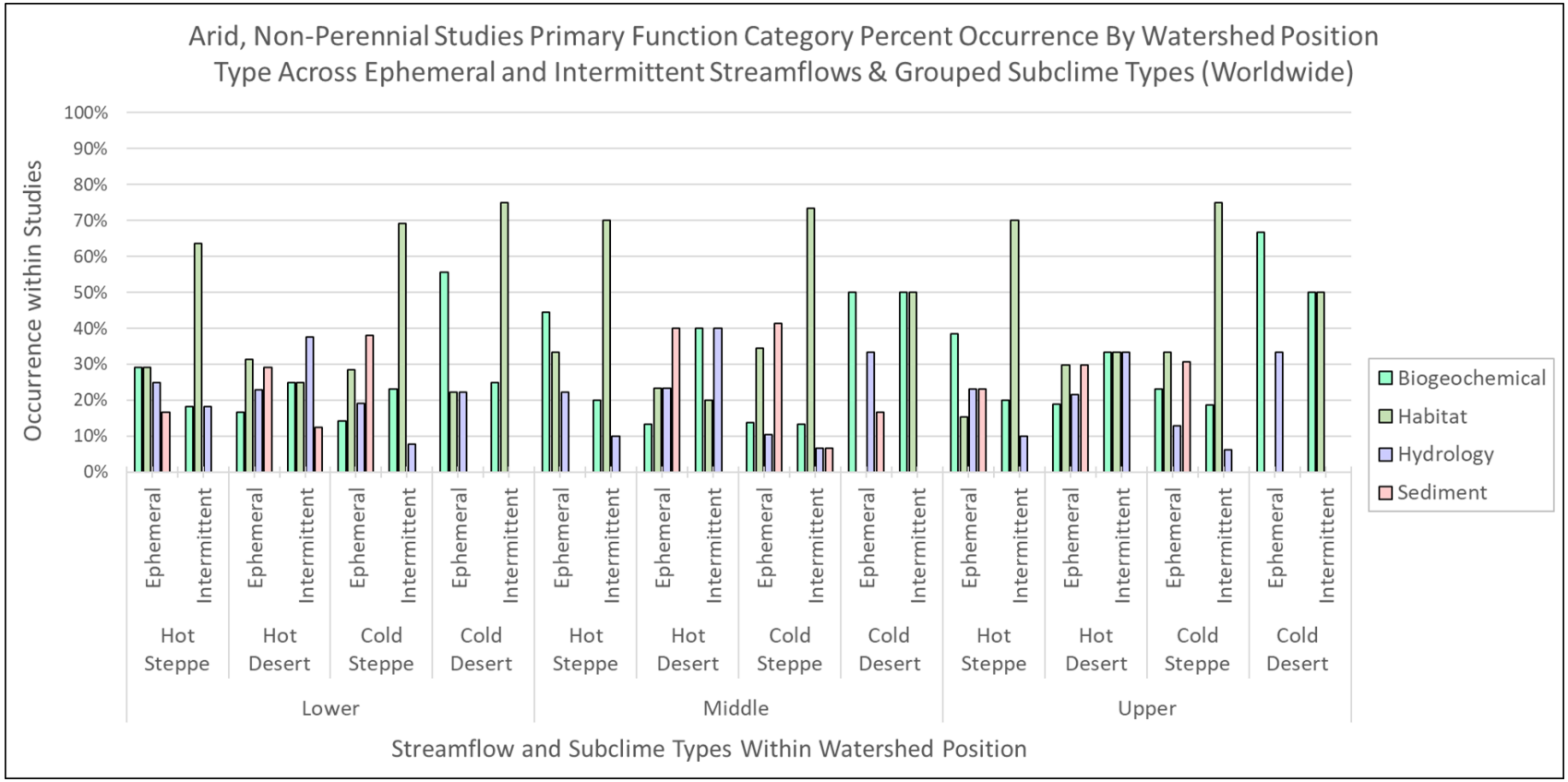


Figure 61. Sampling of watershed position types across primary broad function categories, by subclimes and known streamflow types, within global arid non-perennial stream literature.

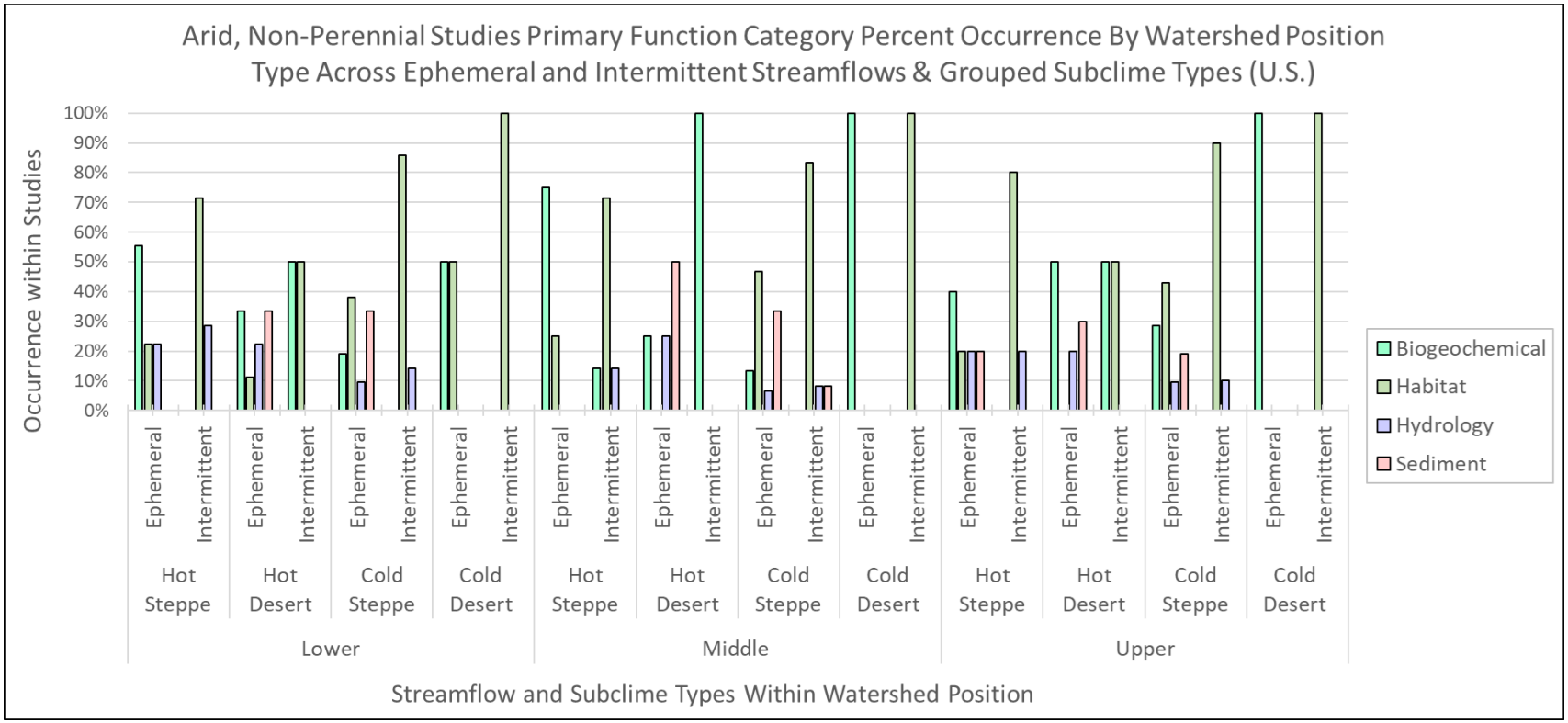


Figure 62. Sampling of watershed position types across primary broad function categories, by subclimes and known streamflow types, within U.S. arid non-perennial stream literature.



Figure 63. Sampling of each known watershed position type across primary broad function categories and subclimes by known streamflow types, within global arid non-perennial stream literature.



Figure 64. Sampling of each known watershed position type across primary broad function categories and subclimes by known streamflow types, within U.S. arid non-perennial stream literature.

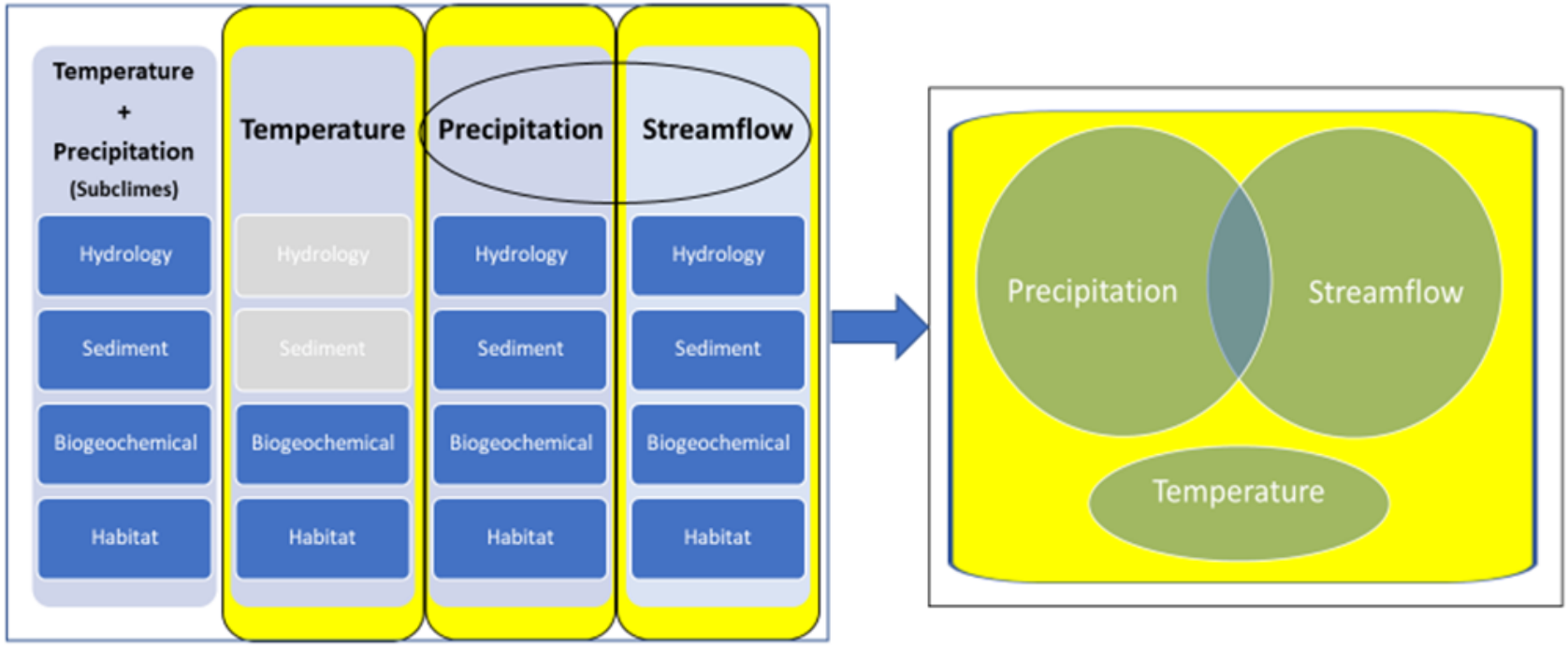


Figure 65. The conceptual relations and hierarchies of subclime components (temperature and precipitation types) and hydrology (inherent precipitation and streamflow types) factors and their influence on broad stream function categories.

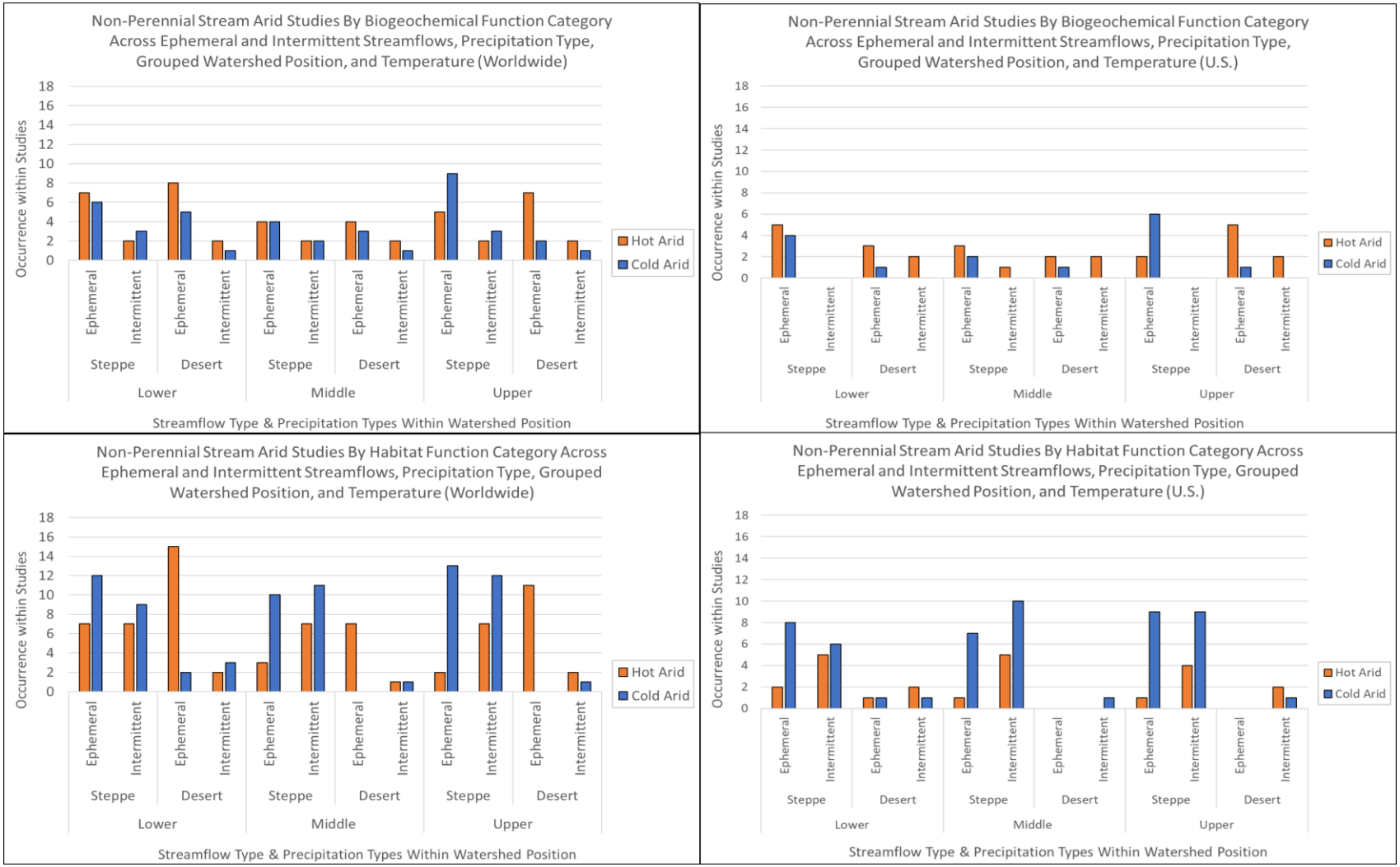


Figure 66. Sampling of Biogeochemical and Habitat primary function categories across known watershed position types and temperatures, by precipitation and known streamflow types, within global and U.S. arid non-perennial stream literature.

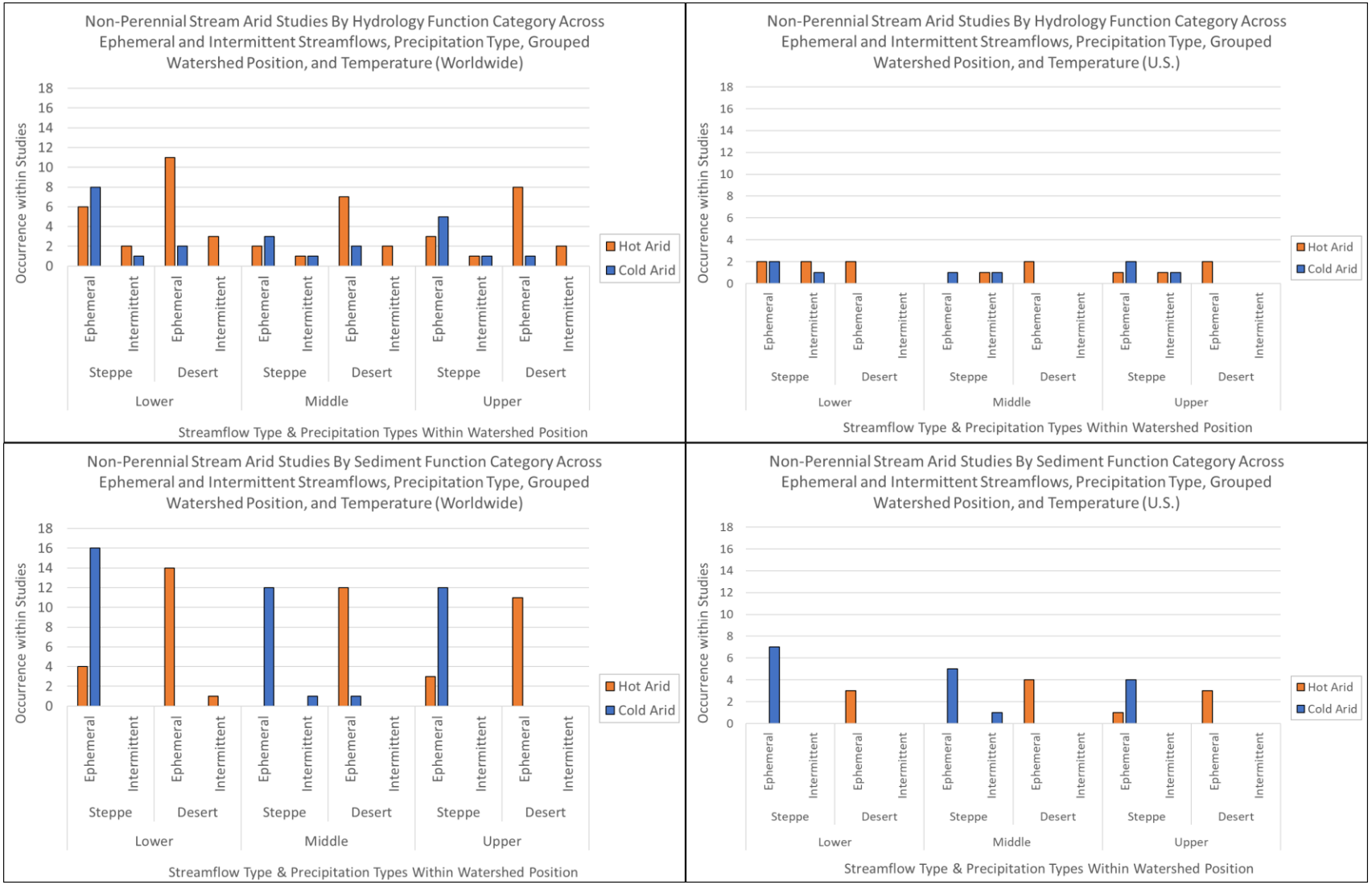


Figure 67. Sampling of Hydrology and Sediment primary function categories across known watershed position types and temperatures, by precipitation and known streamflow types, within global and U.S. arid non-perennial stream literature.

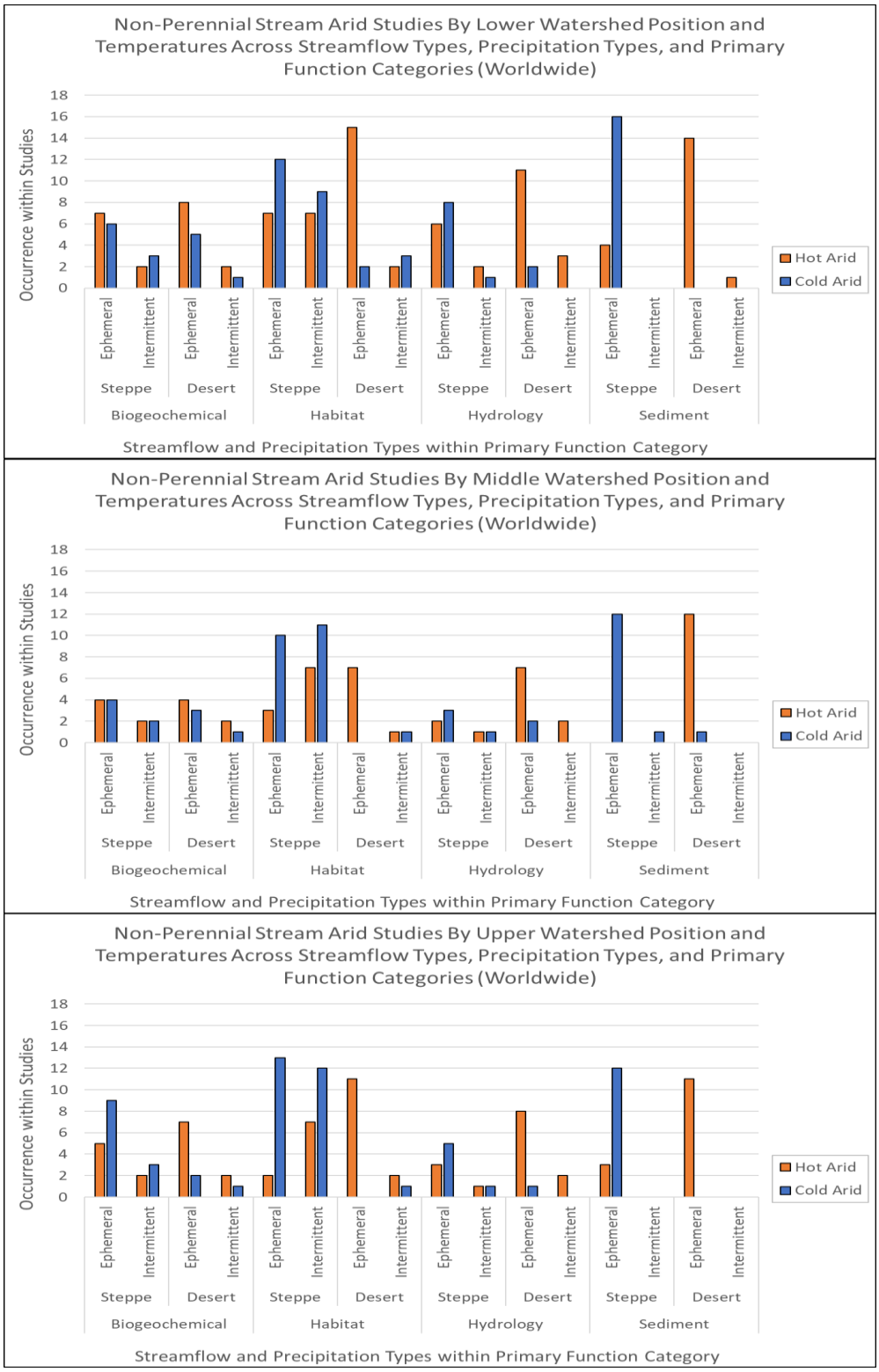


Figure 68. Sampling of each watershed position type across primary broad function categories and temperatures, by precipitation and known streamflow types, within global arid non-perennial stream literature.

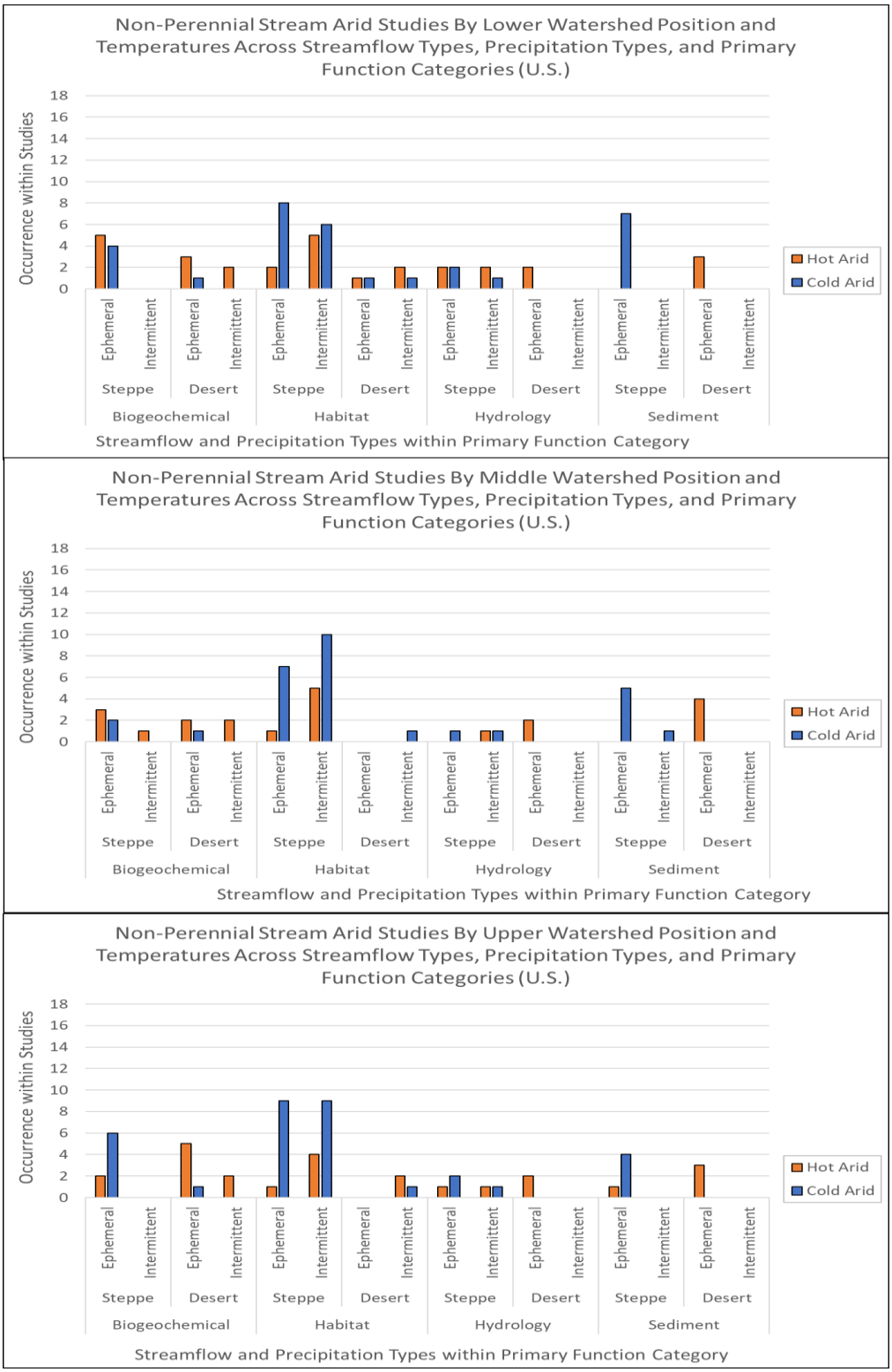


Figure 69. Sampling of each watershed position type across primary broad function categories and temperatures, by precipitation and known streamflow types, within U.S. arid non-perennial stream literature.

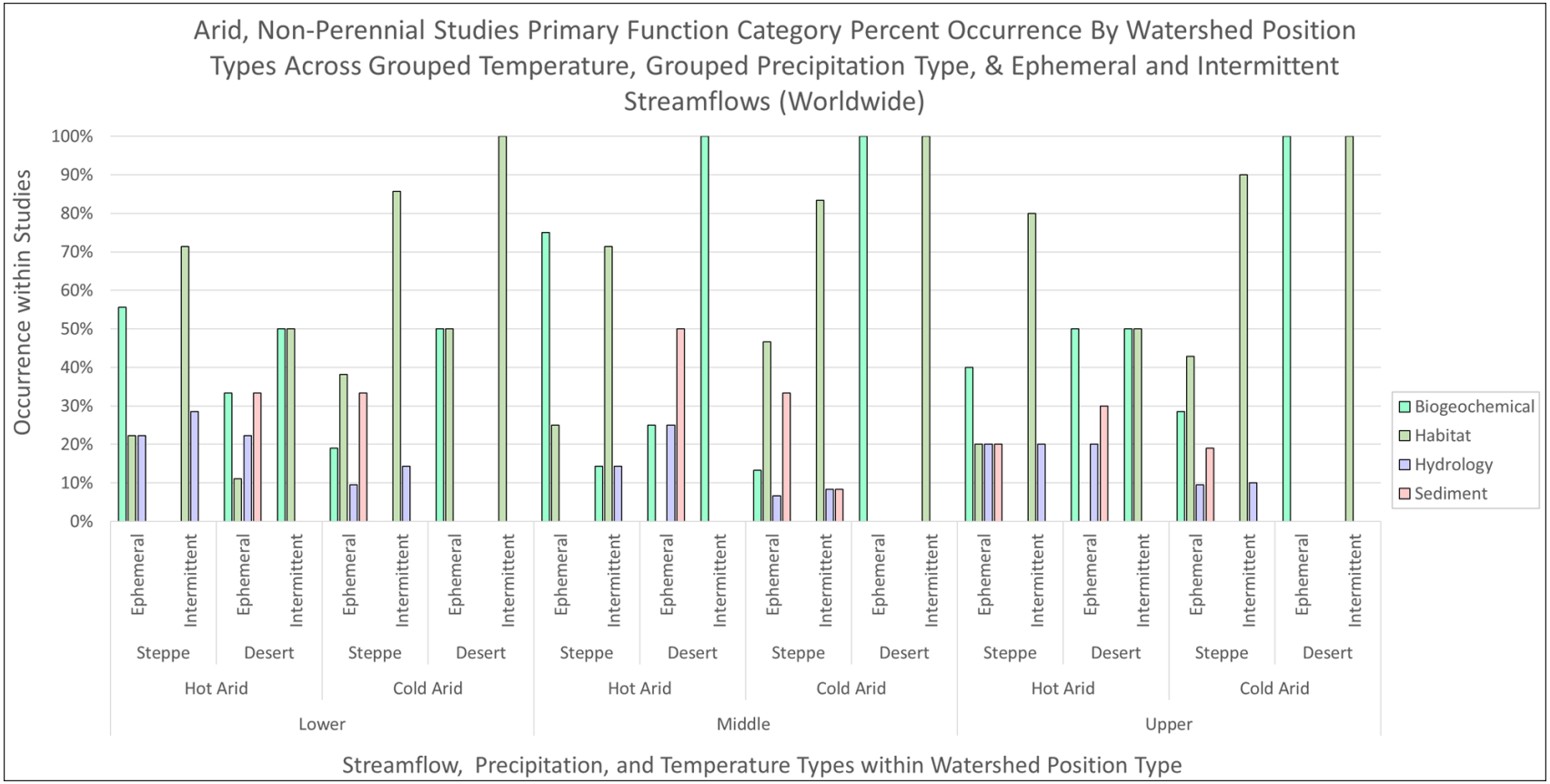


Figure 70. Sampling of watershed position types across primary broad function categories and temperatures, by precipitation and known streamflow types, within global arid non-perennial stream literature.

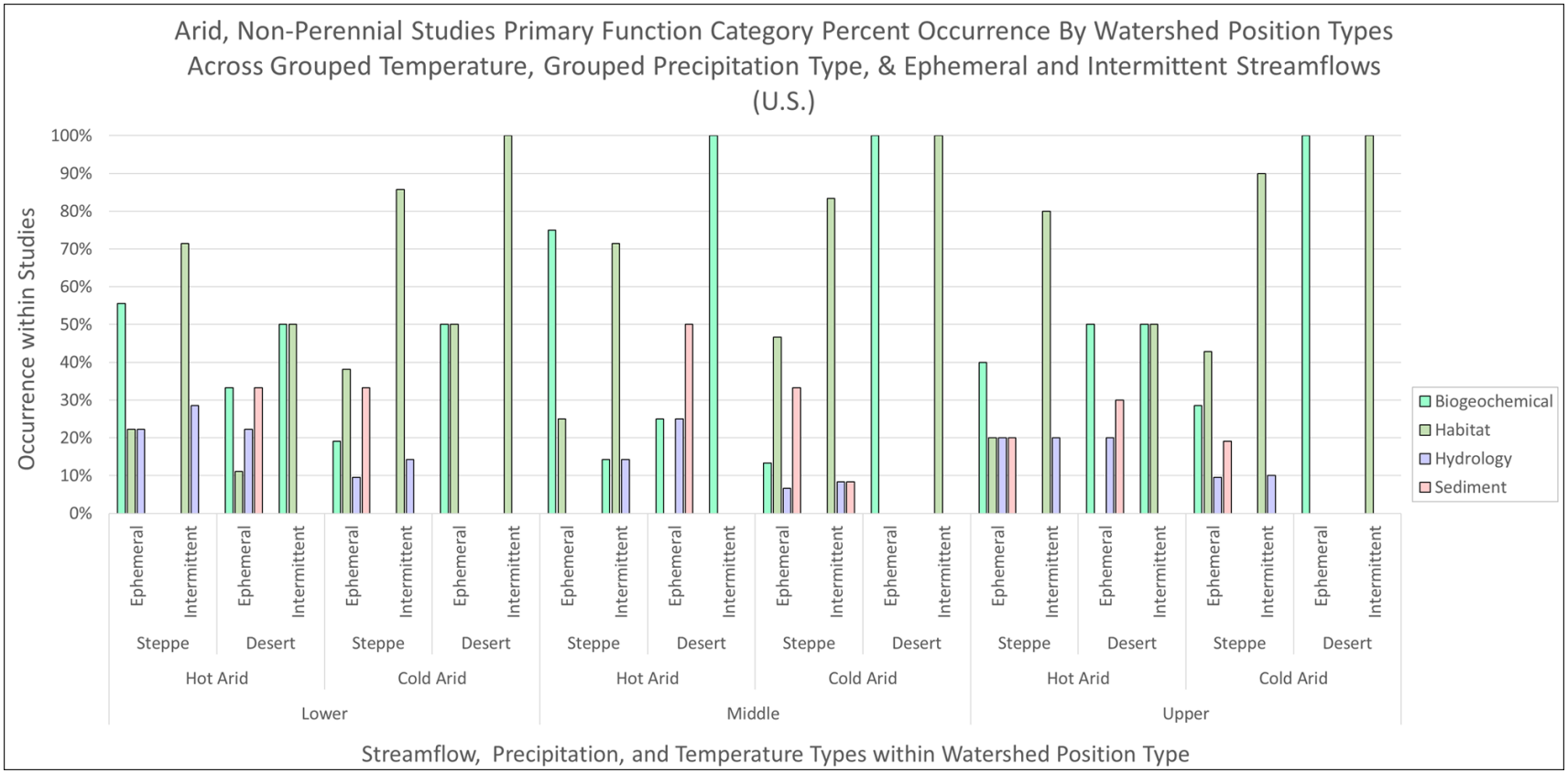


Figure 71. Sampling of watershed position types across primary broad function categories and temperatures, by precipitation and known streamflow types, within U.S. arid non-perennial stream literature.

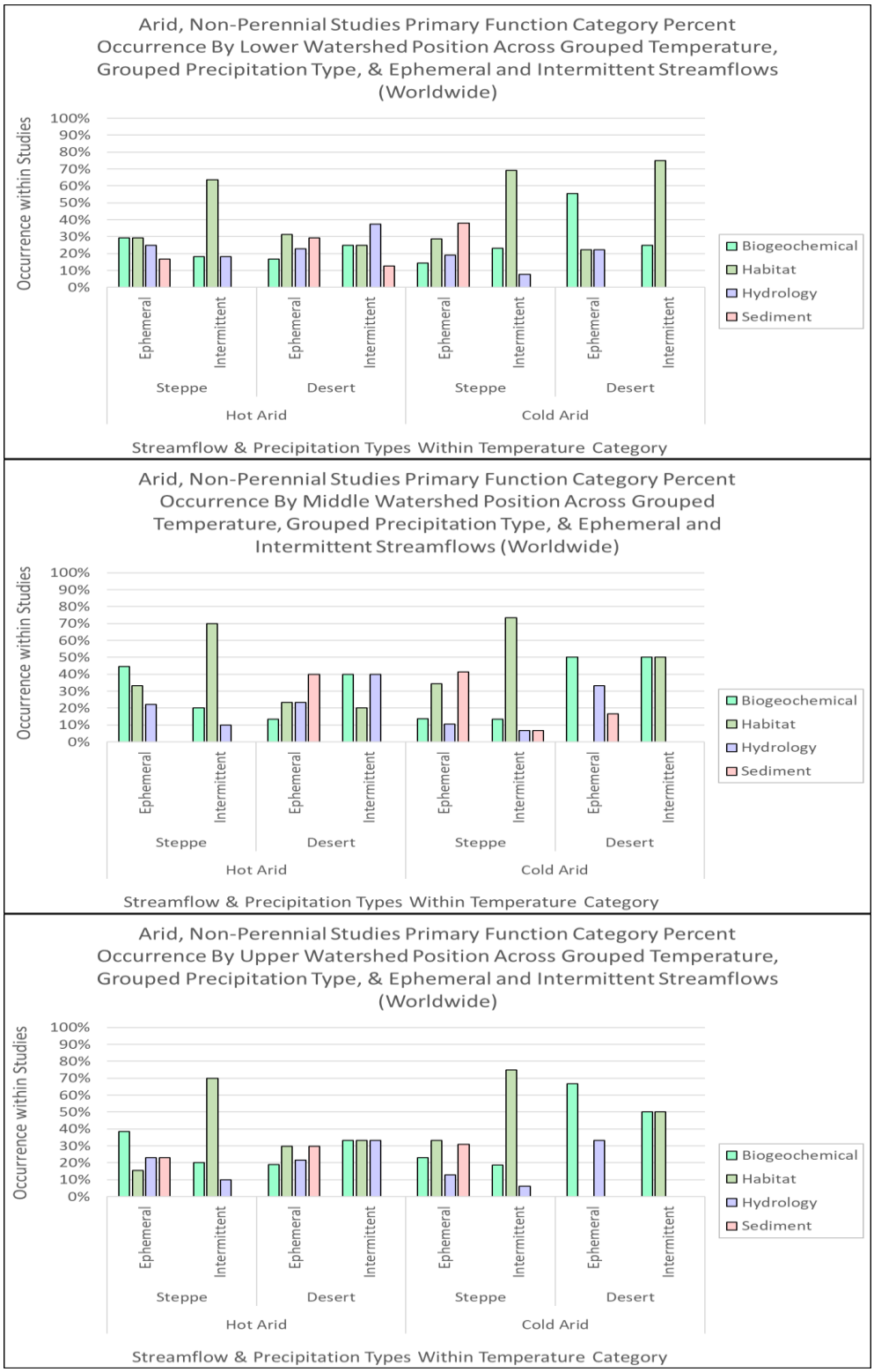


Figure 72. Sampling of each watershed position type across primary broad function categories by temperatures, and by precipitation and known streamflow types, within global arid non-perennial stream literature.



Figure 73. Sampling of each watershed position type across primary broad function categories by temperatures, and by precipitation and known streamflow types, within U.S. arid non-perennial stream literature.

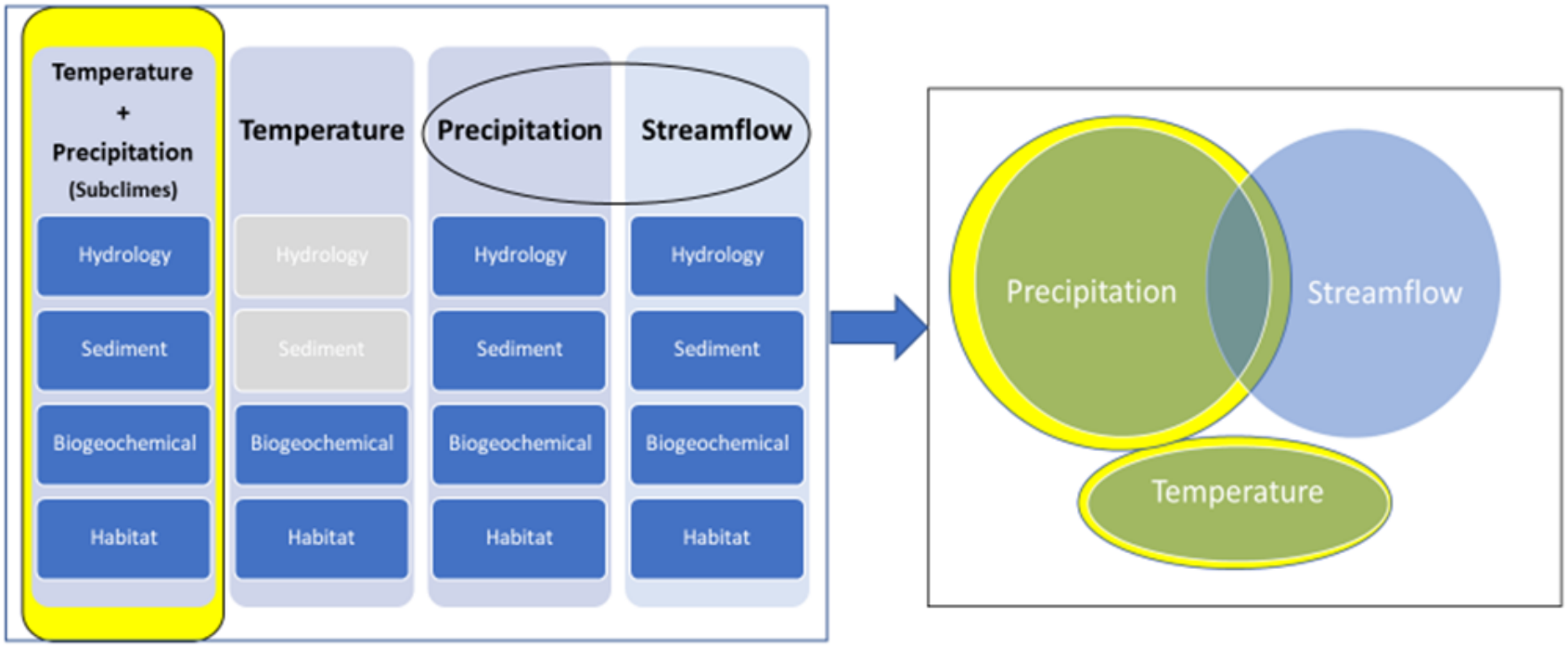


Figure 74. The conceptual relations and hierarchies of subclime (combined temperature and precipitation types) factors and an inherent hydrology component (precipitation types) factor and their influence on broad stream function categories.

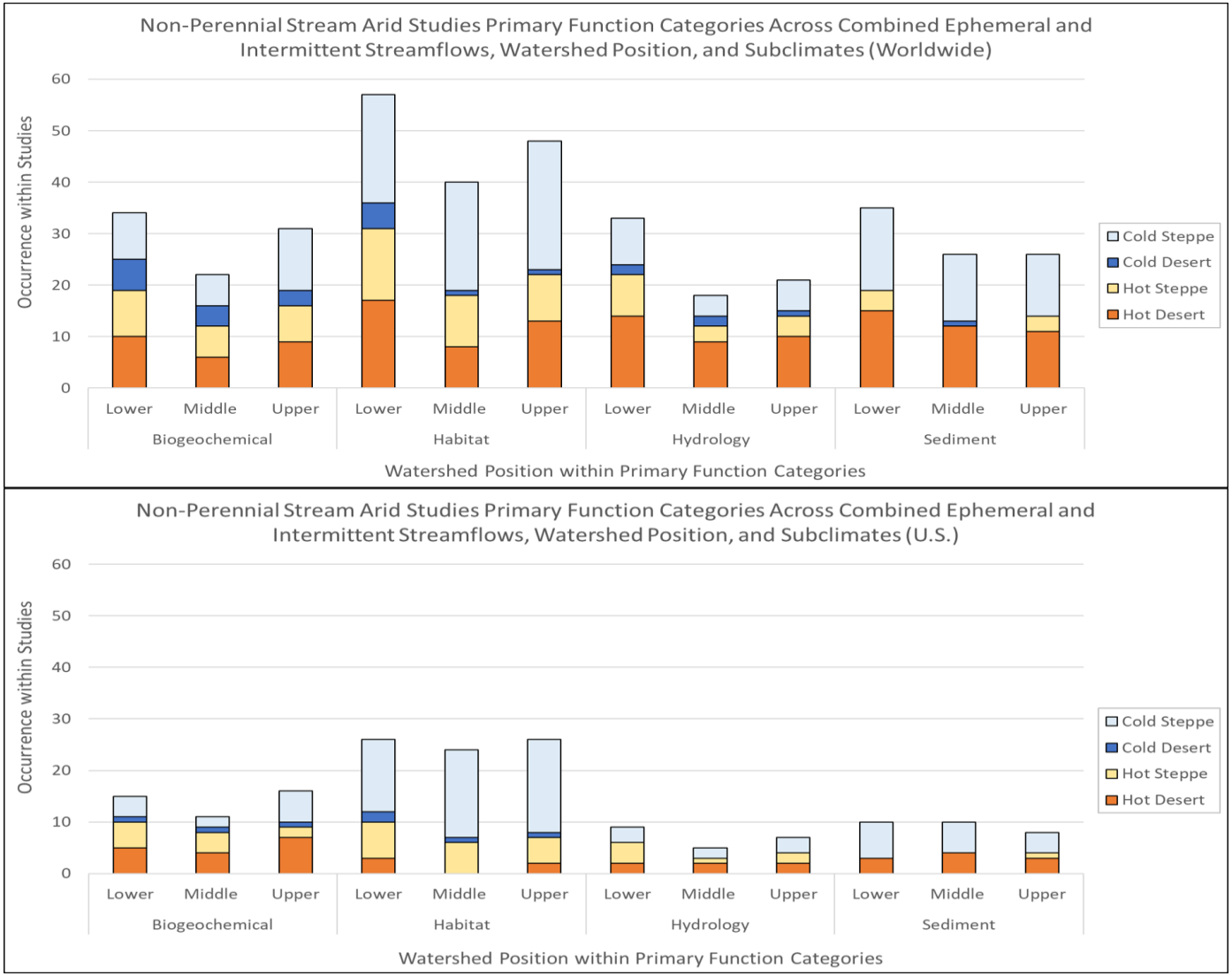


Figure 75. Sampling of primary broad function categories across subclimes and known watershed positions, within global and U.S. arid non-perennial stream literature.

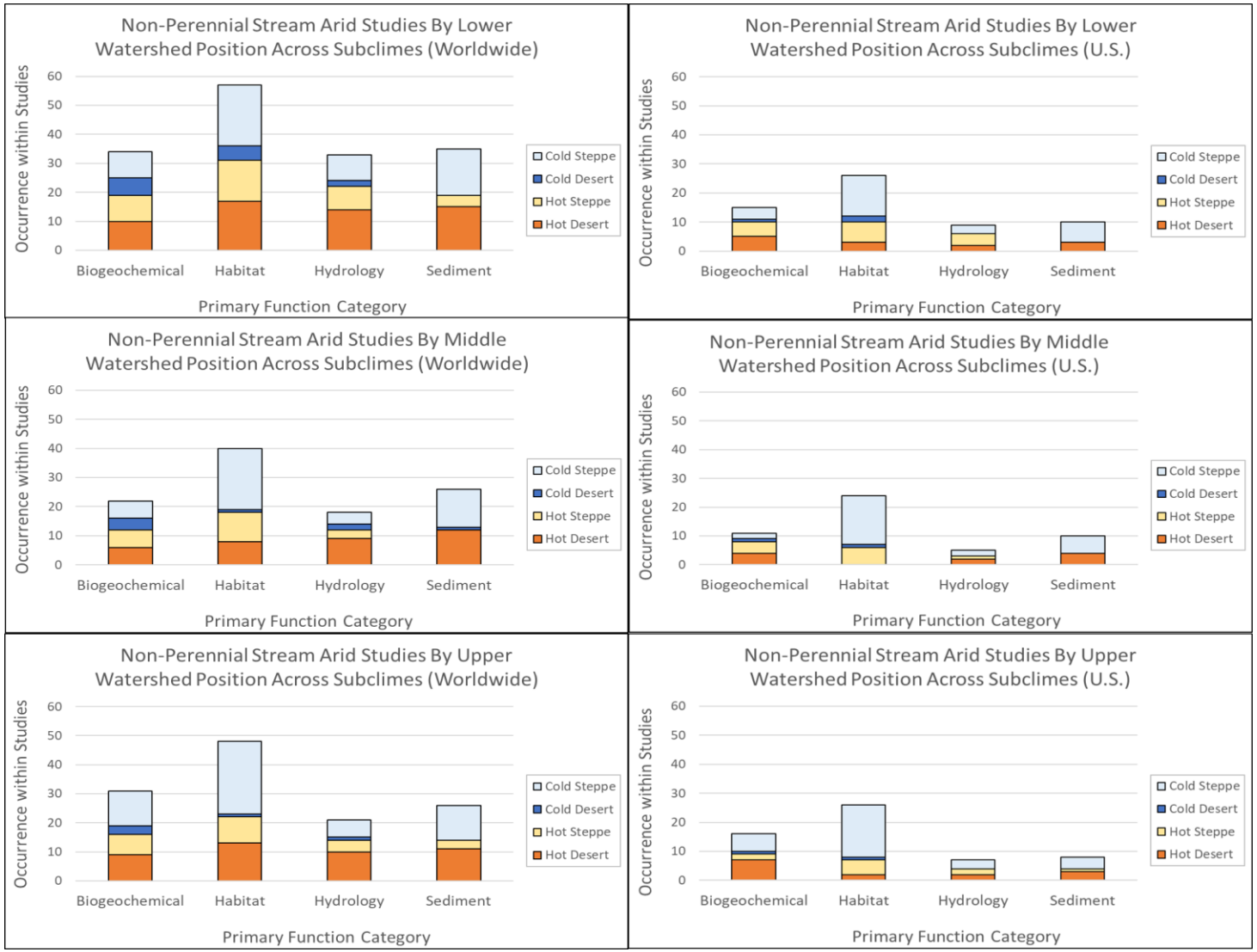


Figure 76. Sampling of each watershed position type across primary broad function categories and subclimes, within global and U.S. arid non-perennial stream literature.



Figure 77. Sampling of watershed position types across primary broad function categories by subclimes, within global and U.S. arid non-perennial stream literature.



Figure 78. Sampling of each watershed position type across primary broad function categories by subclimes, within global arid non-perennial stream literature.

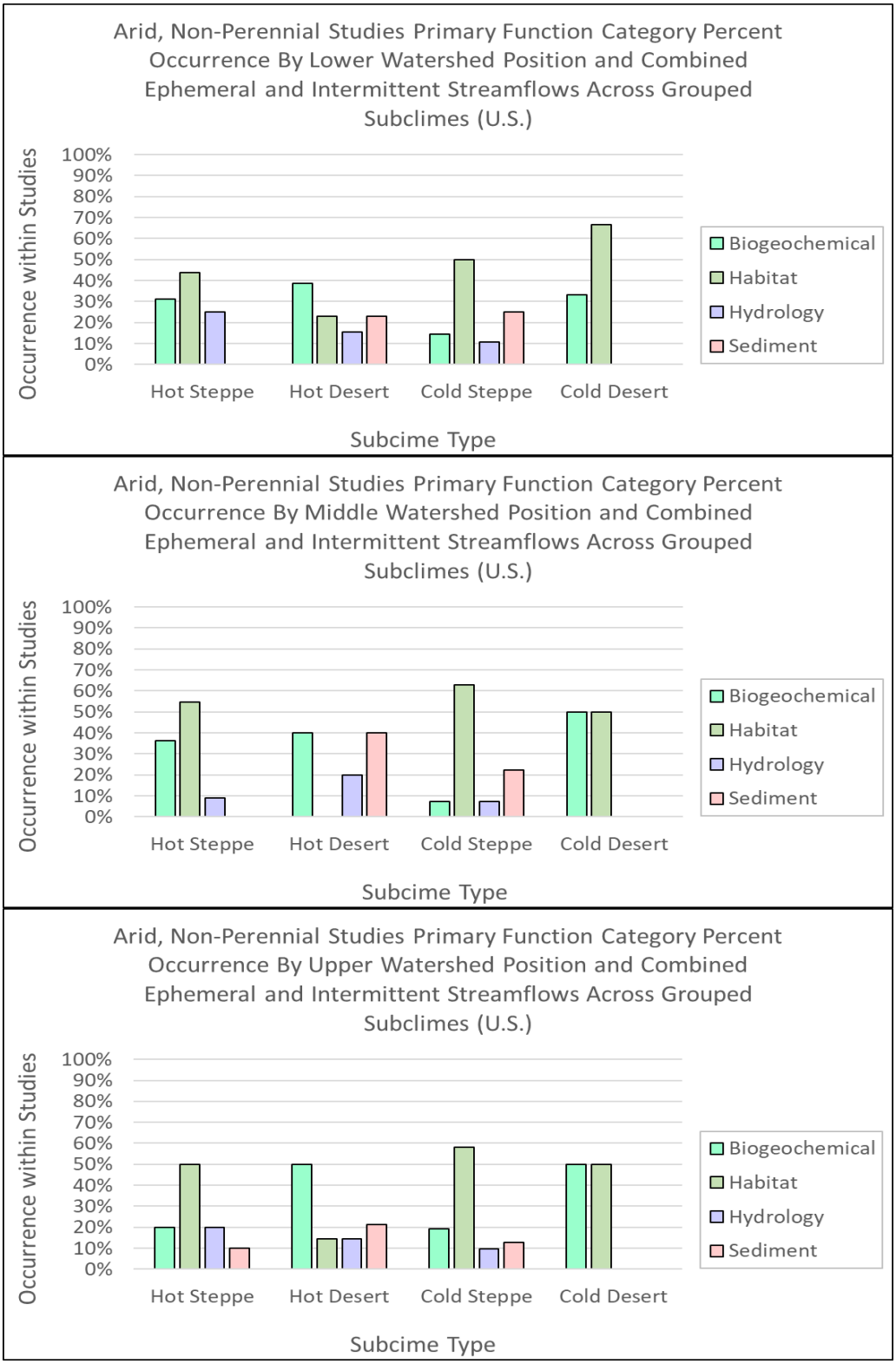


Figure 79. Sampling of each watershed position type across primary broad function categories by subclimes, within U.S. arid non-perennial stream literature.

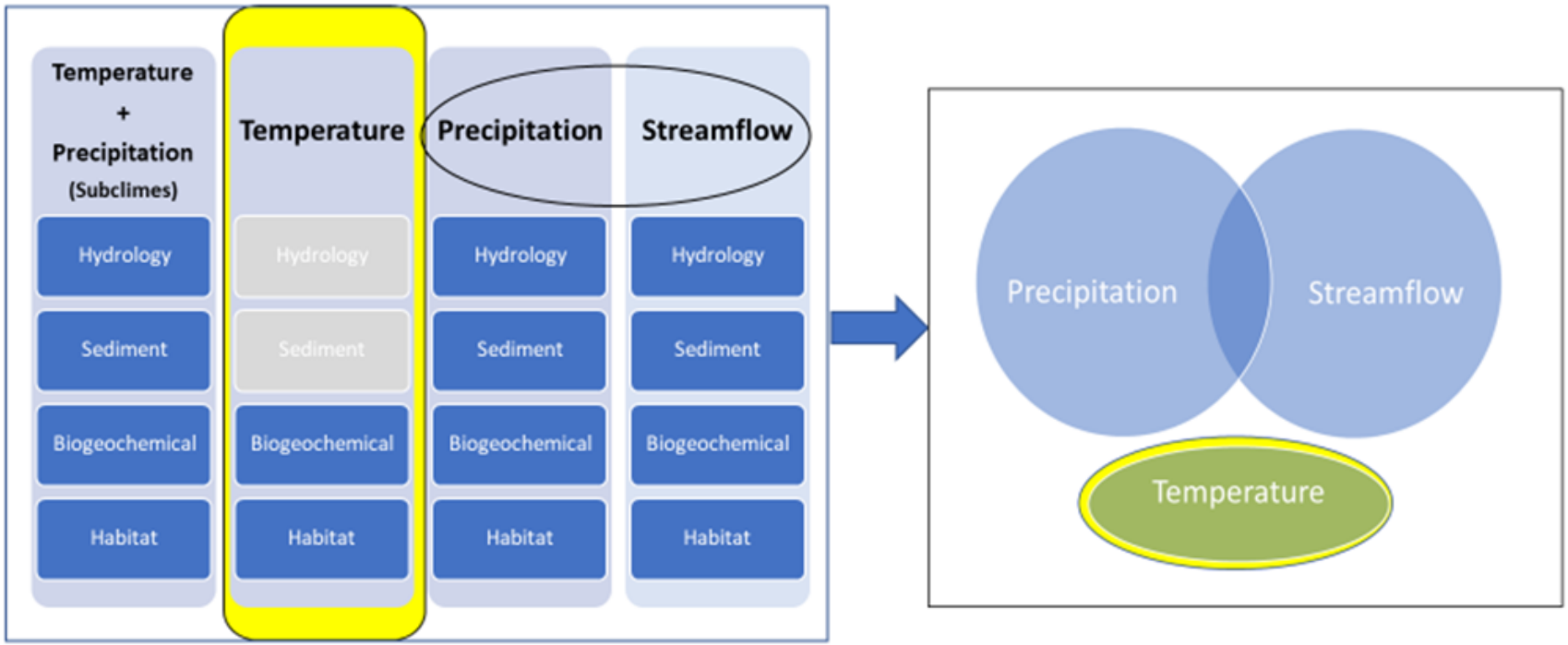


Figure 80. The conceptual relations and hierarchies of a subclime component (temperature) factor and its influence on broad stream function categories.

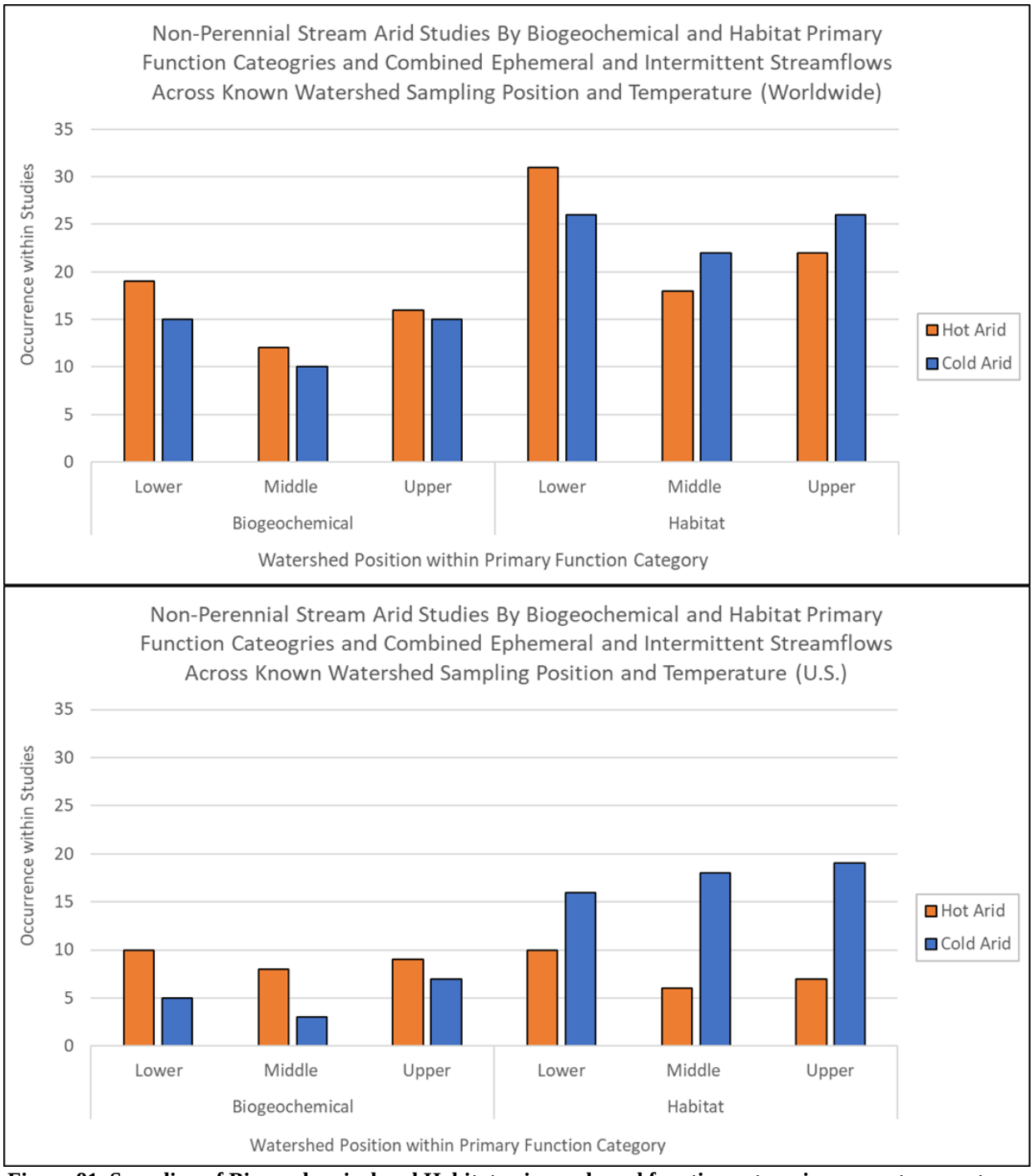


Figure 81. Sampling of Biogeochemical and Habitat primary broad function categories across temperatures by known watershed positions, within global and U.S. arid non-perennial stream literature.

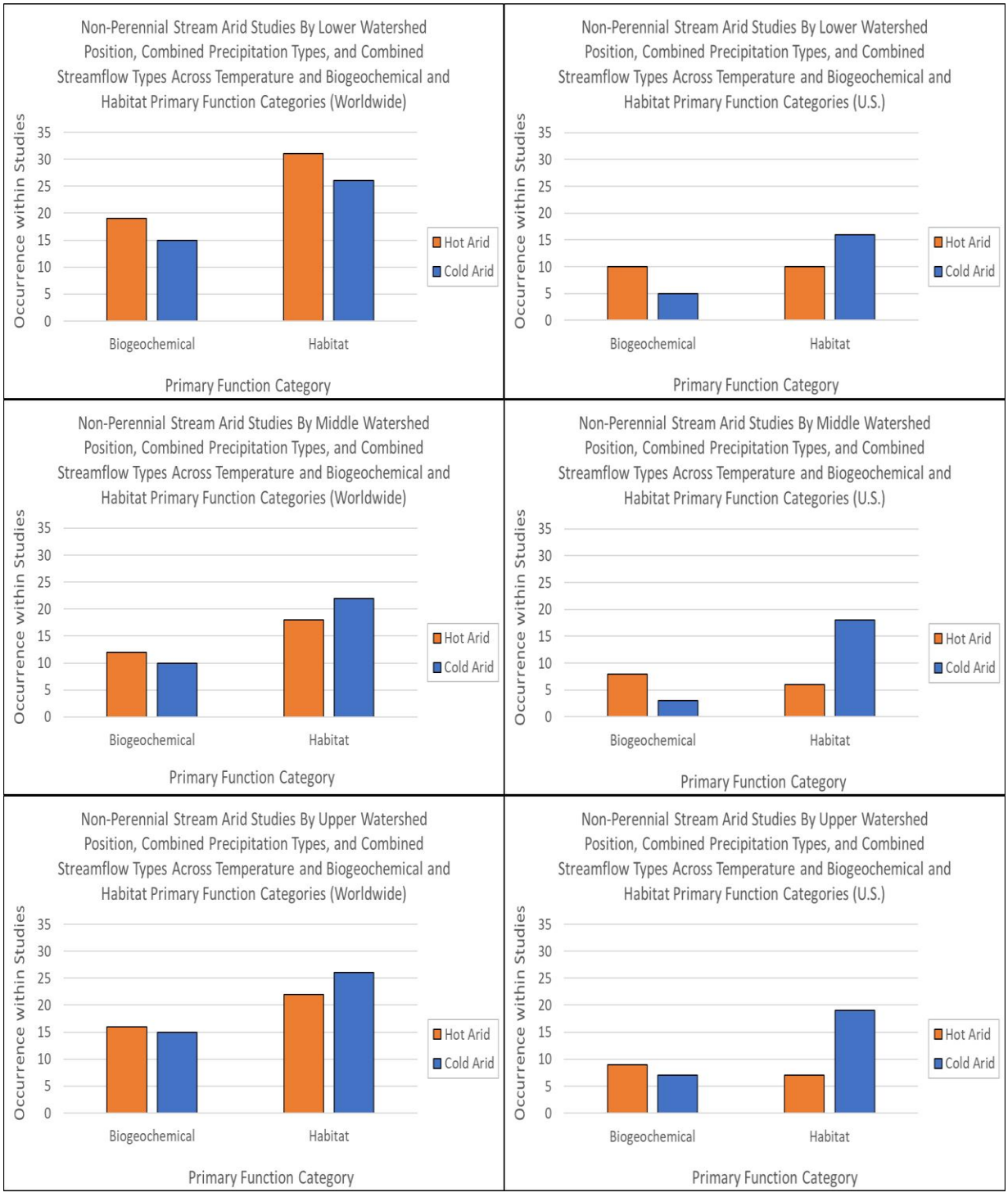


Figure 82. Sampling of each watershed position type across Biogeochemical and Habitat primary broad function categories and temperatures, within global and U.S. arid non-perennial stream literature.

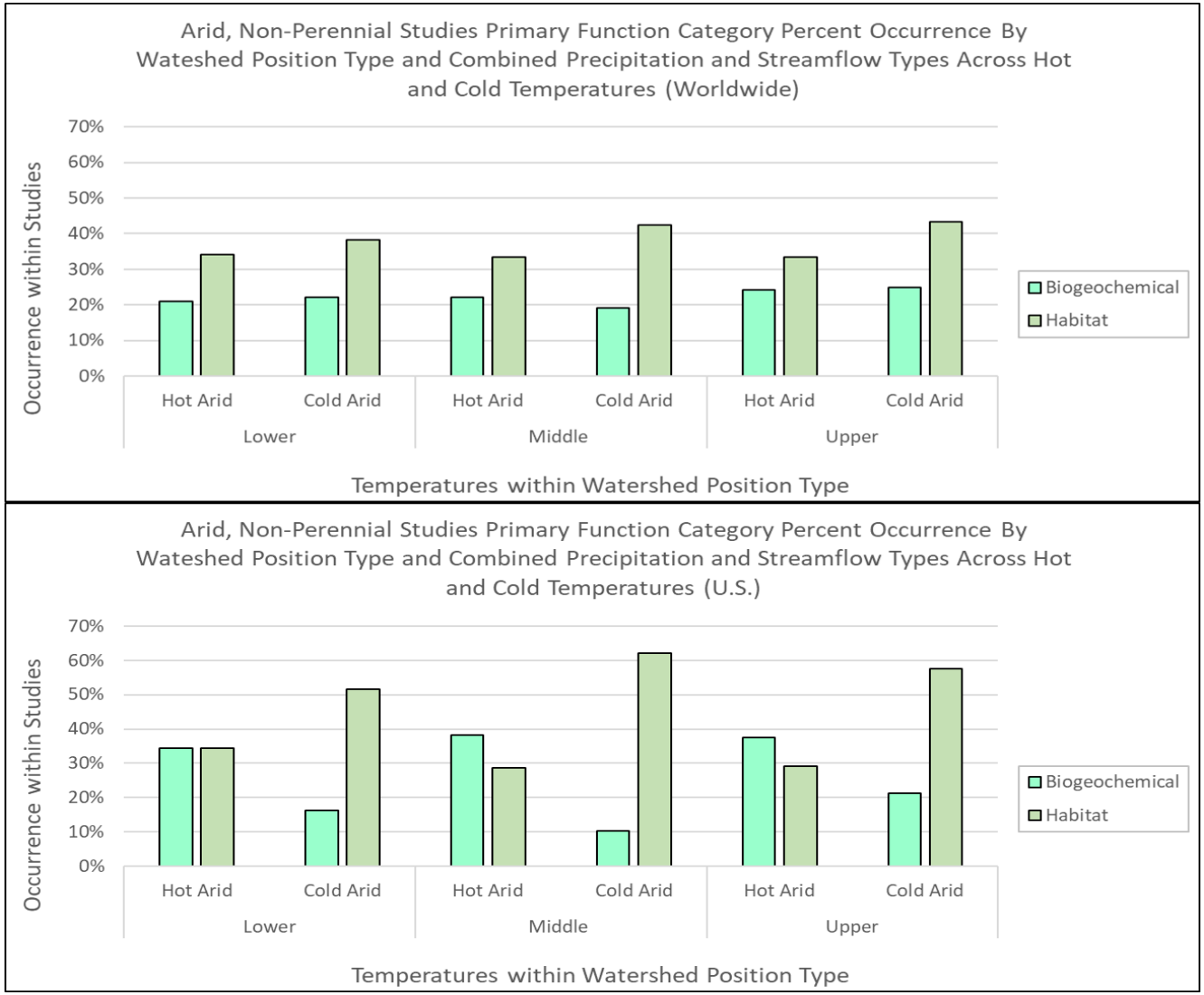


Figure 83. Sampling of watershed position types across Biogeochemical and Habitat primary broad function categories by temperatures, within global and U.S. arid non-perennial stream literature.

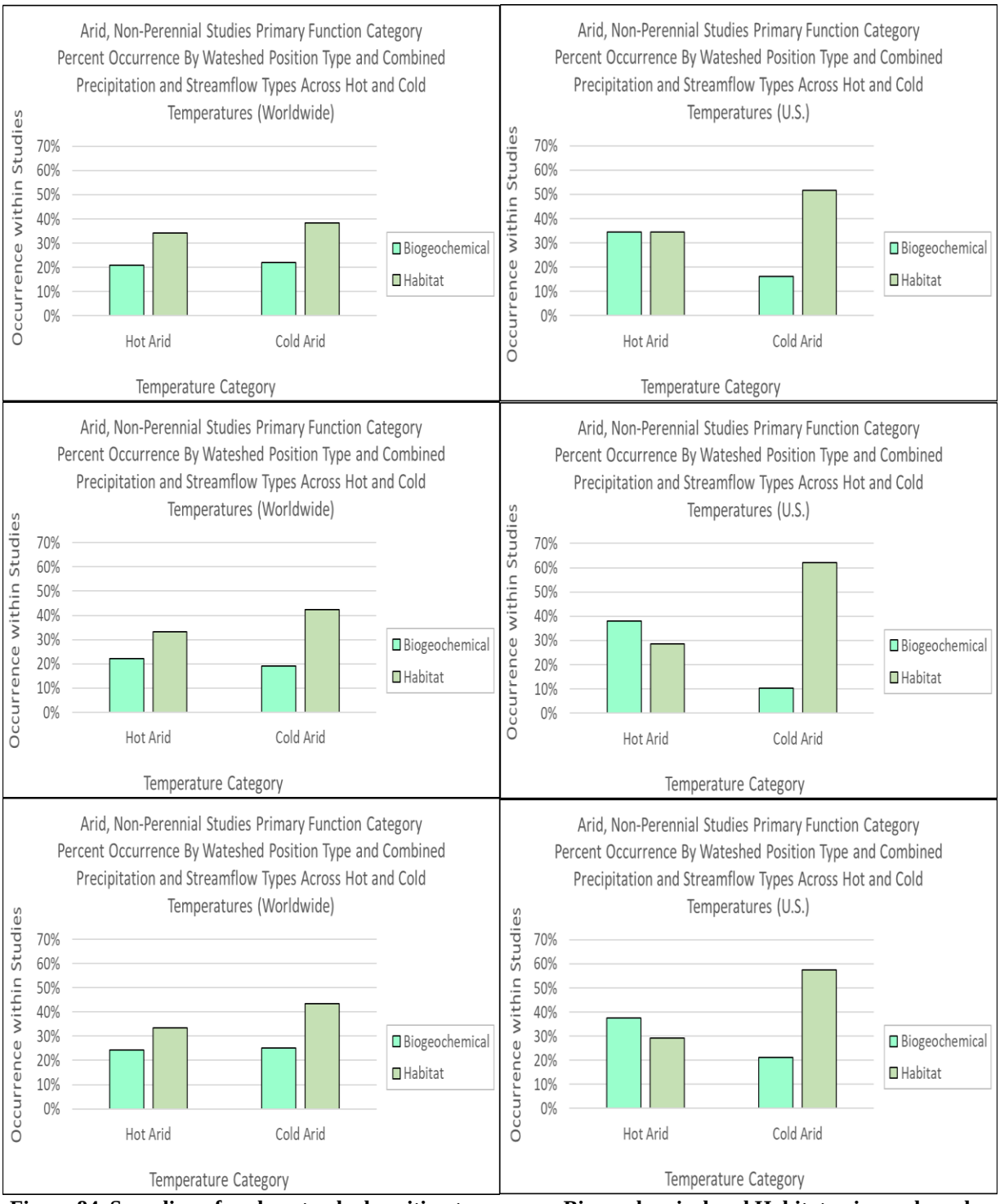


Figure 84. Sampling of each watershed position type across Biogeochemical and Habitat primary broad function categories by temperatures, within global and U.S. arid non-perennial stream literature.

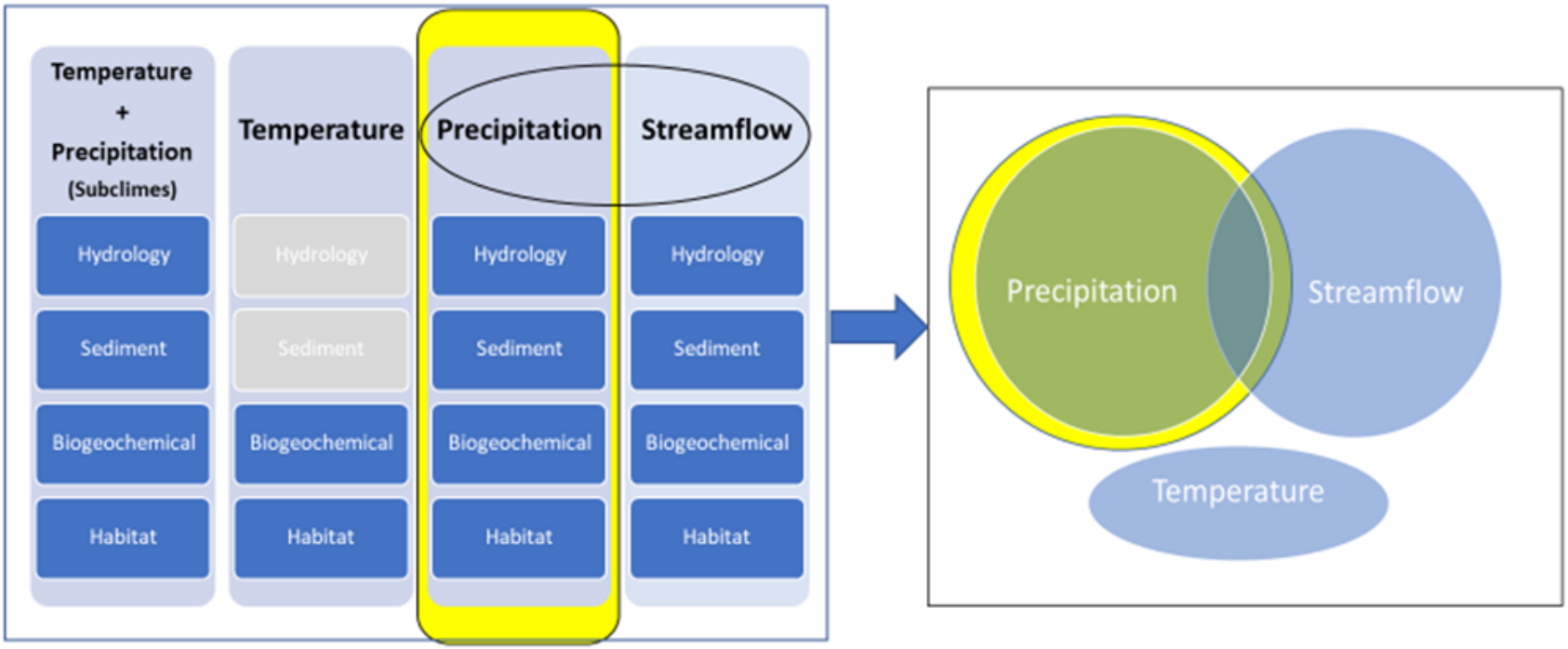
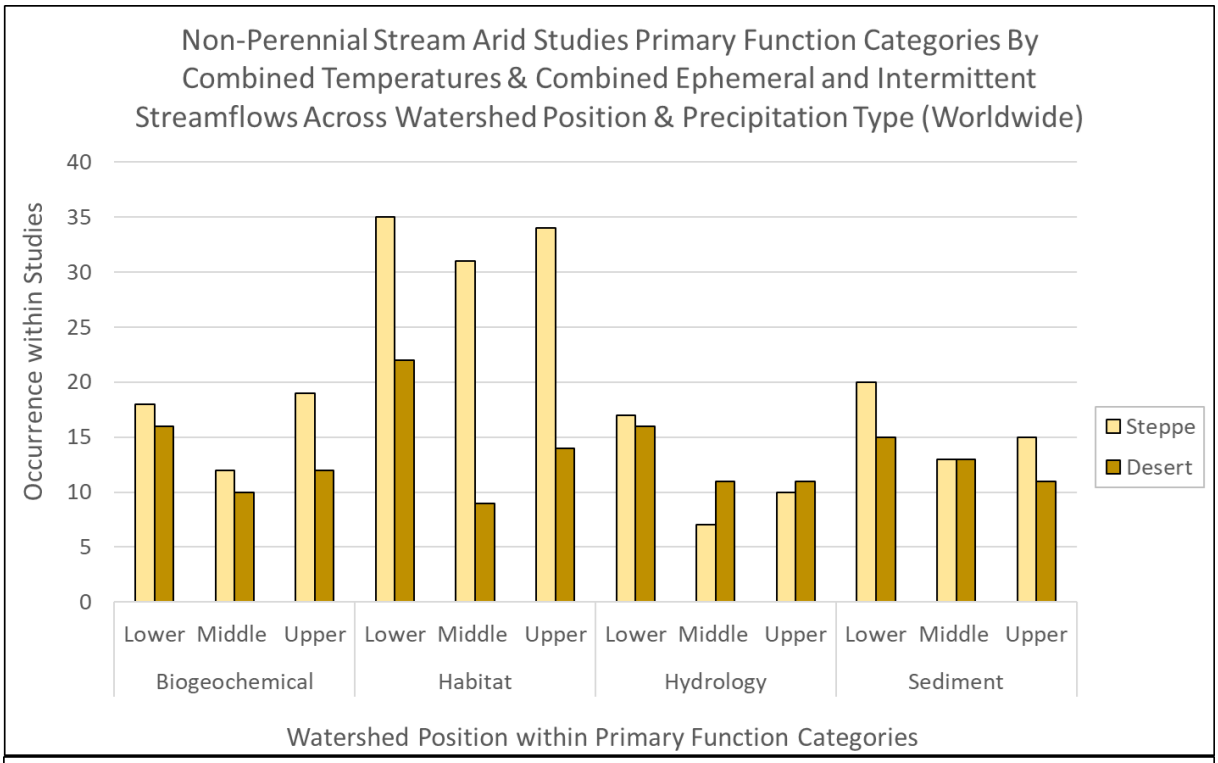


Figure 85. The conceptual relations and hierarchies of a subclime component (precipitation types) and an inherent hydrology component (precipitation types) factor and its influence on broad stream function categories.



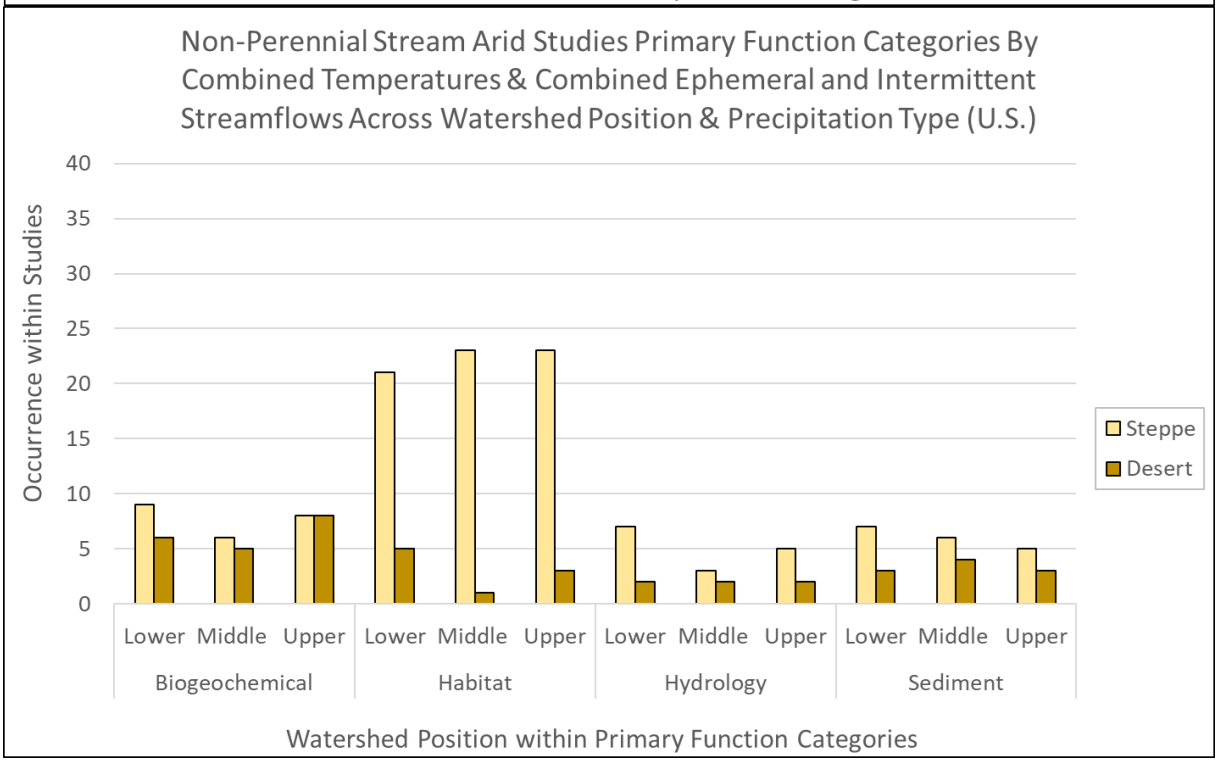


Figure 86. Sampling of primary broad function categories across precipitation types by known watershed positions, within global and U.S. arid non-perennial stream literature.

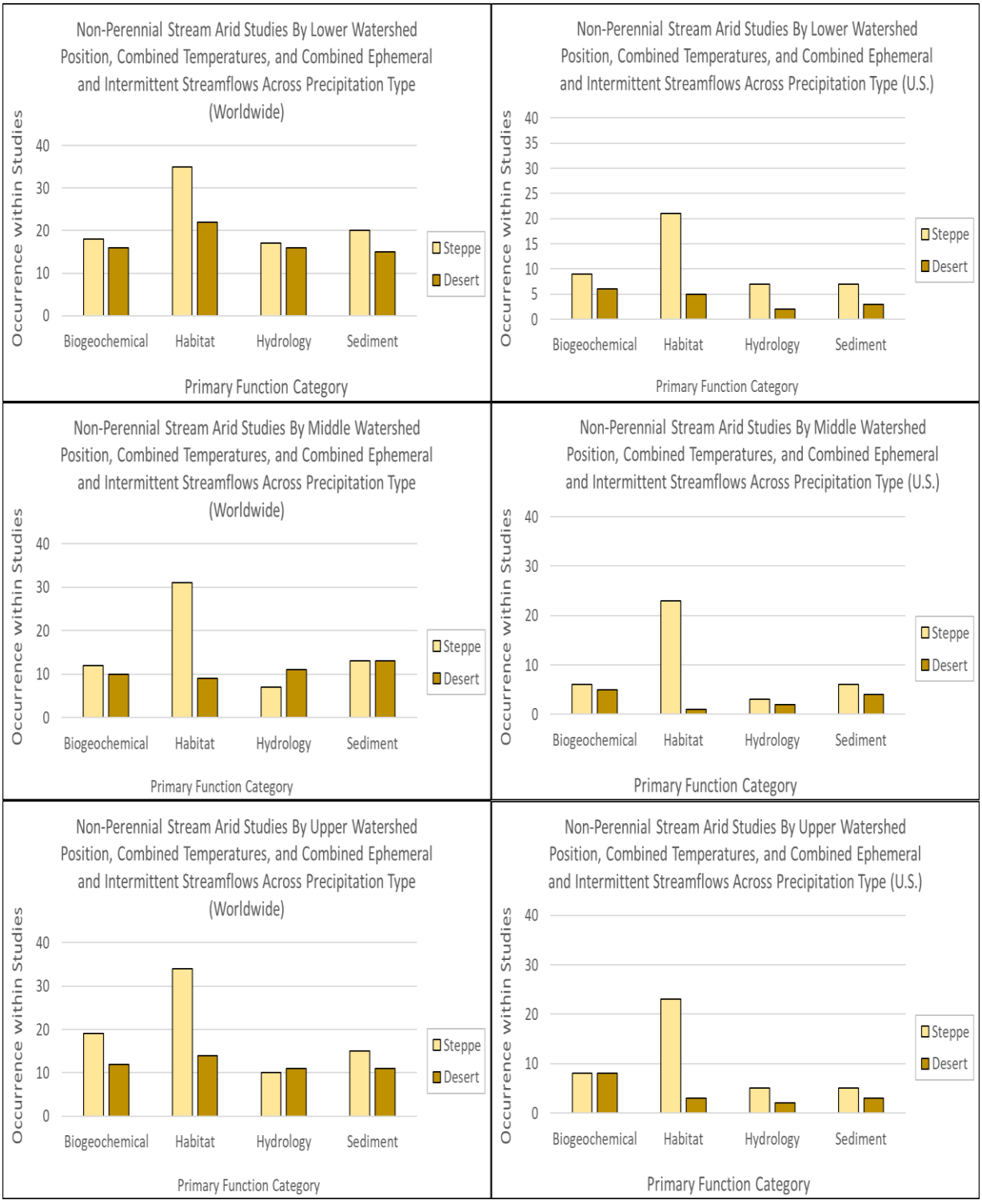


Figure 87. Sampling of each known watershed position type across primary broad function categories and precipitation types, within global and U.S. arid non-perennial stream literature.

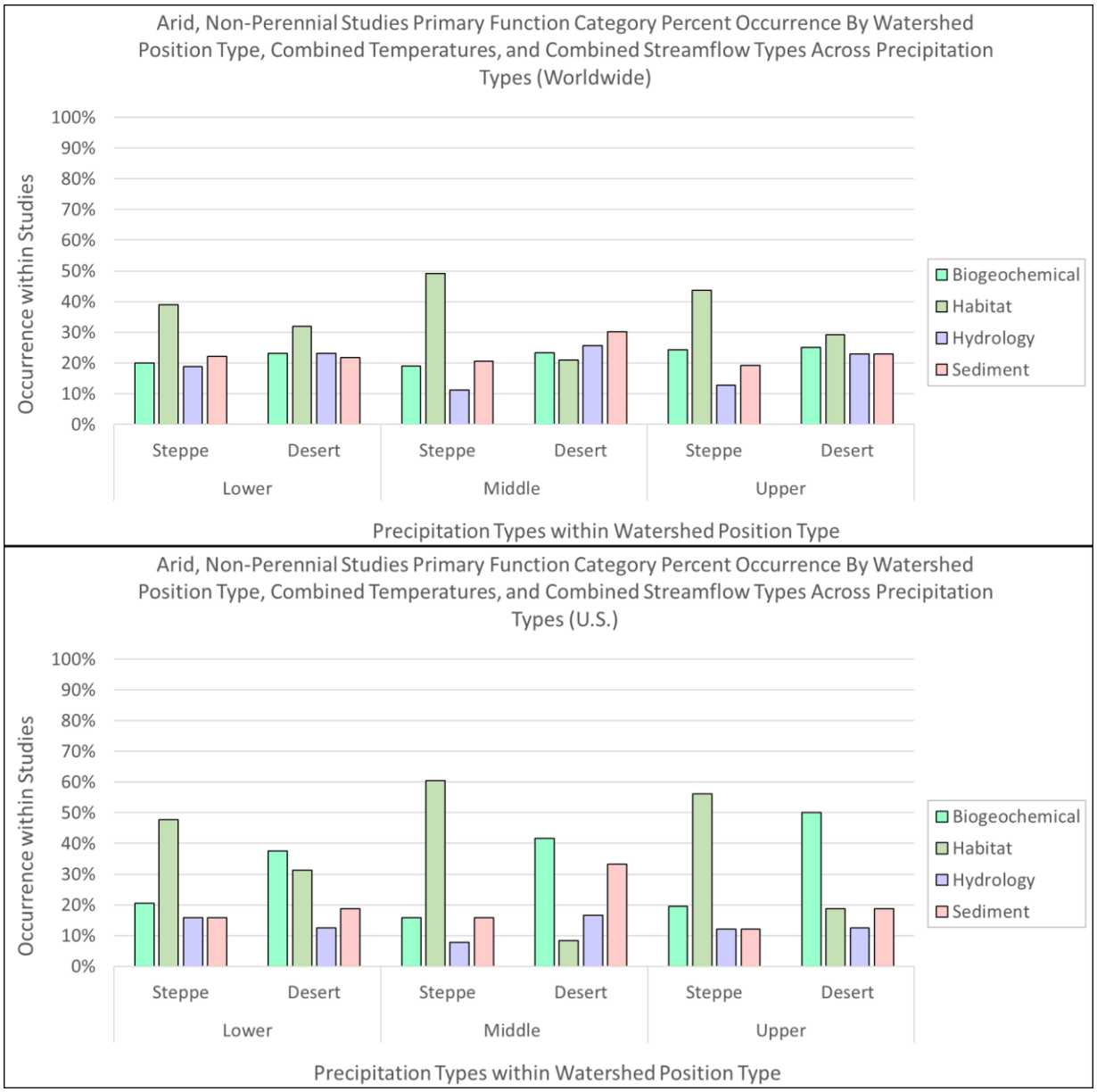


Figure 88. Sampling of known watershed position types across primary broad function categories by precipitation types, within global and U.S. arid non-perennial stream literature.

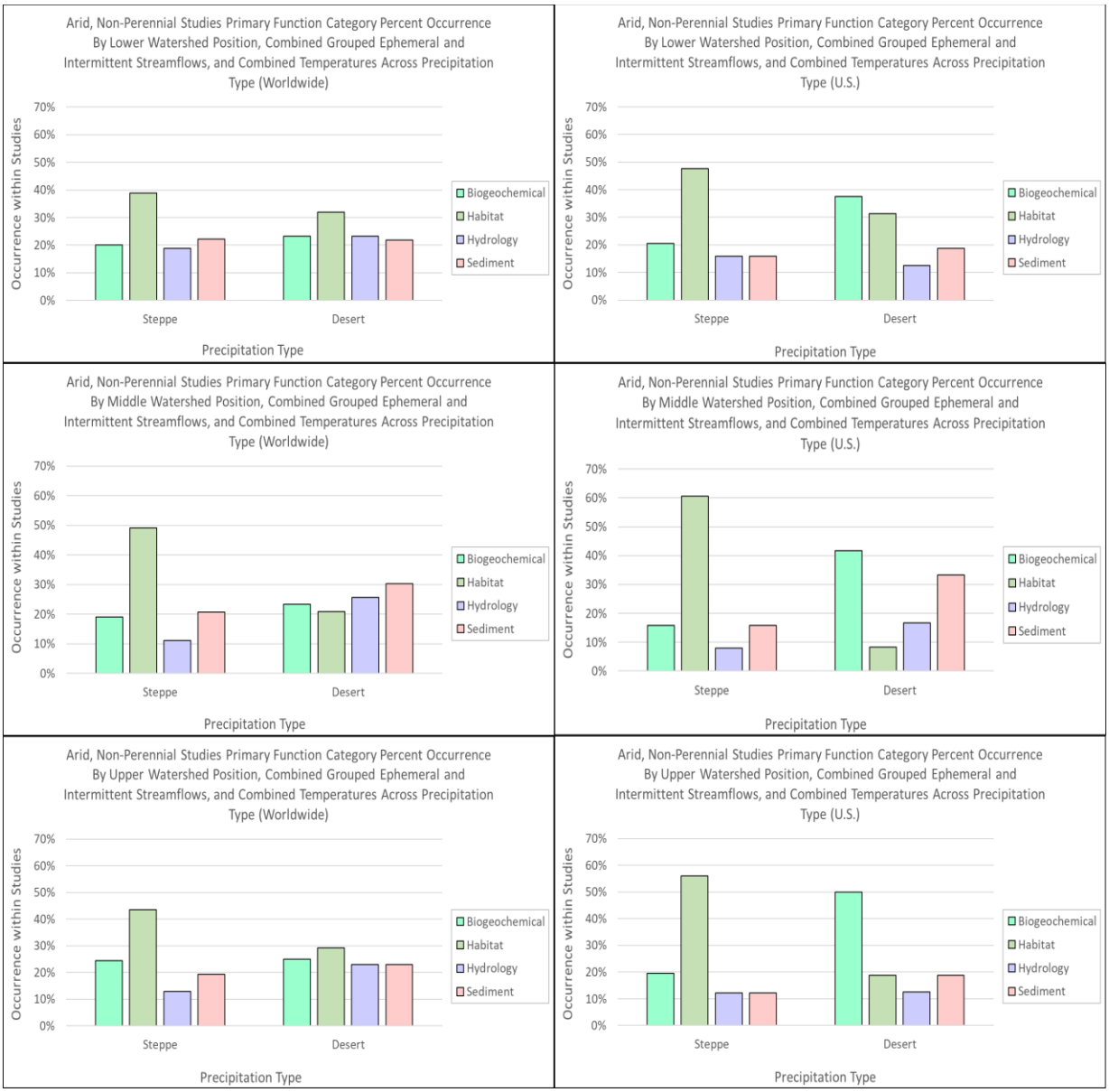


Figure 89. Sampling of each known watershed position type across primary broad function categories by precipitation types, within global and U.S. arid non-perennial stream literature.

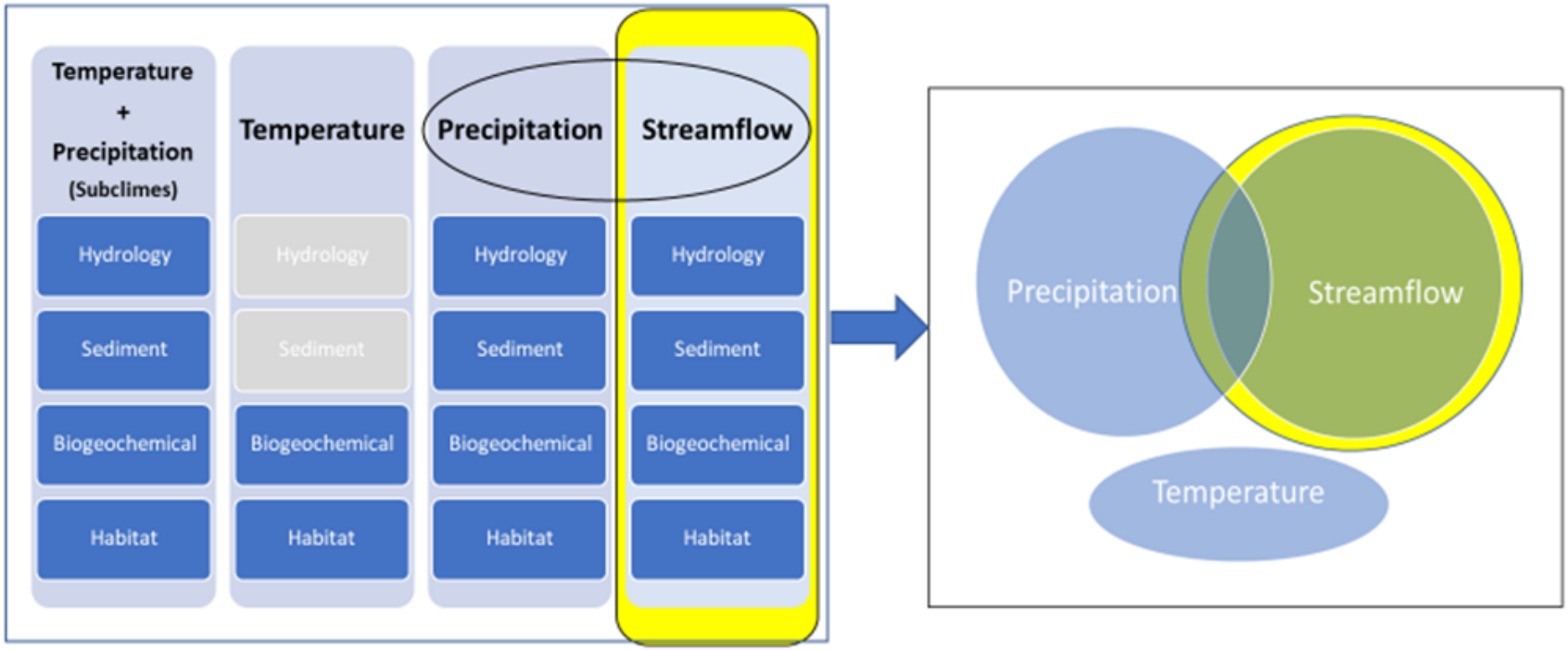


Figure 90. The conceptual relations and hierarchies of a hydrology component (streamflow types) factor and its influence on broad stream function categories.

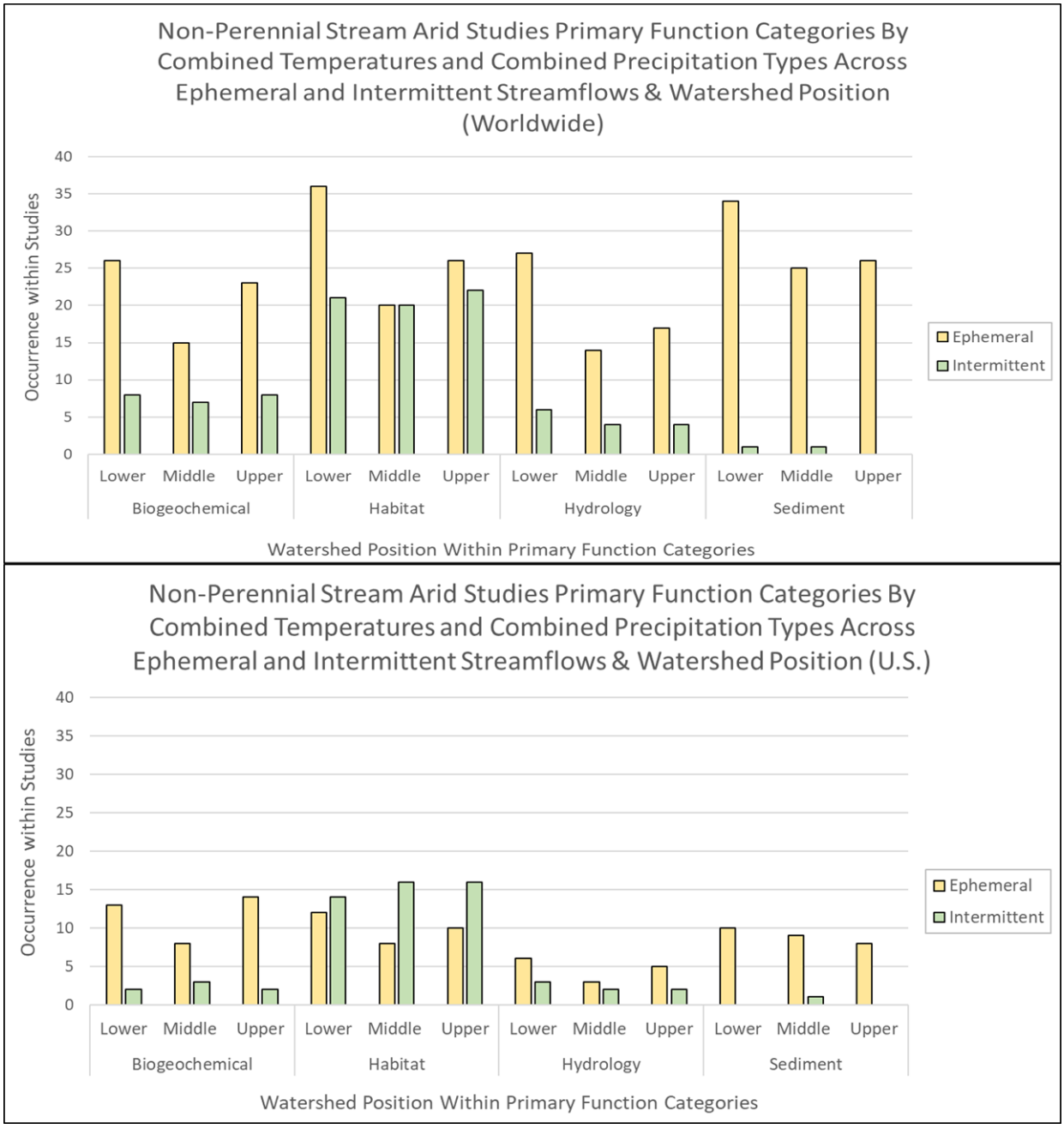


Figure 91. Sampling of primary broad function categories across known streamflow types by known watershed positions, within global and U.S. arid non-perennial stream literature.

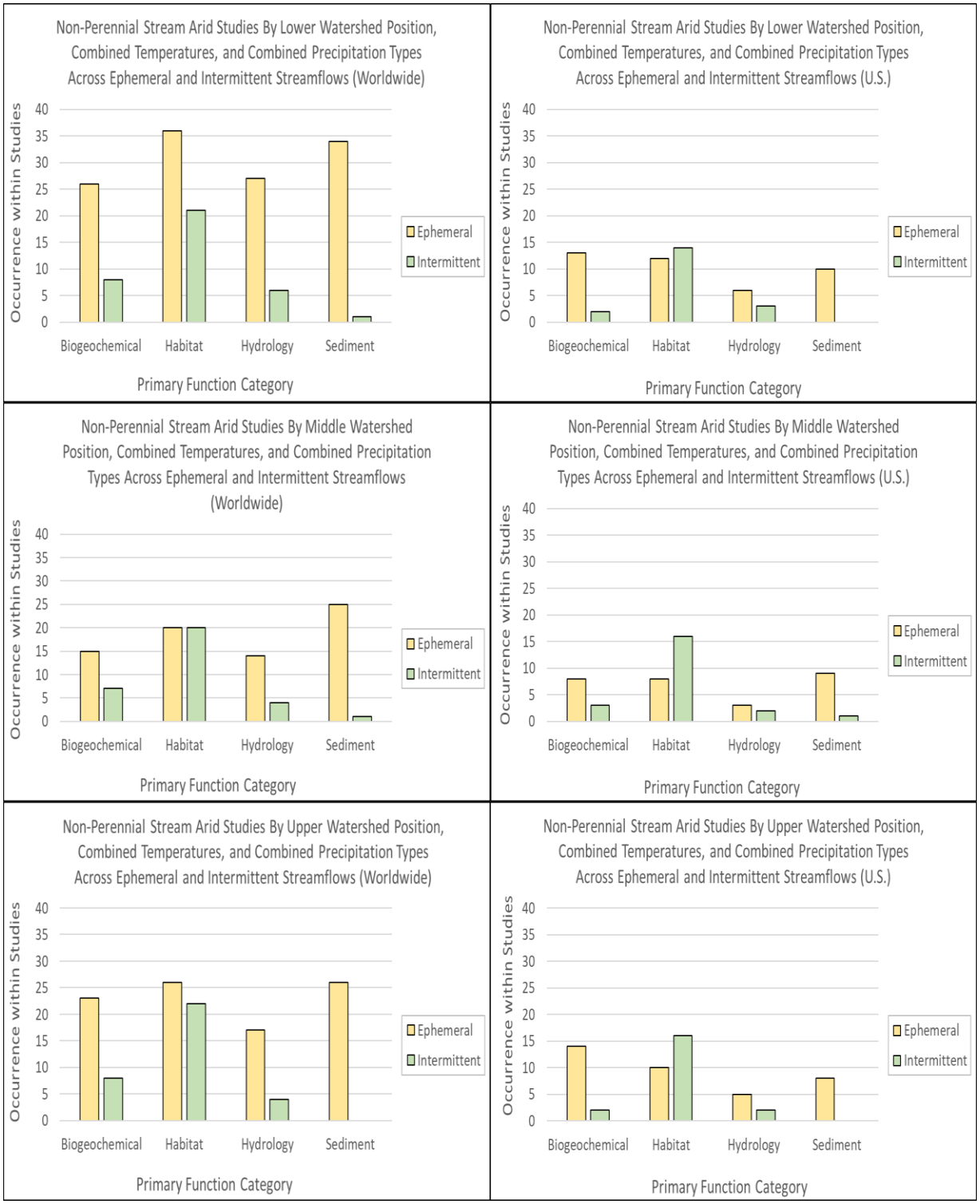


Figure 92. Sampling of each known watershed position type across primary broad function categories and known streamflow types, within global and U.S. arid non-perennial stream literature.

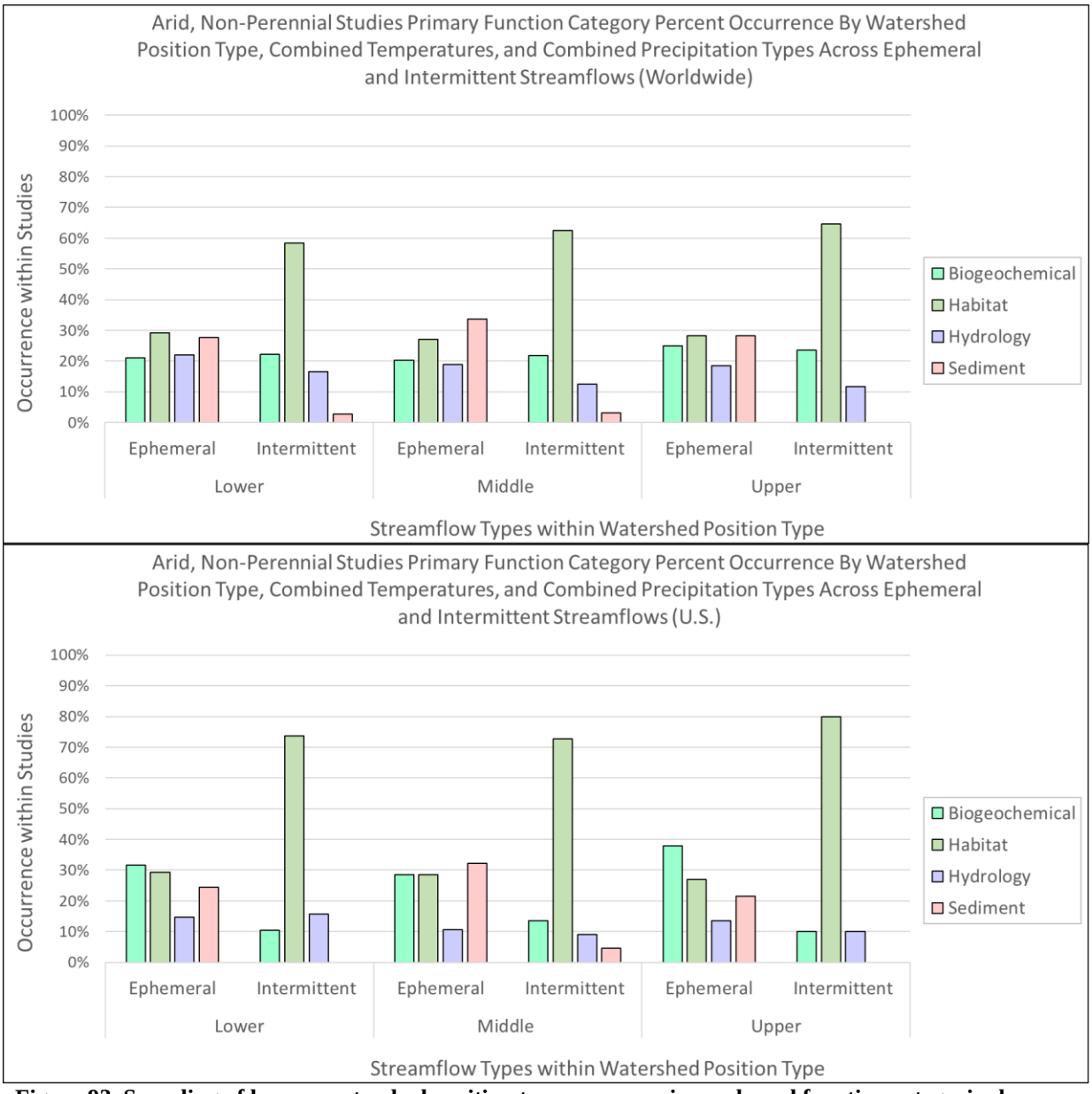


Figure 93. Sampling of known watershed position types across primary broad function categories by known streamflow types, within global and U.S. arid non-perennial stream literature.

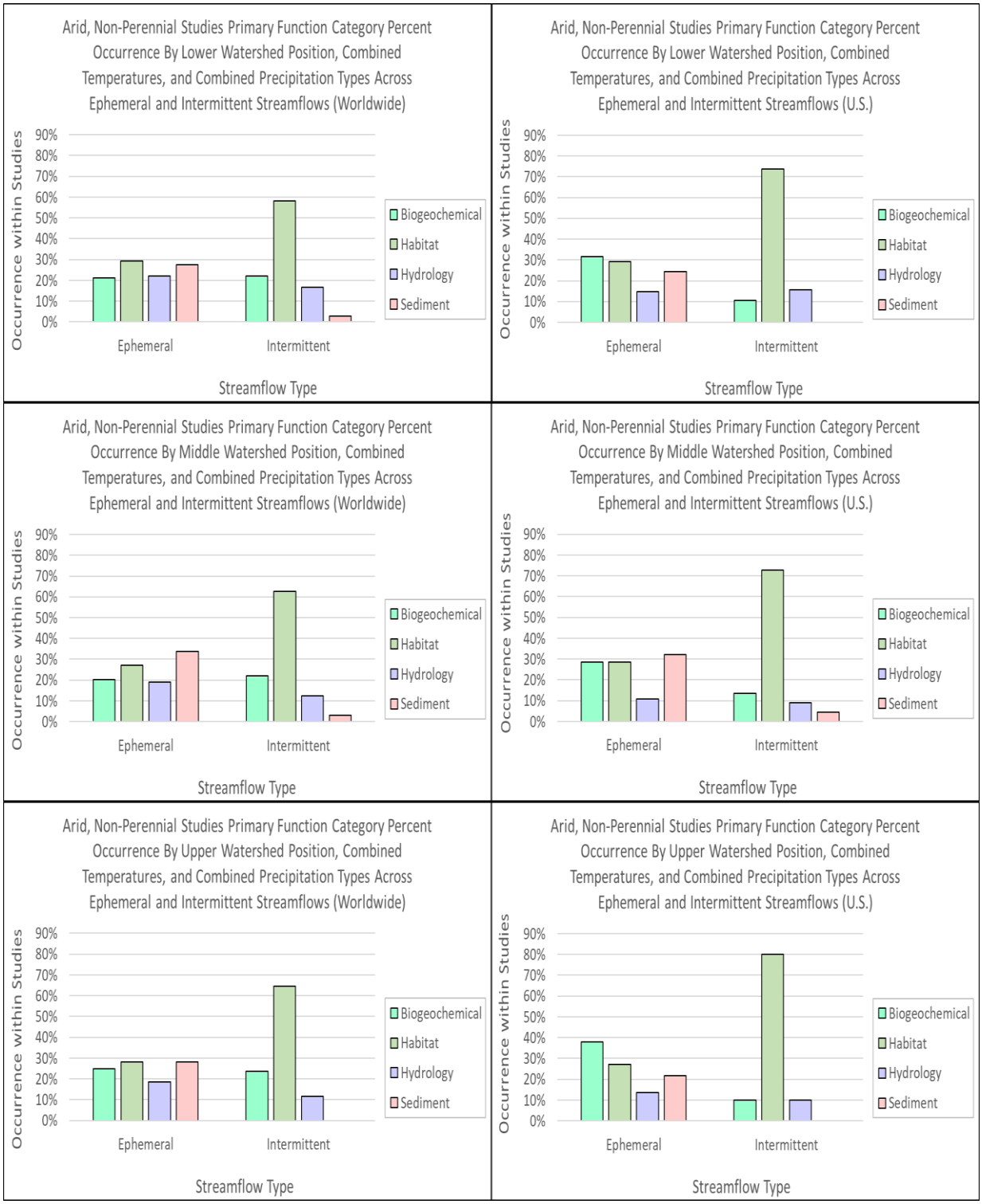


Figure 94. Sampling of each known watershed position across primary broad function categories by known streamflow types, within global and U.S. arid non-perennial stream literature.

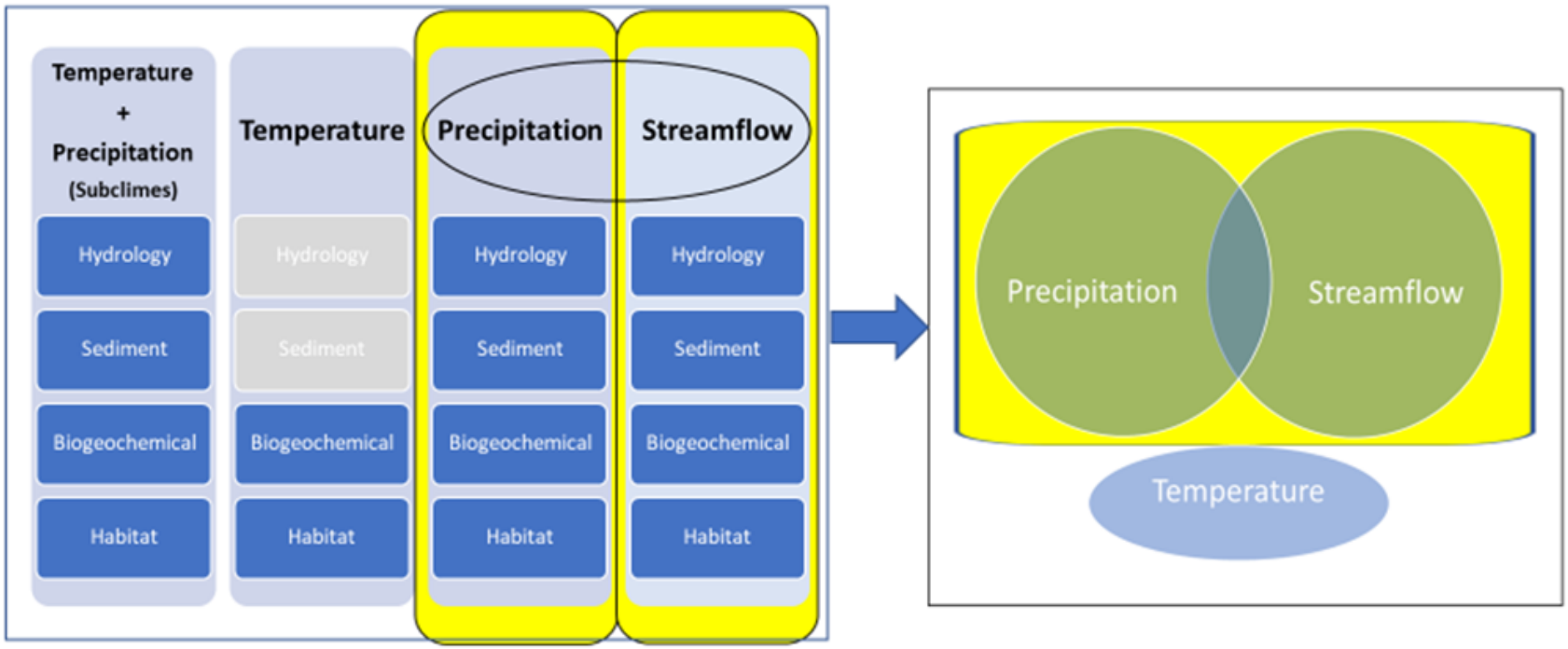


Figure 95. The conceptual relations and hierarchies of hydrology (precipitation and streamflow types) factors and their influence on broad stream function categories.

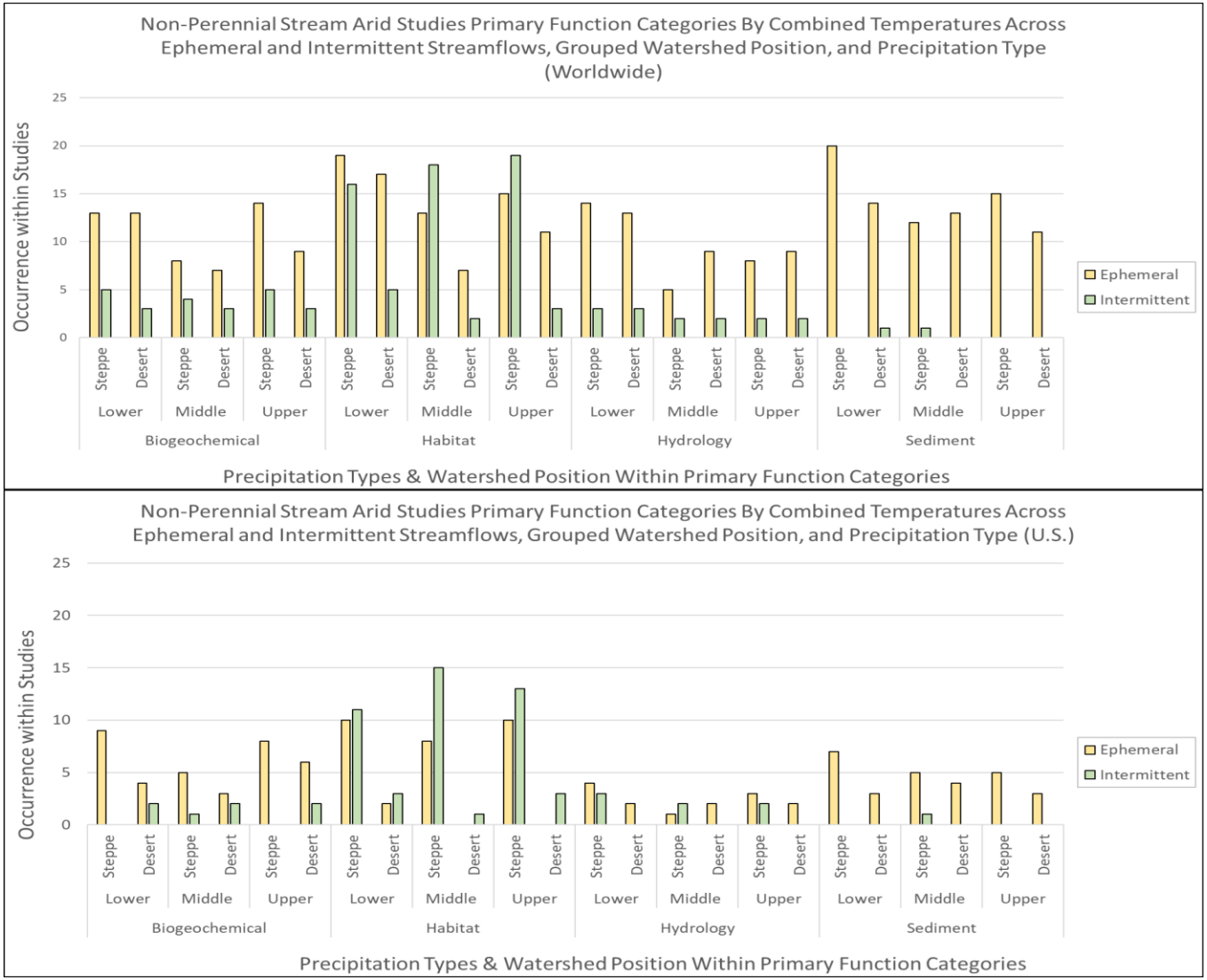


Figure 96. Sampling of primary broad function categories across known watershed position and streamflow types by precipitation types, within global and U.S. arid non-perennial stream literature.

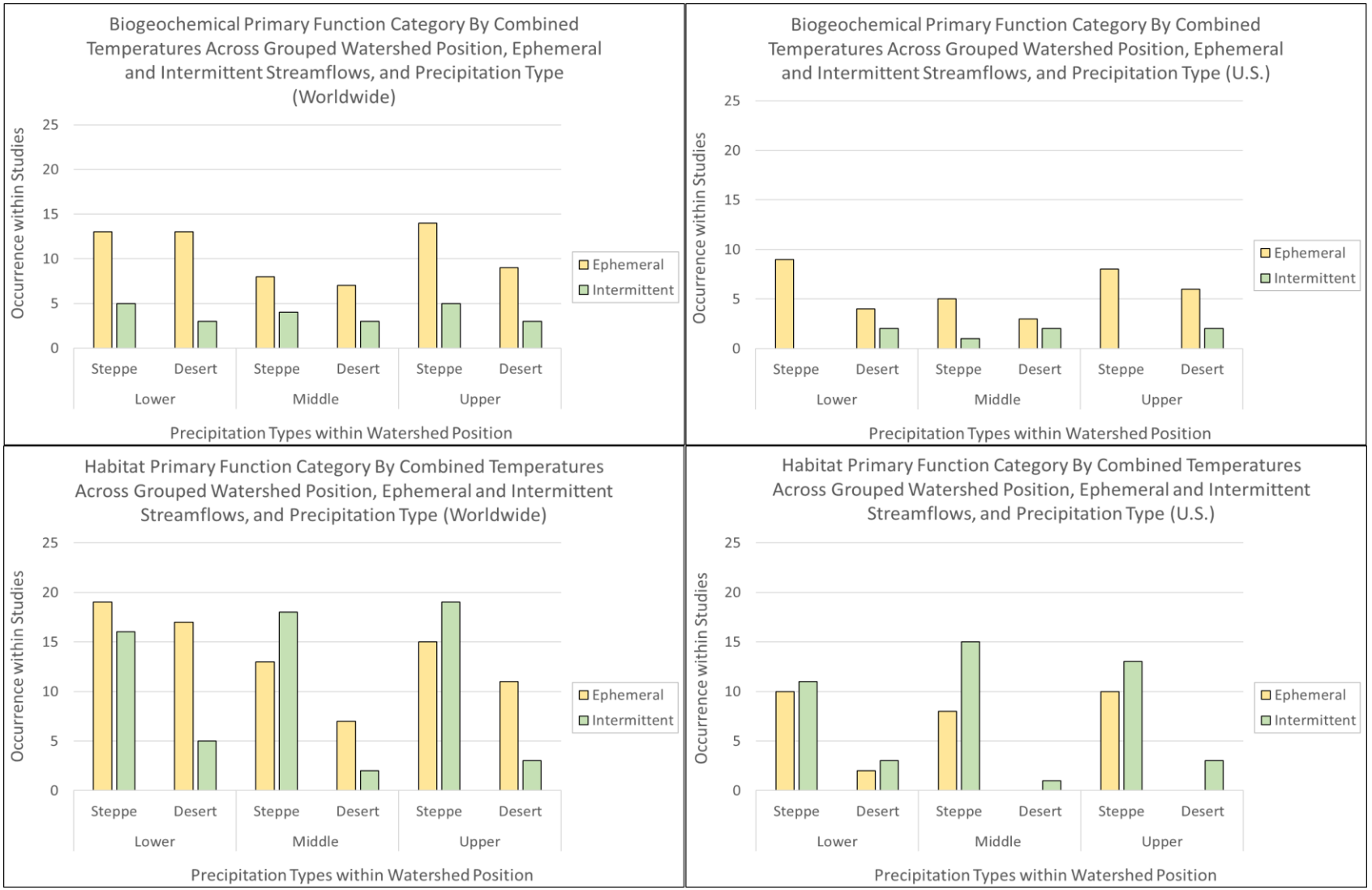


Figure 97. Sampling of Biogeochemical and Habitat function categories across known watershed position and streamflow types by precipitation type, within global and U.S. arid non-perennial stream literature.

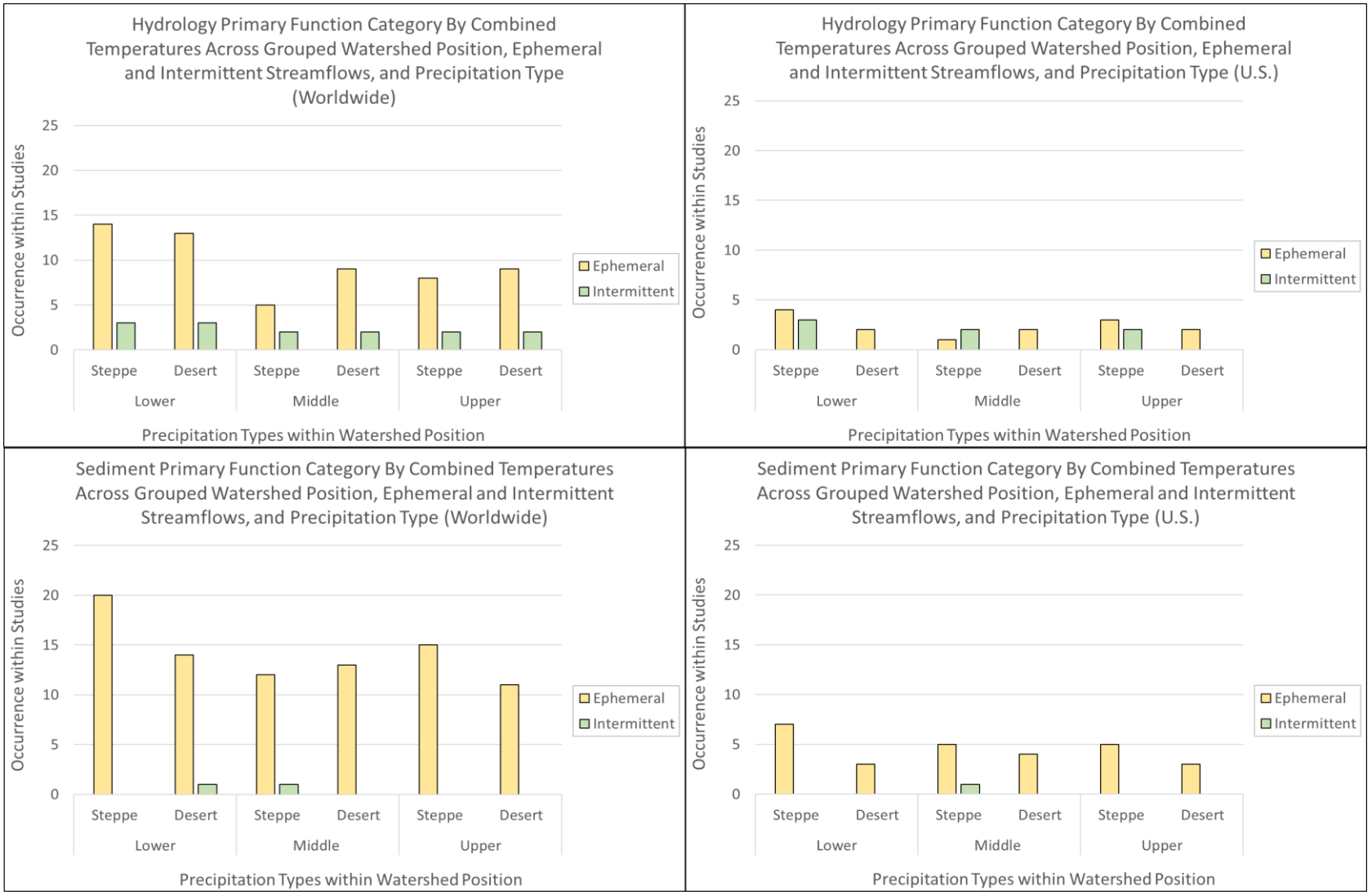


Figure 98. Sampling of Hydrology and Sediment function categories across known watershed position and streamflow types by precipitation type, within global and U.S. arid non-perennial stream literature.

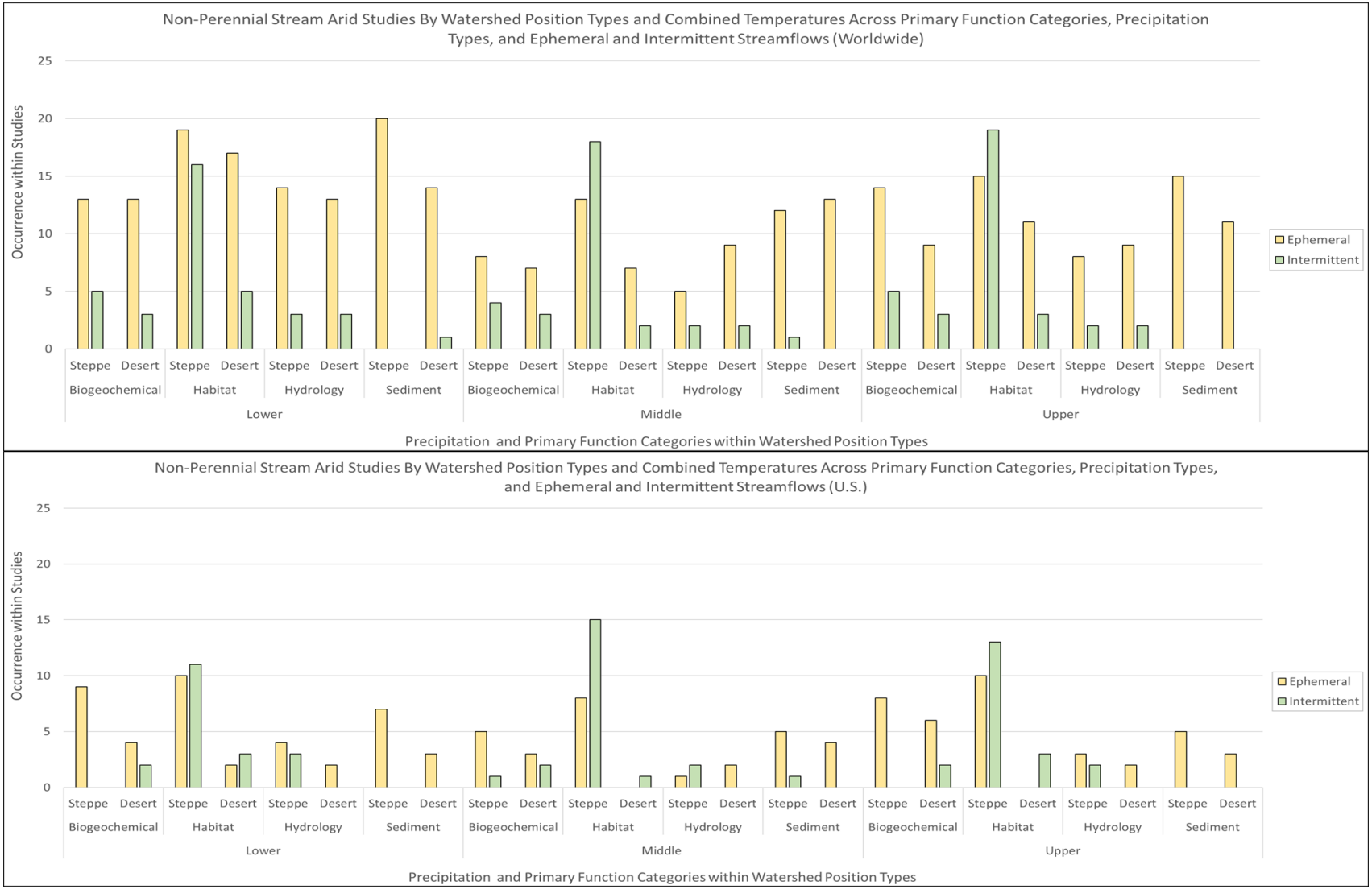


Figure 99. Sampling of known watershed types across primary broad function categories and known streamflow types by precipitation types, within global and U.S. arid non-perennial stream literature.

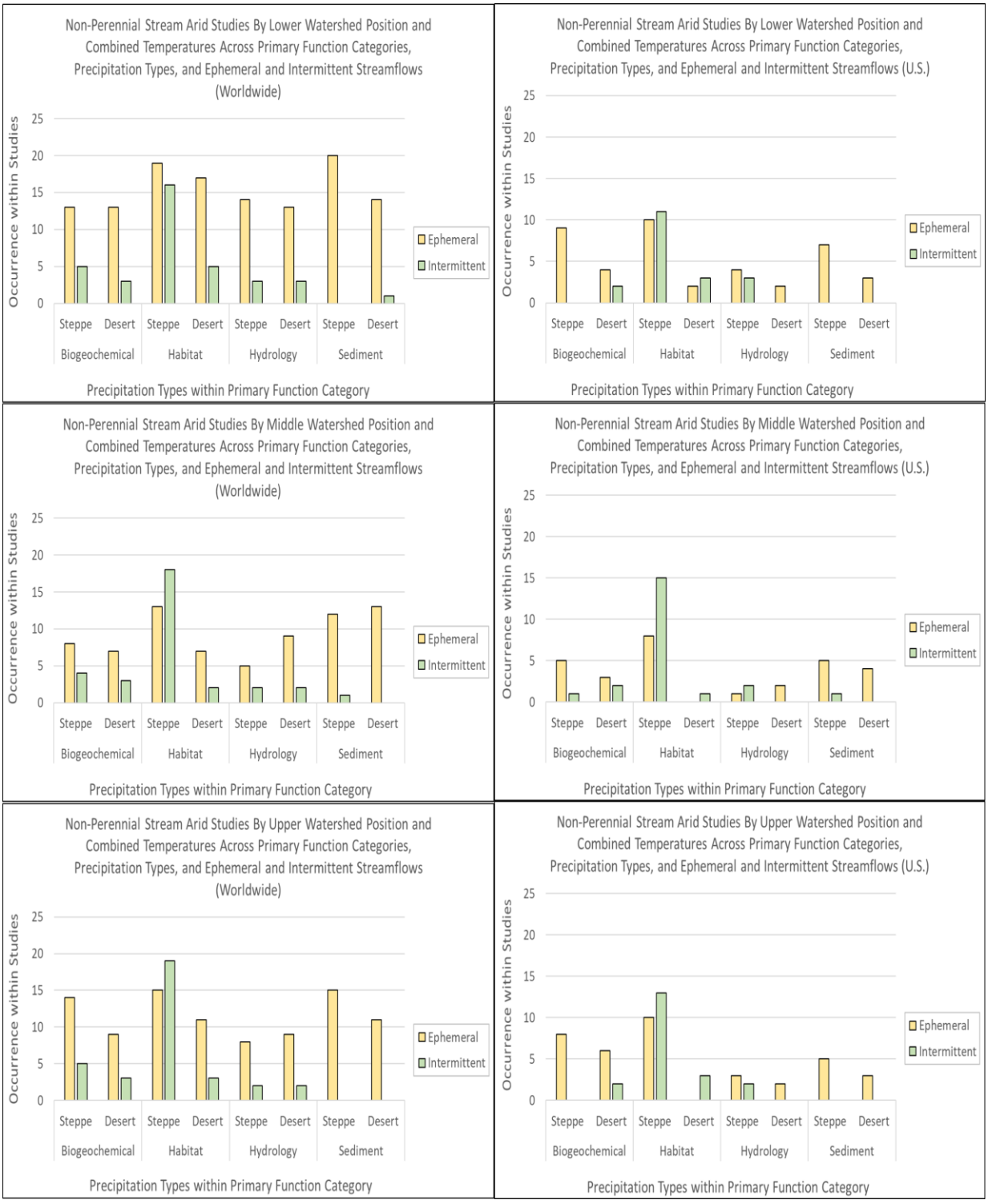


Figure 100. Sampling of each known watershed type across primary broad function categories and known streamflow types by precipitation types, within global and U.S. arid non-perennial stream literature.

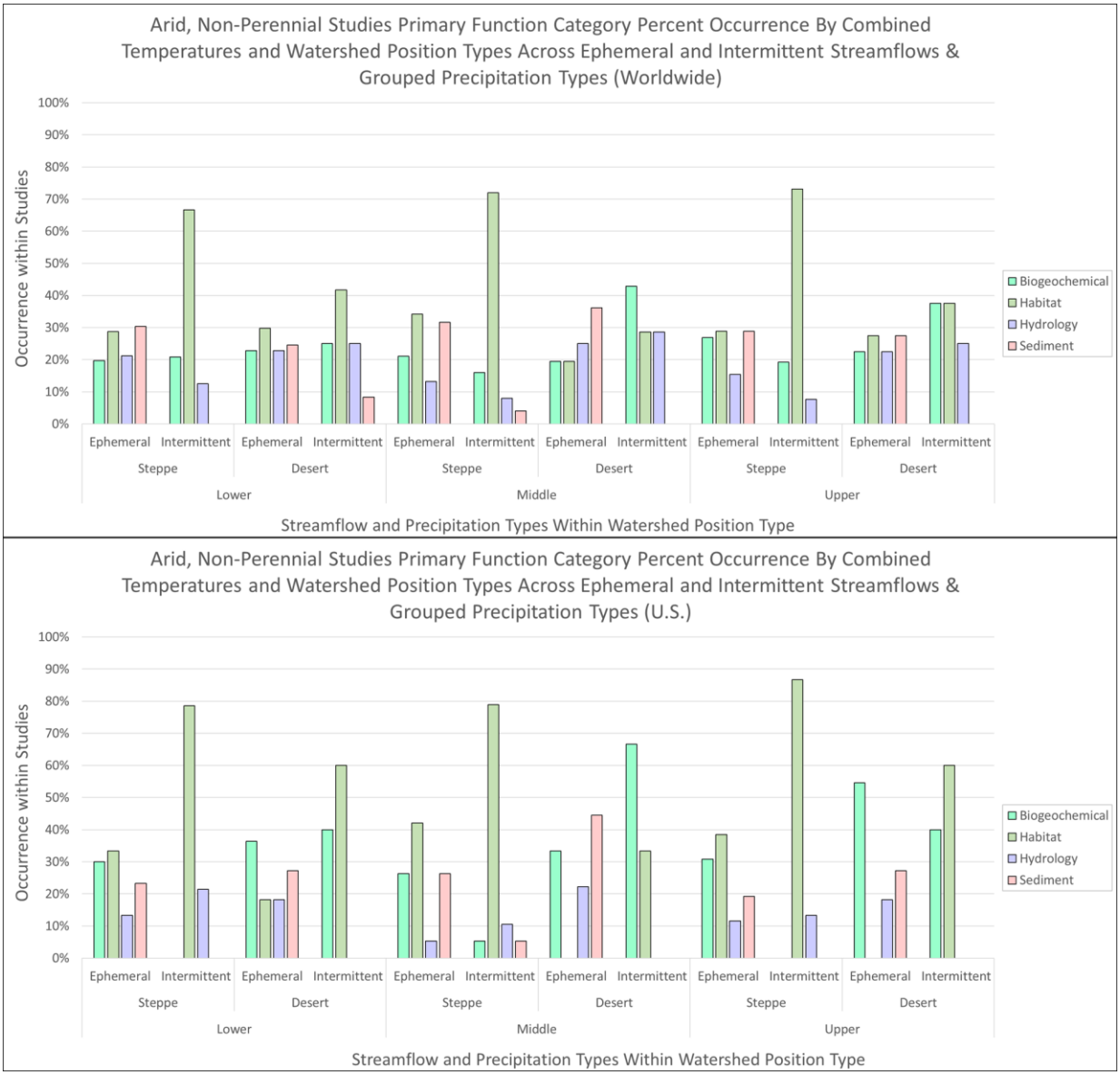


Figure 101. Sampling of known watershed position types across primary broad function categories and precipitation types by known streamflow types, within global and U.S. arid non-perennial stream literature.



Figure 102. Sampling of each known watershed position type across primary broad function categories and precipitation types by known streamflow types, within global and U.S. arid non-perennial stream literature.

Functions and Planform Parameter

The specific functions and level of functions a stream may provide are in context of the environmental settings, including the consideration of stream planform type (Figure 103). Classification of streams by planform type is a means to group similar stream forms, and thus functions (Fisher et al., 2007; Meitzen et al., 2013), based on prevailing hydrological and geomorphic characteristics (Harman et al., 2012; Lefebvre, Lichvar, Curtis, et al., 2013; Li et al., 2015; Meitzen et al., 2013; Sutfin, 2014). As a method of stream systems classification, it serves as a main precursor to evaluating stream functions for assessment methods, management, regulation and other purposes (David et al., 2021; Mersel et al., 2014; D.E. Somerville & Pruitt, 2004). The particular planform type a given stream site may exhibit is not necessarily limited to any particular watershed position and can also change over time depending on climate, landscape, sediment and hydrology inputs, and other factors (David et al., 2021; Lefebvre, Lichvar, Curtis, et al., 2013; Pyne et al., 2017; Wohl et al., 2016). Therefore, channel form is an important environmental parameter for consideration in stream studies (D.E. Somerville, 2010), in addition to streamflow regimes and climactic factors.

Stream planform type, as listed or discernable within arid studies, was only available for 50% of the global literature set and 45% of U.S. literature set. The different channel forms initially included: “headwater”, “prairie”, “delta”, “straight”, “single thread”, “single”, “meandering”, “distributary”, “discontinuous”, “compound”, “braided”, “anastomosing”, “anabranching”, and “alluvial fan” (Table 23) (Figure 104). For practicality of data analyses, these forms were condensed into the ten subcategories of: “headwater”. “straight”, “single

thread", "single", "meandering", "distributary", "discontinuous", "compound", "braided", "anastomosing", and "alluvial fan" subcategories (Figure 105). Though some of these channel form descriptions are not strictly two-dimensional channel forms, such as "headwater" and "alluvial fan", they are both important channel forms in distinct landscape stream settings and in some cases were the only available level of channel form distinction within studies. Therefore, the term stream planform used herein is slightly broader, encompassing all recorded channel forms. Furthermore, as there are some general, broad similarities among the various planform types, results were typically organized within the three general groupings of (1) "single thread", "meandering", "straight", and "headwater", (2) "anastomosing", "braided", and "compound", and (3) "alluvial fan", "discontinuous", and "distributary". The first grouping has the commonality of stream systems typically confined to a single channel setting. The second grouping is linked by systems balancing dynamics of sediment and hydrology transport, while the third grouping can be broadly portrayed as energy dissipation systems. As U.S. studies data is relatively limited, with approximately two thirds of global data from countries other than the U.S., except for the basic overview of stream functions with planform type described below, all other data are presented primarily for the global literature set.

Both the U.S. and global literature sets exhibit similar trends highest representation of single thread and braided stream planform types covered across all primary function categories, with these same planform types dominating across all Biogeochemical, Habitat, Hydrology and Sediment function studies (Figure 105) (Table 24). These results are consistent with others having noted single thread and braided channels are the most common planform types worldwide in arid areas (Tal & Paola, 2007; Tooth, 2000). Though compound channels have been noted as

most common specifically within the Arid West (Lefebvre, Lichvar, Curtis, et al., 2013), the difficulty sometimes in distinguishing compound and braided channels may explain the discrepancy of braided channels being second most common. In terms of the opposite perspective, focusing on the stream planform subcategories and the coverage of all stream function categories within each (Figure 106), the overall global studies covered the Sediment function category the most, followed by Habitat, Hydrology and Biogeochemical function studies. Though U.S. studies followed general global patterns of the level of the primary functions covered within the dominant braided and single thread stream planform types, the overall coverage of all four functions deviated from global stream planform studies with a predominance of Habitat function coverage, followed by Sediment, Biogeochemical, and Hydrology. It's interesting that overall coverage of the primary function categories across stream planform types within both global and U.S. are not consistent with the pattern of the overall studies coverage of the primary function categories (Figure 23, Figure 38), where representation from highest to lowest is Habitat, Biogeochemical, Sediment and Hydrology functions. For global studies with discernable planform types, there is a distinct difference of greater Sediment and Hydrology function categories coverage.

The next steps of global data layering included all climate and hydrology aspects, in addition to that of the primary function categories with stream planform subcategories (Figure 107). As detailed within Figure 108, the broad function categories of arid non-perennial studies were examined in terms of overall climate (e.g., subclimes) with all hydrology components (inherent precipitation types and specific streamflow regimes). This data layering represented the most influence on the function categories, as it combined both system hydrology components

along with temperature. When examining the distribution of Koppen-Geiger subclimes, stream planform subcategories, and ephemeral and intermittent streamflow regimes across each primary function category, there is an general pattern of predominance of ephemeral stream coverage across all planform types within the hot desert subclime, followed by coverage of intermittent streams within hot steppe subclime (Figure 109, Figure 110) (Table 25). This is mostly consistent with the overall data pattern of greater coverage of ephemeral vs intermittent streams for all functions other than the Habitat category (Figure 32), although here Habitat stream planform studies were also dominated by ephemeral stream coverage. The only departure from predominant ephemeral stream coverage within the hot desert subclime was within Habitat function studies, where most ephemeral streams were represented within the cold steppe subclime across all planform types. And for intermittent stream coverage the only deviation was within Sediment function studies, where highest coverage was split between hot and cold desert subclimes. There were no notable differences in these data patterns when looking at the planform types across the three general groupings (Figure 111, Figure 112, Figure 113). In terms of the opposite perspective, focusing on the percent contribution of primary function categories within studies covering a specific planform type, subclime, and streamflow regime, most function categories coverage across all planform types were primarily within ephemeral stream studies, higher representation of Sediment and Habitat functions were evident across all planform types, and especially those with limited data. The highest percentage coverage of the least well represented Biogeochemical function primarily occurred within most subclimes of single thread and headwater studies of the first planform group, and the least coverage of all functions across all subclimes and streamflow types occurred within straight and compound planform types

(Figure 114, Figure 115, Figure 116). The latter is likely due to a very small sampling size, as the highest represented planform types of single thread, braided, and headwater stream planforms also had the greatest coverage of all function categories across subclime and streamflow types.

Similar to the above global data analyses, the subclimes data were subdivided into the separate temperature and precipitation components, which were also examined with streamflow regime types among the primary function categories and planform subcategories (Figure 117, Figure 98). Figure 118 and Figure 119 depict these data layerings in terms of each primary function category, while Figure 120, Figure 121, and Figure 122 provide a similar global data set comparison in terms of the three groupings of the stream planform types. Likely influenced by overall studies coverage of precipitation (Figure 46), streamflow regime (Figure 32), and arid temperatures (Figure 42), the overall trend across global studies was an equal or greater coverage of steppe precipitation, ephemeral streams, and hot arid temperatures across all stream planform types (Table 26). And similar to the planform types being overlain with subclime and all other data layers, there were no other distinct data patterns when examining the planform types across the three general groupings (Figure 120, Figure 121, Figure 122). In terms of the opposite perspective, focusing on the percent contribution of all primary function categories within a specific temperature, arid precipitation, and streamflow regime type (Figure 123, Figure 124, Figure 125), the results were the same as those above addressing subclimes (Figure 114). Most function categories coverage across all planform types were primarily within ephemeral stream studies, higher representation of Sediment and Habitat functions were evident across all planform types, and the highest percentage coverage of the least well represented

Biogeochemical function primarily occurred within most subclimes of single thread and headwater studies (the first planform group).

In beginning to separate out the hydrology components, by not including specific streamflow regimes, the coverage of the primary functions categories was layered with only subclimes (temperature and inherent precipitation) and stream planform subcategories (Figure 126). Within global studies across all stream planform types, the overall trend is similar with a predominance of all primary functions coverage within hot desert subclime, except for the Biogeochemical function that was equally split between hot desert and hot steppe occurrences (Figure 127) (Table 27). There was also the least coverage of all function categories within the cold desert subclime. When examining the data by individual planform type, both alluvial fan and single thread planforms deviated from the overall trend with higher representation within cold steppe subclimes, as well as compound and straight channels highest representation within cold desert and hot steppe subclimes, respectively (Figure 128, Figure 129, Figure 130). In terms of the opposite perspective, focusing on the percent contribution of all primary function categories within studies covering a specific planform and subclime type, the general trend continued to be a predominance of Sediment functions coverage across all planform types and by planform groups (Figure 131, Figure 132, Figure 133). For the least overall represented Hydrology and Biogeochemical function studies, the highest relative percent occurrence among the other function categories was within studies of alluvial fan streams within hot and cold steppe subclimes and of anastomosing streams within the hot steppe subclime, respectively.

Similar to the above data analyses, and in continuing to separate out the literature data among separate climate and hydrology components, the subclimes were further subdivided into

the temperature (Figure 134) and then precipitation (Figure 143) components among the function categories they primarily influence and among stream planform types, in the absence of streamflow regime contributions. Similar to all global studies exhibiting an overall pattern of predominance within hot arid areas (Figure 42), this was mirrored within all stream planform types for Biogeochemical studies and most stream planform types for Habitat studies (Figure 135) (Table 28). There was a marked shift in global Habitat studies with equal overall sampling within cold arid areas, occurring within alluvial fan, compound, meandering and headwater planform types (Figure 136, Figure 137, Figure 138). Additionally, there was a complete lack of representation for both Biogeochemical and Habitat functions coverage within straight and discontinuous planforms, as well as no representation of Biogeochemical functions within at least a third of each planform grouping and half of all stream planform types (meandering, straight, compound, alluvial fan, discontinuous). In terms of the opposite perspective, focusing on the percent contribution of Biogeochemical and Habitat function studies covered within a specific planform and arid temperature type, global studies had a strong pattern of Habitat studies outpacing Biogeochemical studies across all planform types and hot and cold arid temperatures (Figure 139). Out of the half of stream planform types that did include a small percentage of Biogeochemical functions coverage, most were situated within hot arid temperature areas with only two (single thread and headwater planforms) also including studies within cold arid temperatures (Figure 140, Figure 141, Figure 142). When subsequently examining the other half component of both subclimes and hydrology, or precipitation type, in the absence of streamflow regime contributions and among the primary function categories and stream planform types, (Figure 143), there is a slight majority of all study occurrences within

steppe precipitation areas (Table 29). However, only two (headwater and straight) of the individual planform types exhibited the overall dominant occurrence of steppe precipitation areas within each function category (Figure 144). Rather, when occurrences of planform types are summed across all function categories, most studies were situated within desert precipitation areas (Figure 145, Figure 146, Figure 147). Moreover, only Habitat planform studies had a clear majority of occurrences within steppe precipitation areas (over all planform types), while Biogeochemical and Hydrology planform studies were equally split across steppe and desert precipitation types and Sediment planform studies mainly occurred within desert precipitation areas. In terms of the opposite perspective, focusing on the percent contribution of primary function categories within a specific planform and precipitation type, there was only global coverage of all functions across both precipitation types within braided, single thread, and headwater planforms. On the other end of the spectrum, compound, discontinuous, meandering and straight planforms had the least coverage of all functions (including absence of Biogeochemical functions) across both precipitation types (Figure 148). Following overall planform study trends (Figure 105), Sediment and Habitat functions studies were most represented coverage across all planform types and by planform groups (Figure 149, Figure 150, Figure 151). Furthermore, over all planform types, the predominance of Habitat function studies occurred within steppe precipitation areas while Sediment function studies predominantly occurred within desert precipitation areas.

In a similar fashion to the above sections, in terms of regarding individual contributions of precipitation and temperature, the individual contribution of streamflow regimes absent any other hydrology and climate components was examined in concert with the function categories

and stream planform types (Figure 152). The overall pattern of a predominance of ephemeral stream coverage over intermittent streams (Figure 32) generally carried through all planform types for global Biogeochemical, Hydrology, and Sediment studies (Figure 153) (Table 30). Nonetheless, except for headwater and compound planforms, there was a noted alteration from that general pattern for Habitat studies, where there continued to be a predominance of ephemeral over intermittent stream studies for most stream planform types (Figure 154, Figure 155, Figure 156). Similar to precipitation types, as overall hydrology is a critical factor in arid water-limited stream systems influencing the spectrum of primary function categories, it would be beneficial for future studies across all planform types and function categories to provide an increased focus on arid intermittent stream studies. In terms of the opposite perspective, focusing on the percent contribution of primary function categories within a specific planform and streamflow type, there was global coverage of all function categories across both streamflow regimes only for the single thread planform. On the other end of the spectrum, compound, discontinuous, and straight planforms had the least coverage of all functions (including absence of Biogeochemical functions) across both streamflow types (Figure 157). Following overall planform study trends (Figure 105), Sediment and Habitat functions studies were most represented coverage across all planform types and by planform groups (Figure 158, Figure 159, Figure 160). Furthermore, over all planform types, the predominance of Habitat function studies occurred within intermittent streams while Sediment function studies predominantly occurred within ephemeral streams.

The last, and arguably most overall influential ecosystem control for arid stream systems addressed herein are the combined overall hydrology components, precipitation and streamflow

regime, in concert with stream planform types among the primary function categories (Figure 161). The general overarching patterns of a predominance of ephemeral stream studies and steppe precipitation studies carried through most global studies, summed across all planform types and primary function categories (Figure 162, Figure 163) (Table 31). However, when regarding the data by individual function category and by individual planform type, occurrences within desert precipitation areas had a predominance across Sediment function studies and across most planform types (anastomosing, braided, compound, discontinuous, distributary, and meandering planforms). Similarly, for Biogeochemical function studies there was a slight predominance of intermittent stream coverage within steppe precipitation areas, as well as a slight predominance of intermittent stream coverage within anastomosing steppe studies and overall for compound studies (Figure 164, Figure 165, Figure 166). Lastly, in terms of the opposite perspective, focusing on the percent contribution of all primary function categories within a specific stream planform, precipitation, and streamflow type, there was coverage only complete coverage of all function categories across both streamflow regime types for single thread planform studies within steppe precipitation areas. On the other end of the spectrum, compound and straight planforms had the least coverage of all functions (including absence of Biogeochemical functions) across both streamflow and precipitation types (Figure 167). Following overall planform study trends (Figure 105), Sediment and Habitat functions studies were most represented coverage across all planform types and by planform groups (Figure 168, Figure 169, Figure 170). Furthermore, over all planform types, the predominance of Habitat function studies occurred within intermittent streams across both steppe and desert precipitation types, while Sediment function studies predominantly occurred within ephemeral streams of both

precipitation types. Overall, the lack of even coverage across the primary function categories, including differences in coverage among planform types, streamflow and precipitation types, could be benefitted by future studies concentrating more in these key areas.

Tables

Table 23. Primary function categories of arid non-perennial literature by streamflow regime and stream planform type without subclimates worldwide, including the U.S.

Streamflow Type	Stream Planform Type	Biogeochemical		Habitat		Hydrology		Sediment		TOTAL WW	TOTAL U.S.	TOTAL (U.S.%)	% Planform Type/All Planform & Streamflow Types (WW)	% Planform Type/All Planform & Streamflow Types (U.S.)
		WW	U.S.	WW	U.S.	WW	U.S.	WW	U.S.					
Non-perennial	alluvial fan	0	0	0	0	0	0	0	0	0	0	NA	8%	12%
	anabranching	0	0	0	0	0	0	1	0	1	0	0%	6%	1%
	anastomosing	0	0	2	0	3	0	1	0	6	0	0%	5%	1%
	braided	0	0	1	0	0	0	0	0	1	0	0%	21%	19%
	compound	0	0	0	0	0	0	0	0	0	0	NA	0%	0%
	discontinuous	0	0	0	0	0	0	0	0	0	0	NA	2%	1%
	distributary	0	0	2	0	1	0	0	0	3	0	0%	5%	1%
	meandering	0	0	2	0	0	0	0	0	2	0	0%	2%	1%
	single	1	0	1	1	0	0	2	0	4	1	25%	28%	34%
	single thread	0	0	0	0	1	1	0	0	1	1	100%	6%	7%
	straight	0	0	0	0	0	0	0	0	0	0	NA	0%	0%
	delta	0	0	1	0	0	0	0	0	1	0	0%	0%	0%
	prairie	0	0	0	0	0	0	0	0	0	0	NA	0%	1%
	headwater	2	0	2	0	0	0	0	0	4	0	0%	16%	18%
Streamflow Type Subtotals		**3**	**0**	**11**	**1**	**5**	**1**	**4**	**0**	**23**	**2**	**9%**		
Ephemeral	alluvial fan	0	0	6	4	6	1	3	1	15	6	40%		
	anabranching	0	0	4	1	0	0	5	0	9	1	11%		
	anastomosing	0	0	2	1	0	0	1	0	3	1	33%		
	braided	3	1	8	0	10	1	15	4	36	6	17%		
	compound	0	0	0	0	0	0	0	0	0	0	NA		
	discontinuous	0	0	0	0	1	0	4	1	5	1	20%		
	distributary	1	1	1	0	0	0	4	0	6	1	17%		
	meandering	0	0	1	1	1	0	1	0	3	1	33%		
	single	4	4	12	5	7	1	23	7	46	17	37%		
	single thread	0	0	1	0	2	1	6	1	9	2	22%		
	straight	0	0	0	0	0	0	1	0	1	0	0%		
	delta	0	0	0	0	0	0	0	0	0	0	NA		
	prairie	0	0	1	1	0	0	0	0	1	1	100%		
	headwater	4	3	4	1	10	1	5	2	23	7	30%		
Streamflow Type Subtotals		**12**	**9**	**40**	**14**	**37**	**5**	**68**	**16**	**157**	**44**	**28%**		
Intermittent	alluvial fan	0	0	2	2	0	0	0	0	2	2	100%		
	anabranching	2	0	0	0	1	0	0	0	3	0	0%		
	anastomosing	0	0	1	0	1	0	0	0	2	0	0%		
	braided	0	0	6	6	2	1	1	0	9	7	78%		
	compound	0	0	1	0	0	0	0	0	1	0	0%		
	discontinuous	0	0	0	0	0	0	0	0	0	0	NA		
	distributary	0	0	1	0	0	0	0	0	1	0	0%		
	meandering	0	0	0	0	0	0	0	0	0	0	NA		
	single	3	1	5	3	2	1	0	0	10	5	50%		
	single thread	0	0	1	1	0	0	1	1	2	2	100%		
	straight	0	0	0	0	0	0	0	0	0	0	NA		
	delta	0	0	0	0	0	0	0	0	0	0	NA		
	prairie	0	0	0	0	0	0	0	0	0	0	NA		
	headwater	1	1	5	3	1	1	0	0	7	5	71%		
Streamflow Type Subtotals		**6**	**2**	**22**	**15**	**7**	**3**	**2**	**1**	**37**	**21**	**57%**		
Totals		**21**	**11**	**73**	**30**	**49**	**9**	**74**	**17**	**217**	**67**	**31%**		

Table 24. Overall occurrence trends of the primary function categories among planform types within global and U.S. arid non-perennial stream literature. The relative representation between the function categories is noted as slight (>), moderate (>>), or significant (>>>). Data layer trends that mirror overall study trends are denoted as "*".

Global							
Overall	**Habitat**	**>>**	**Biogeochemical**	**>**	**Sediment**	**>**	**Hydrology**
Planform type	**Sediment**	**>**	**Habitat**	**>**	**Hydrology**	**>**	**Biogeochemical**
Single thread	Sediment	>	Habitat	>	Hydrology	>>	Biogeochemical
Braided	Sediment	>	Habitat	>	Hydrology	>>>	Biogeochemical
Headwater	Hydrology	>	Habitat	>>	Sediment	=	Biogeochemical
Alluvial fan	Habitat	>	Hydrology	>>	Sediment		NA
Anastomosing	Habitat	>	Sediment	>>>	Hydrology	=	Biogeochemical
Discontinuous *	Sediment	>>>	Hydrology		NA		NA
Distributary *	Sediment	>>	Habitat	>>	Biogeochemical		NA
Meandering *	Sediment	=	Habitat	=	Hydrology		NA
Compound **	Habitat		NA		NA		NA
Straight **	Sediment		NA		NA		NA

U.S.							
Overall	**Habitat**	**>>**	**Biogeochemical**	**>>**	**Sediment**	**>**	**Hydrology**
Planform type	**Habitat**	**>>**	**Sediment**	**>**	**Biogeochemical**	**>**	**Hydrology**
Single thread	Habitat	=	Sediment	>>	Biogeochemical	>	Hydrology
Braided	Habitat	>	Sediment	>>	Hydrology	>>	Biogeochemical
Headwater	Habitat	=	Biogeochemical	>>	Sediment	=	Hydrology
Anastomosing *	Habitat		NA		NA		NA
Alluvial fan *	Habitat	>>>	Sediment	=	Hydrology		NA
Distributary	Biogeochemical		NA		NA		NA
Discontinuous	Sediment		NA		NA		NA
Meandering	Habitat		NA		NA		NA
Straight *	NA		NA		NA		NA
Compound *	NA		NA		NA		NA

Table 25. Overall occurrence trends of the primary function categories among planform types, Koppen-Geiger subclimes, and streamflow regimes within global arid non-perennial stream literature. The relative representation between the function categories is noted as slight (>), moderate (>>), or significant (>>>). Data layer trends that mirror overall study trends are denoted as "*".

Global								
Overall		**Cold Steppe**	**>**	**Hot Desert**	**>**	**Hot Steppe**	**>>**	**Cold Desert**
By Function	Biogeochemical	*	>	*	>	*	>>	*
	Habitat	*	>>	*	>	*	>>	*
	Hydrology	**Hot Desert**	>	**Hot Steppe**	>	**Cold Steppe**	>>	**Cold Desert**
	Sediment	*	>	*	>	*	>>>	*
By Ephemeral flow	Biogeochemical	**Hot Desert**	>	**Cold Steppe**	>	**Hot Steppe**	>	**Cold Desert**
	Habitat	**Hot Desert**	>	**Cold Steppe**	>	**Hot Steppe**	>>>	**Cold Desert**
	Hydrology	**Hot Desert**	>	**Hot Steppe**	>	**Cold Steppe**	>>	**Cold Desert**
	Sediment	**Hot Desert**	>	**Cold Steppe**	>>	**Hot Steppe**	>>>	**Cold Desert**
By Intermittent flow	Biogeochemical	**Cold Steppe**	>	**Hot Steppe**	>	**Hot Desert**	>>>	**Cold Desert**
	Habitat	**Cold Steppe**	>>	**Hot Steppe**	>>	**Hot Desert**	>>	**Cold Desert**
	Hydrology	**Hot Desert**	>>	**Hot Steppe**	>>>	**Cold Steppe**		NA
	Sediment	*	>	*		NA		NA
Planform type		**Hot Desert**	**>**	**Cold Steppe**	**>**	**Hot Steppe**	**>>**	**Cold Desert**
By Function	Biogeochemical	**Hot Desert**	=	**Hot Steppe**	>>>	**Cold Steppe**	=	**Cold Desert**
	Habitat	*	>	*	>>	*	>>	*
	Hydrology	**Hot Desert**	>	**Hot Steppe**	>	**Cold Steppe**	>>	**Cold Desert**
	Sediment	**Hot Desert**	>>	**Cold Steppe**	>>	**Hot Steppe**	>>>	**Cold Desert**
By Ephemeral flow	Biogeochemical	**Hot Desert**	>>	**Hot Steppe**	>	**Cold Desert**	>>	**Hot Steppe**
	Habitat	**Hot Desert**	>	**Cold Steppe**	>>	**Hot Steppe**	>>	**Cold Desert**
	Hydrology	**Hot Desert**	>	**Cold Steppe**	>	**Hot Steppe**	>>	**Cold Desert**
	Sediment	**Hot Desert**	>>	**Cold Steppe**	>>	**Hot Steppe**	>>>	**Cold Desert**
By Intermittent flow	Biogeochemical	**Hot Steppe**	>>>	**Cold Steppe**	=	**Hot Desert**		NA
	Habitat	**Cold Steppe**	>>>	**Hot Steppe**	>	**Hot Desert**	>>	**Cold Desert**
	Hydrology	**Hot Steppe**	>	**Hot Desert**		NA		NA
	Sediment	*	=	*		NA		NA

Table 26. Overall occurrence trends of the primary function categories among planform types, hot and cold temperatures, and streamflow regimes within global arid non-perennial stream literature. The relative representation between the function categories is noted as slight (>), moderate (>>), or significant (>>>). Data layer trends that mirror overall study trends are denoted as "*".

Global				
Overall		**Hot arid**	**>**	**Cold arid**
By Function	Biogeochemical	*	>	*
	Habitat	*	>	*
	Hydrology	*	>>	*
	Sediment	*	>	*
By Ephemeral flow	Biogeochemical	*	>	*
	Habitat	*	>>	*
	Hydrology	*	>>	*
	Sediment	*	>>	*
By Intermittent flow	Biogeochemical	*	>	*
	Habitat	Cold arid	>	Hot arid
	Hydrology	*	>>>	*
	Sediment	Cold arid	>>	Hot arid
Planform type		*	>>	*
By Function	Biogeochemical	*	>>>	*
	Habitat	Cold arid	>	Hot arid
	Hydrology	*	>>	*
	Sediment	*	>>	*
By Ephemeral flow	Biogeochemical	*	>>>	*
	Habitat	*	>	*
	Hydrology	*	>	*
	Sediment	*	>>	*
By Intermittent flow	Biogeochemical	*	>>>	*
	Habitat	Cold arid	>>	Hot arid
	Hydrology	*		NA
	Sediment	Cold arid	=	Hot arid

Table 27. Overall occurrence trends of the primary function categories among planform types and Koppen-Geiger subclimes within global arid non-perennial stream literature. The relative representation between the function categories is noted as slight (>), moderate (>>), or significant (>>>). Data layer trends that mirror overall study trends are denoted as "*".

Global							
Overall	**Cold Steppe**	**>**	**Hot Desert**	**>**	**Hot Steppe**	**>>**	**Cold Desert**
Biogeochemical	*	>	*	>	*	>>	*
Habitat	*	>>	*	>	*	>>	*
Hydrology	Hot Desert	>	Hot Steppe	>	Cold Steppe	>>	Cold Desert
Sediment	*	>	*	>	*	>>>	*
Planform type	**Hot Desert**	**>**	**Cold Steppe**	**>**	**Hot Steppe**	**>>**	**Cold Desert**
Biogeochemical	Hot Desert	=	Hot Steppe	>>>	Cold Steppe	=	Cold Desert
Habitat	*	>	*	>>	*	>>	*
Hydrology	Hot Desert	>	Hot Steppe	>	Cold Steppe	>>	Cold Desert
Sediment	Hot Desert	>>	Cold Steppe	>>	Hot Steppe	>>>	Cold Desert

Table 28. Overall occurrence trends of the primary function categories among planform types and hot and cold temperatures within global arid non-perennial stream literature. The relative representation between the function categories is noted as slight (>), moderate (>>), or significant (>>>). Data layer trends that mirror overall study trends are denoted as "*".

Global			
Overall	**Hot arid**	**>**	**Cold arid**
Biogeochemical	*	>	*
Habitat	*	>	*
Hydrology	*	>>	*
Sediment	*	>	*
Planform type	*	>>	*
Biogeochemical	*	>>>	*
Habitat	Cold arid	>	Hot arid
Hydrology	*	>>	*
Sediment	*	>>	*

Table 29. Overall occurrence trends of the primary function categories among planform types and arid precipitation types within global arid non-perennial stream literature. The relative representation between the function categories is noted as slight (>), moderate (>>), or significant (>>>). Data layer trends that mirror overall study trends are denoted as "*".

Global			
Overall	**Steppe**	**>**	**Desert**
Biogeochemical	*	>	*
Habitat	*	>>	*
Hydrology	*	>	*
Sediment	*	>	*
Planform type	*	>>>	*
Biogeochemical	*	=	*
Habitat	*	>	*
Hydrology	*	=	*
Sediment	Desert	>	Steppe

Table 30. Overall occurrence trends of the primary function categories among planform types and streamflow regimes within global arid non-perennial stream literature. The relative representation between the function categories is noted as slight (>), moderate (>>), or significant (>>>). Data layer trends that mirror overall study trends are denoted as "*".

Global			
Overall	**Ephemeral**	**>>**	**Intermittent**
Biogeochemical	*	>>	*
Habitat	Intermittent	>	Ephemeral
Hydrology	*	>>>	*
Sediment	*	>>>	*
Planform type	*	>>>	*
Biogeochemical	*	>>	*
Habitat	*	>>	*
Hydrology	*	>>>	*
Sediment	*	>>>	*

Table 31. Overall occurrence trends of the primary function categories among planform types, arid precipitation types, and streamflow regimes within global arid non-perennial stream literature. The relative representation between the function categories is noted as slight (>), moderate (>>), or significant (>>>). Data layer trends that mirror overall study trends are denoted as "*".

Global				
Overall		**Steppe**	**>**	**Desert**
By Function	Biogeochemical	*	>	*
	Habitat	*	>>	*
	Hydrology	*	>	*
	Sediment	*	>	*
By Ephemeral flow	Biogeochemical	*	>	*
	Habitat	*	>	*
	Hydrology	*	>	*
	Sediment	*	>	*
By Intermittent flow	Biogeochemical	*	>>	*
	Habitat	*	>>>	*
	Hydrology	**Desert**	>	**Steppe**
	Sediment	*	>	*
Planform type		*	>>>	*
By Function	Biogeochemical	*	=	*
	Habitat	*	>	*
	Hydrology	*	=	*
	Sediment	**Desert**	>	**Steppe**
By Ephemeral flow	Biogeochemical	**Desert**	>>	**Steppe**
	Habitat	**Desert**	>	**Steppe**
	Hydrology	**Desert**	>	**Steppe**
	Sediment	**Desert**	>	**Steppe**
By Intermittent flow	Biogeochemical	*	>>>	*
	Habitat	*	>>>	*
	Hydrology	*	>	*
	Sediment	*	=	*

Figures

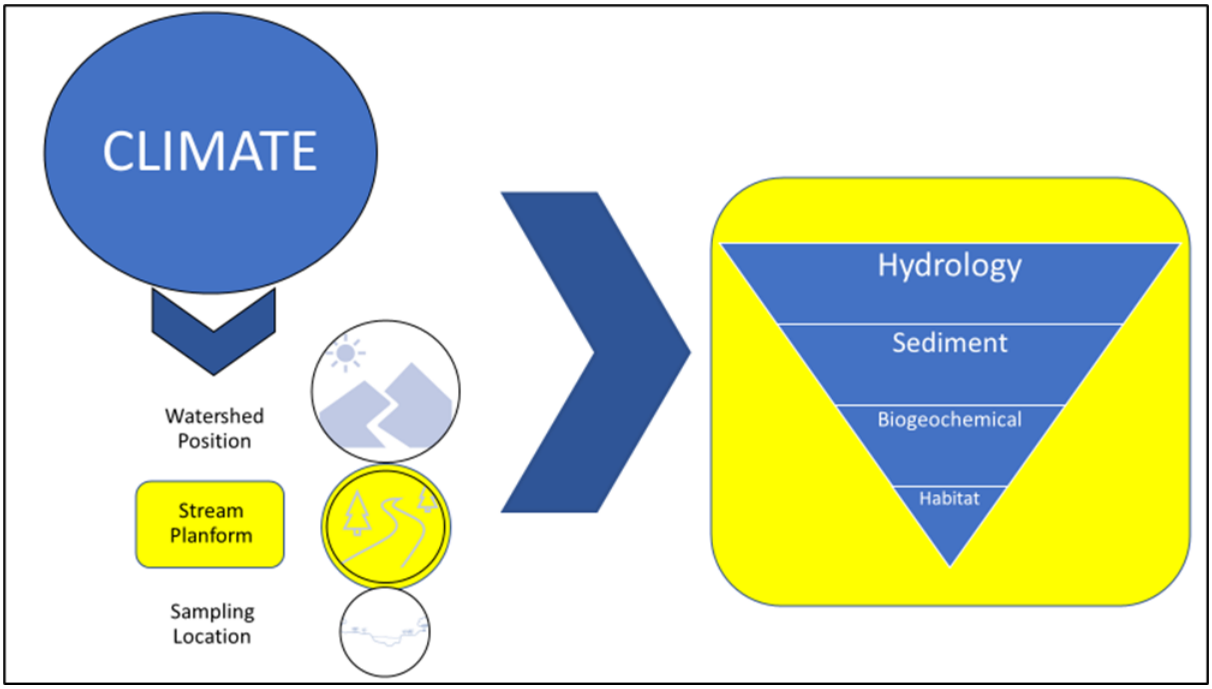


Figure 103. The conceptual relation of stream planform type (environmental parameter) to the hierarchy of broad stream function categories.

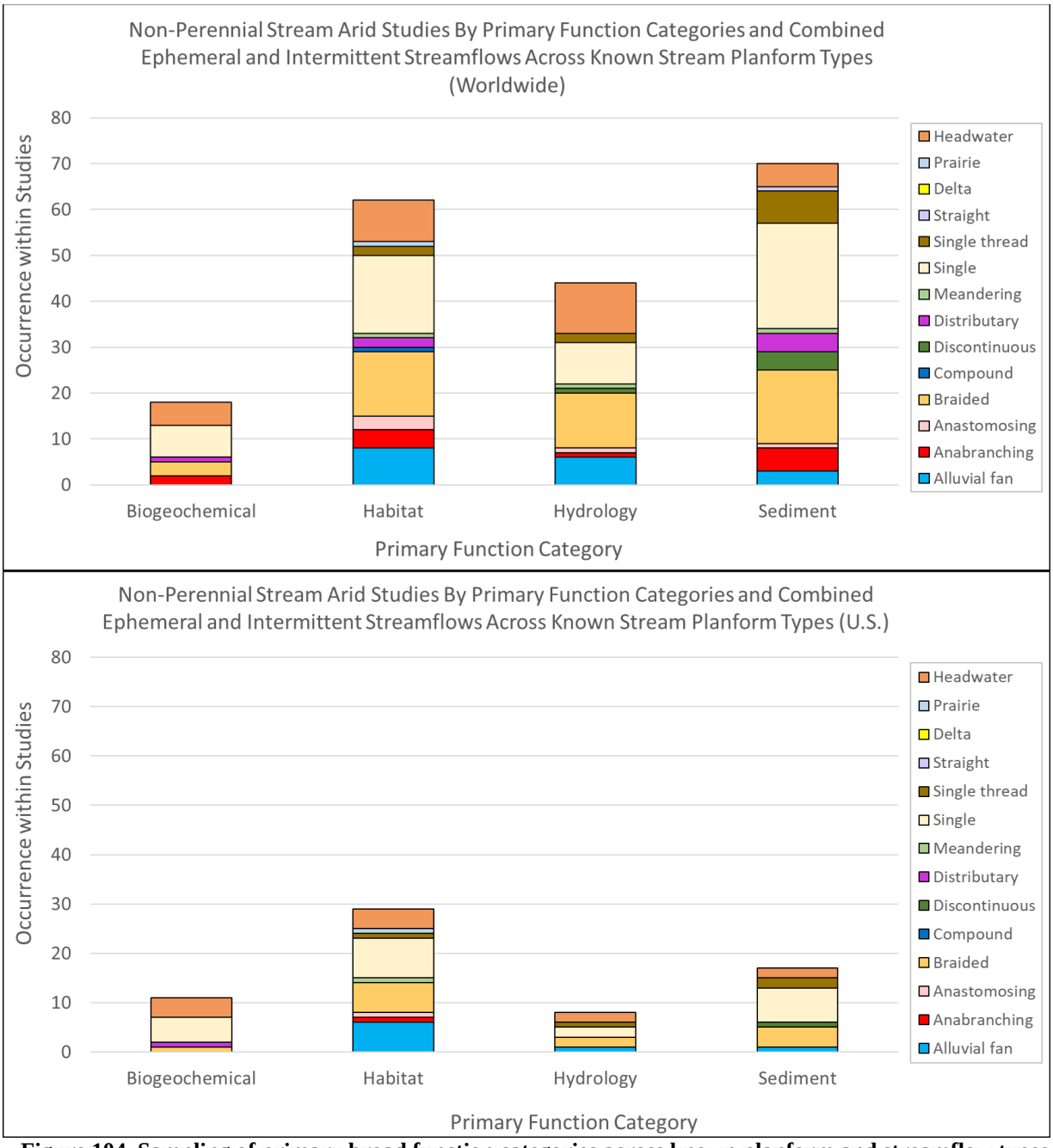


Figure 104. Sampling of primary broad function categories across known planform and streamflow types, within global and U.S. arid non-perennial stream literature.

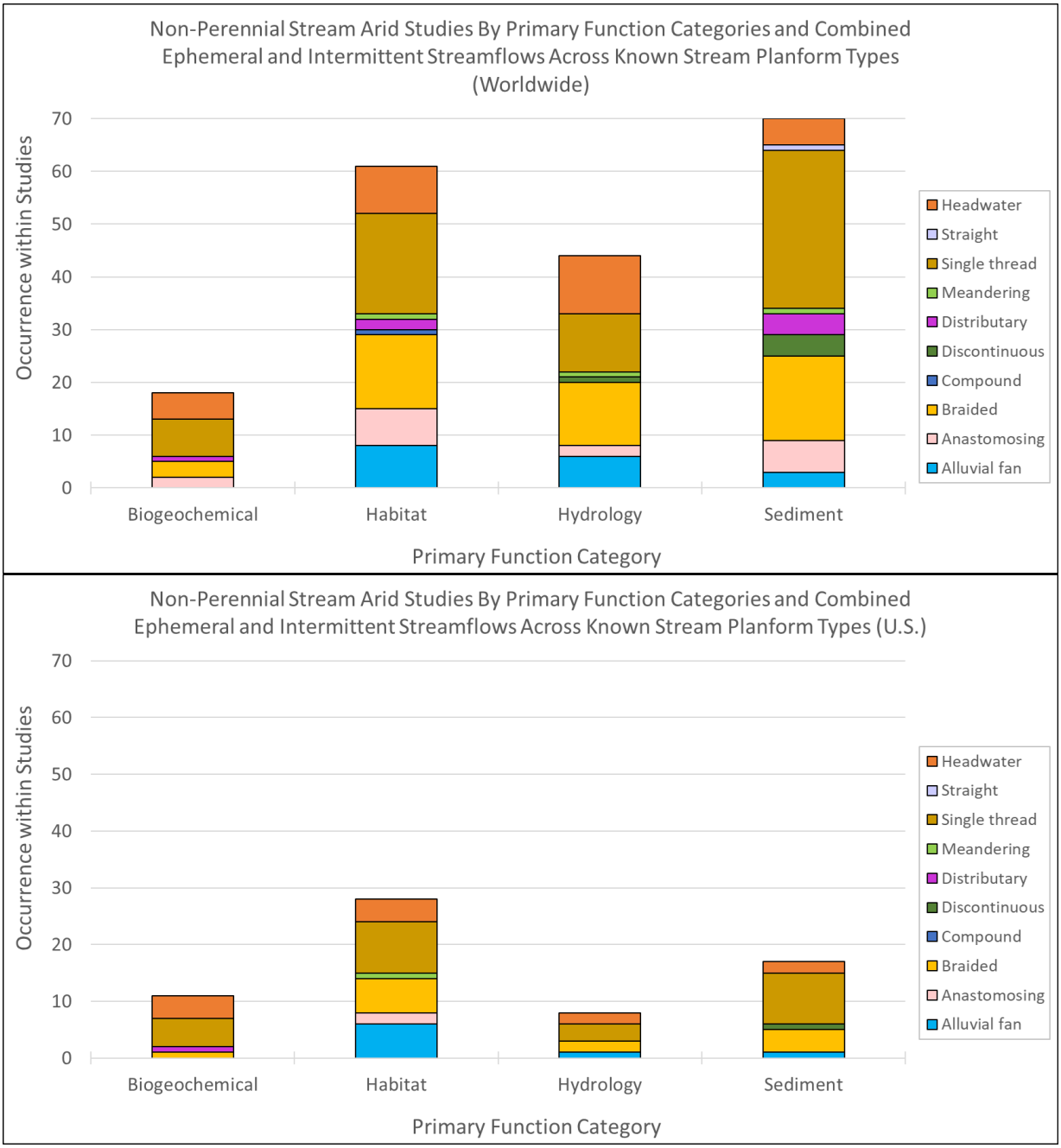


Figure 105. Sampling of primary broad function categories across condensed planform types and known streamflow types, within global and U.S. arid non-perennial stream literature.

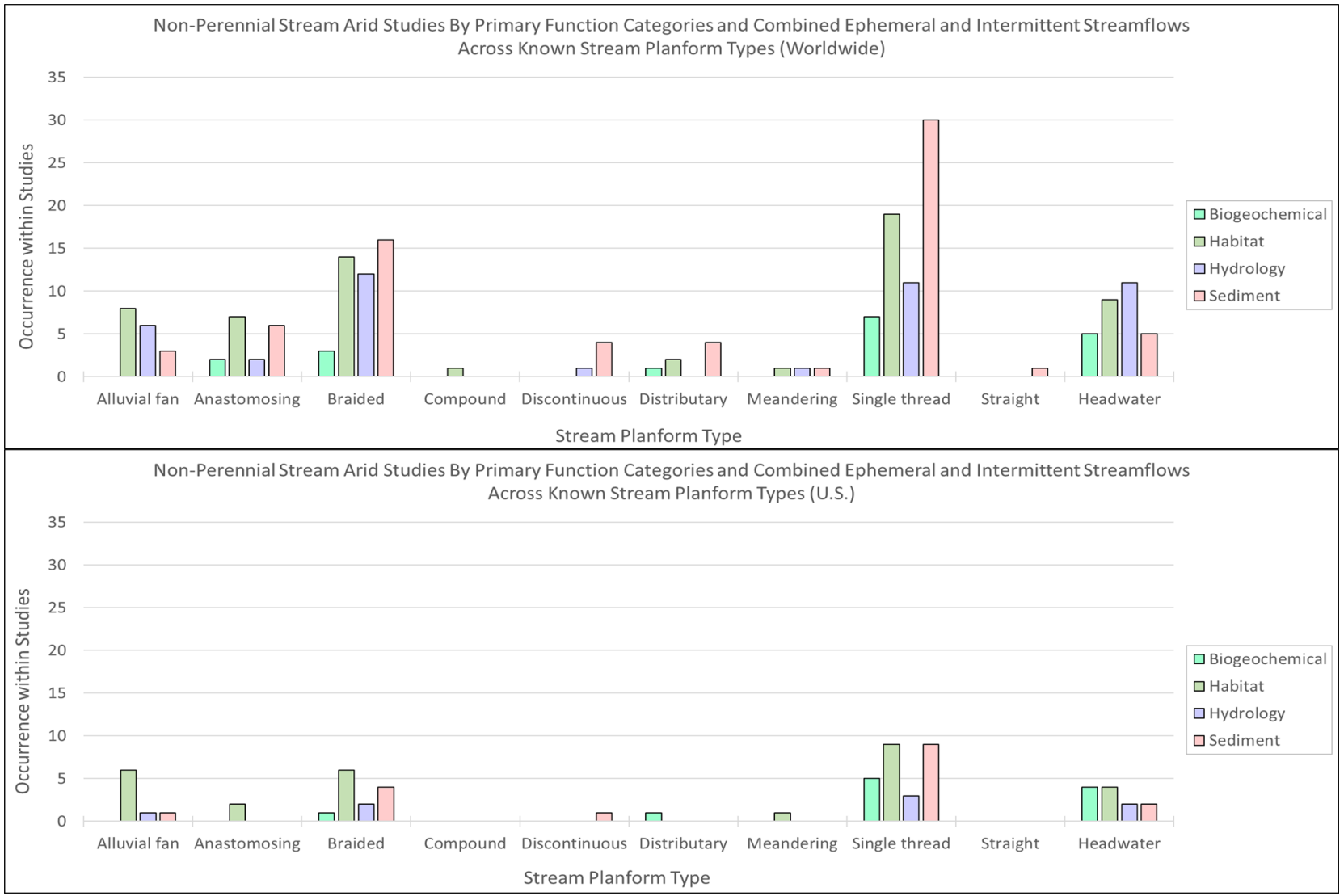


Figure 106. Sampling of condensed planform types across primary broad function categories and known streamflow types, within global and U.S. arid non-perennial stream literature.

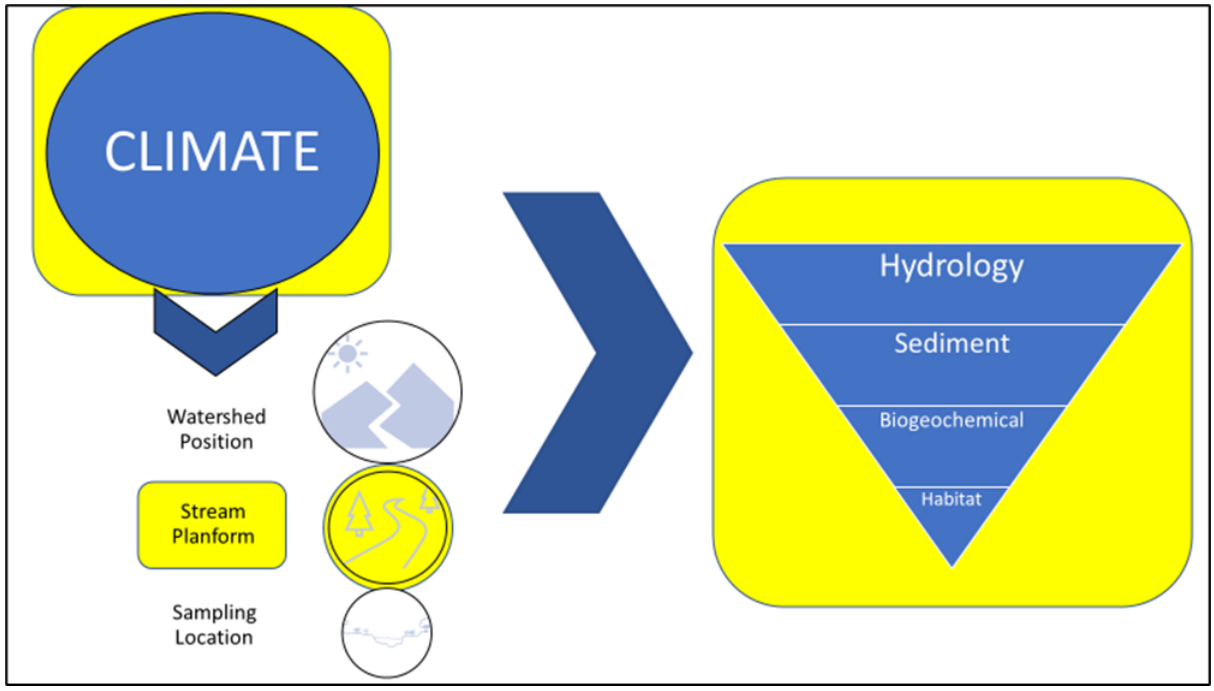


Figure 107. The conceptual relations of climate and stream planform type (environmental parameter) to the hierarchy of broad stream function categories.

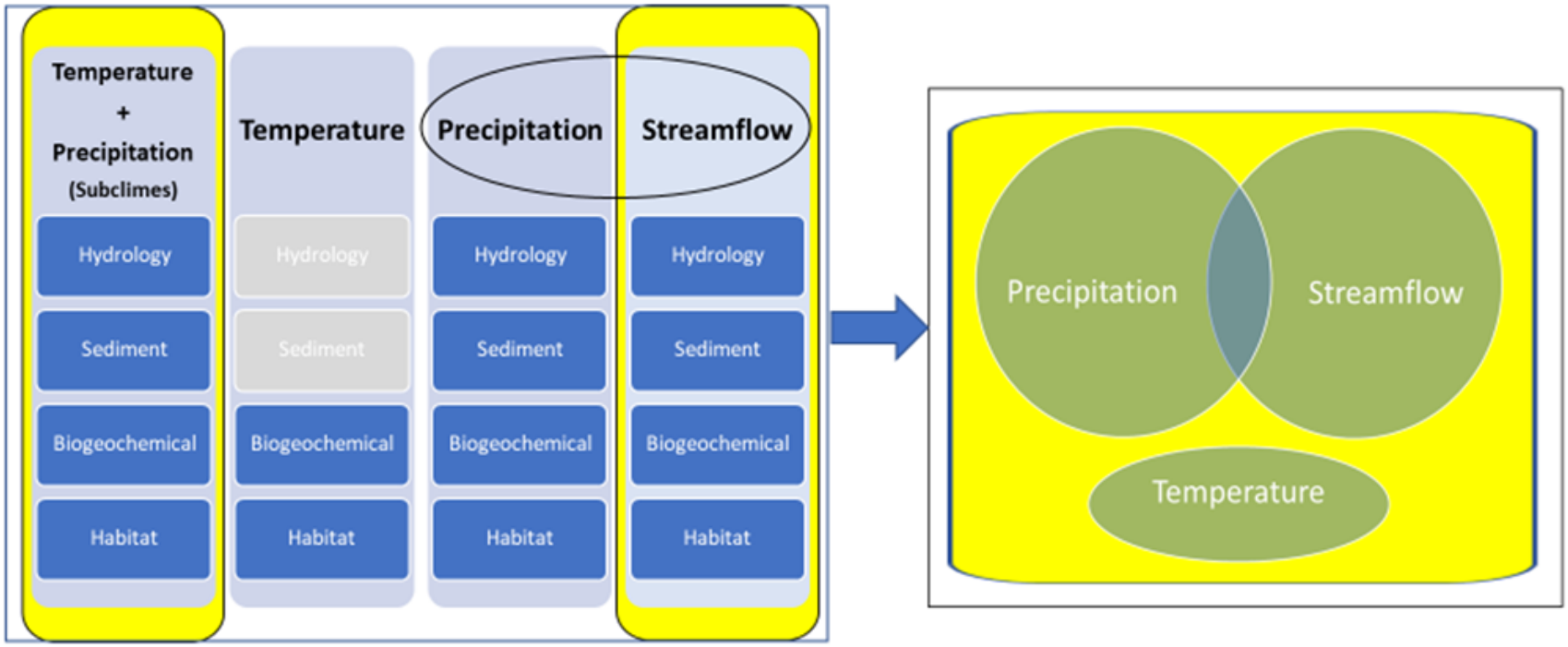


Figure 108. The conceptual relations and hierarchies of subclimes (combined temperature and precipitation types) and hydrology (inherent precipitation and streamflow types) factors and their influence on broad stream function categories.



Figure 109. Sampling of Biogeochemical and Habitat function categories across combined planform and streamflow types by subclimes, within global arid non-perennial stream literature.

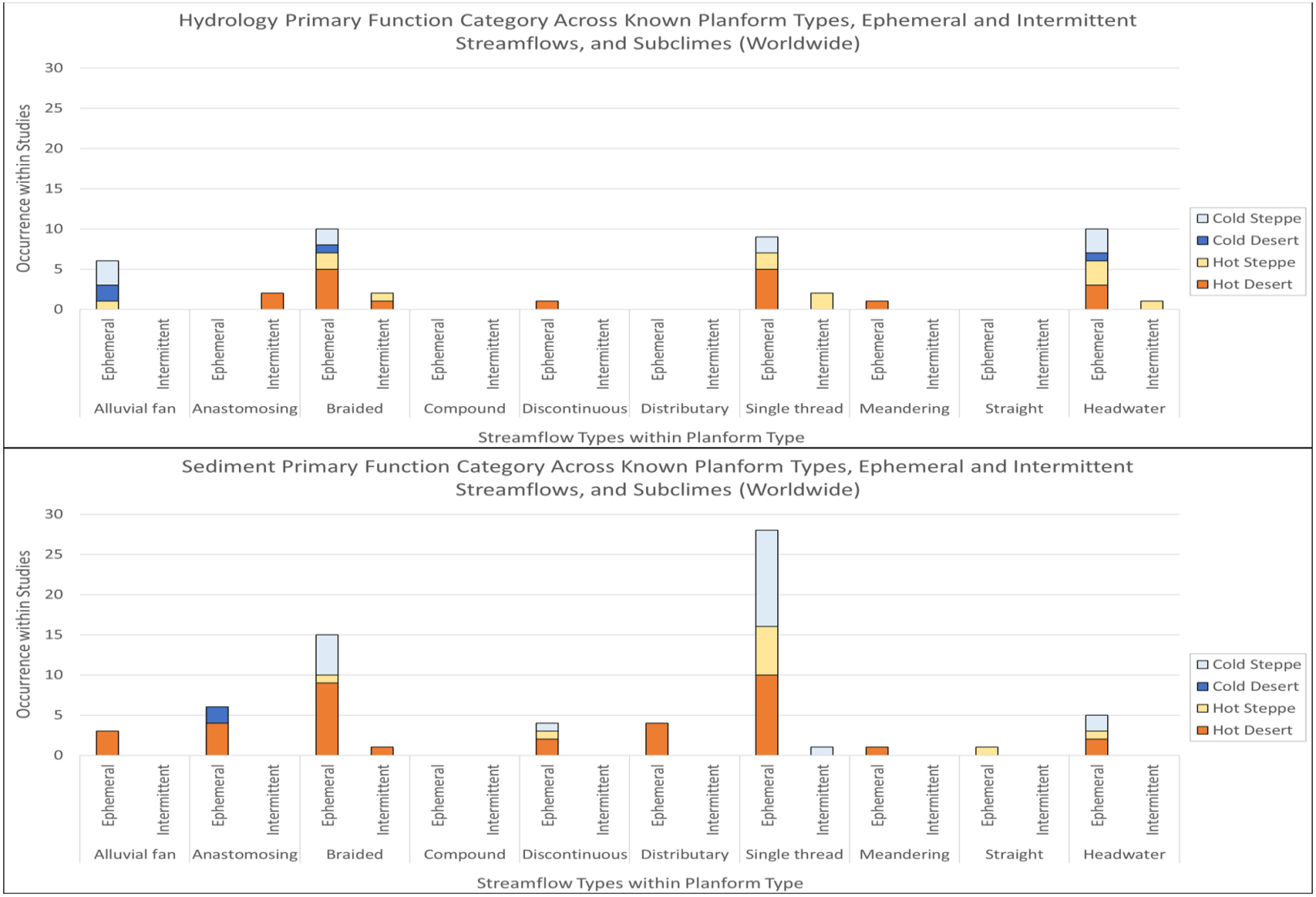


Figure 110. Sampling of Hydrology and Sediment function categories across combined planform and streamflow types by subclimes, within global arid non-perennial stream literature.

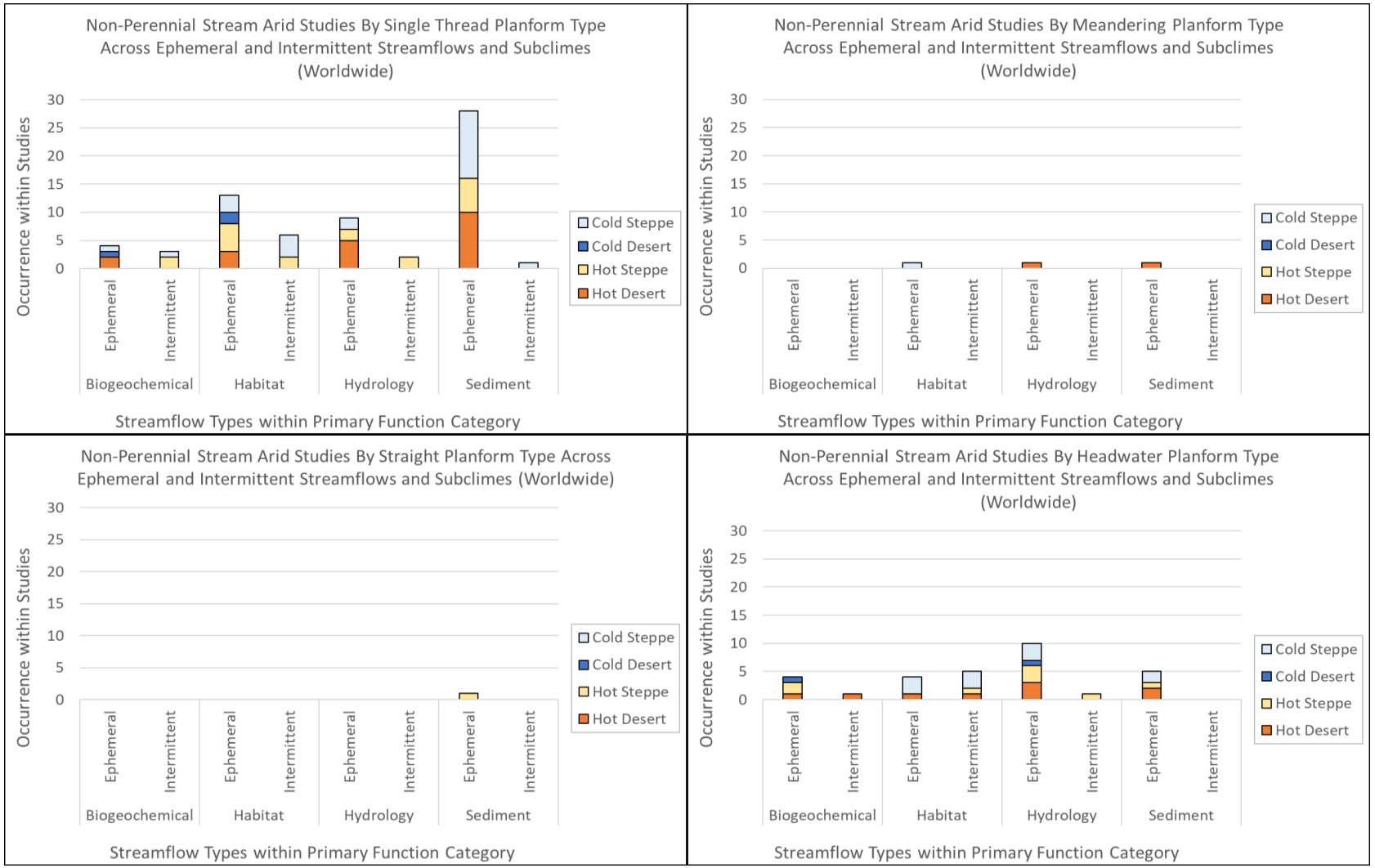


Figure 111. Sampling of each Group 1 stream planform type across primary broad function categories and subclimes, by ephemeral and intermittent streamflow, within global arid non-perennial stream literature.

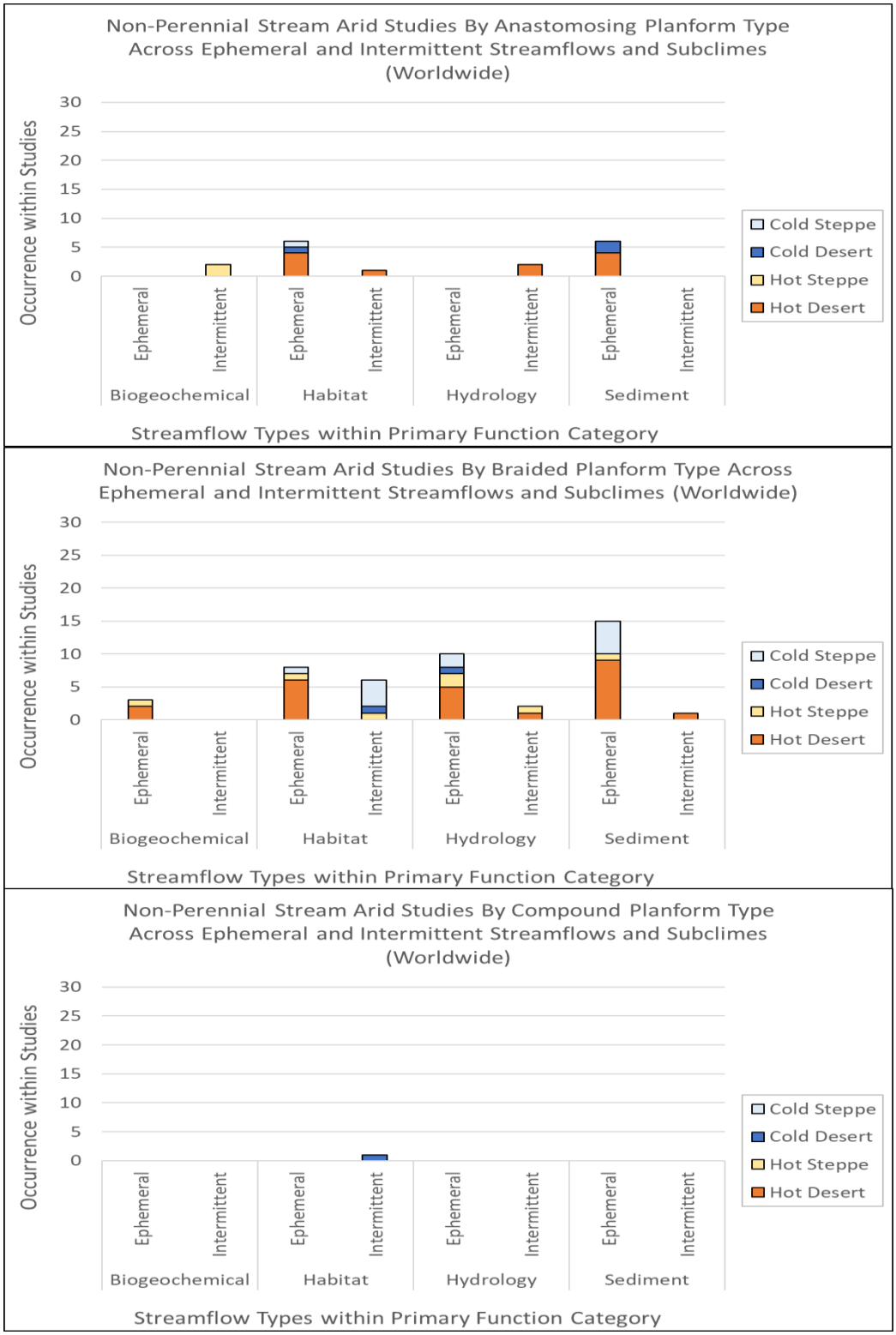


Figure 112. Sampling of each Group 2 stream planform type across primary broad function categories and subclimes, by ephemeral and intermittent streamflow, within global arid non-perennial stream literature.

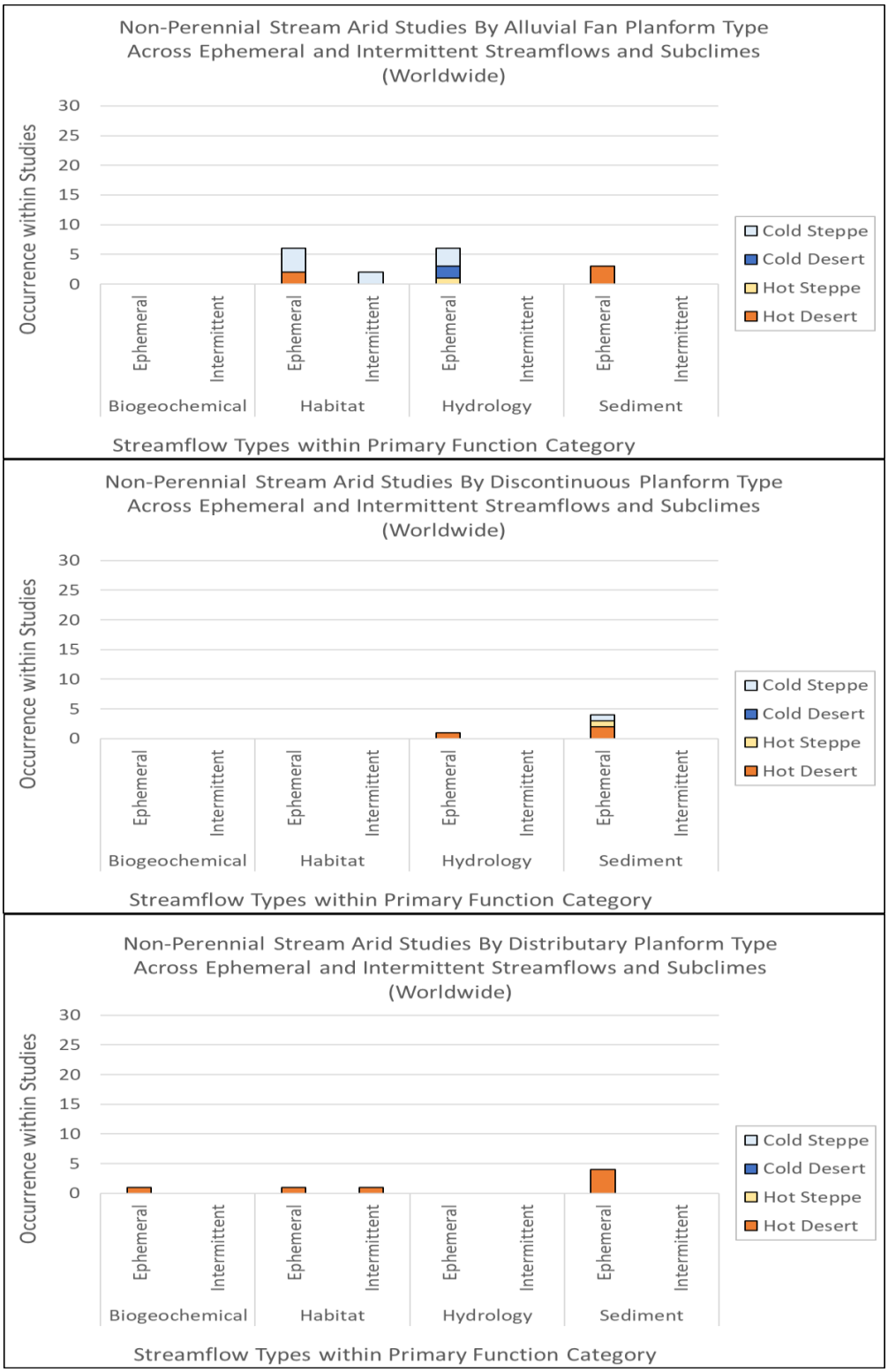


Figure 113. Sampling of each Group 3 stream planform type across primary broad function categories and subclimes, by ephemeral and intermittent streamflow, within global arid non-perennial stream literature.

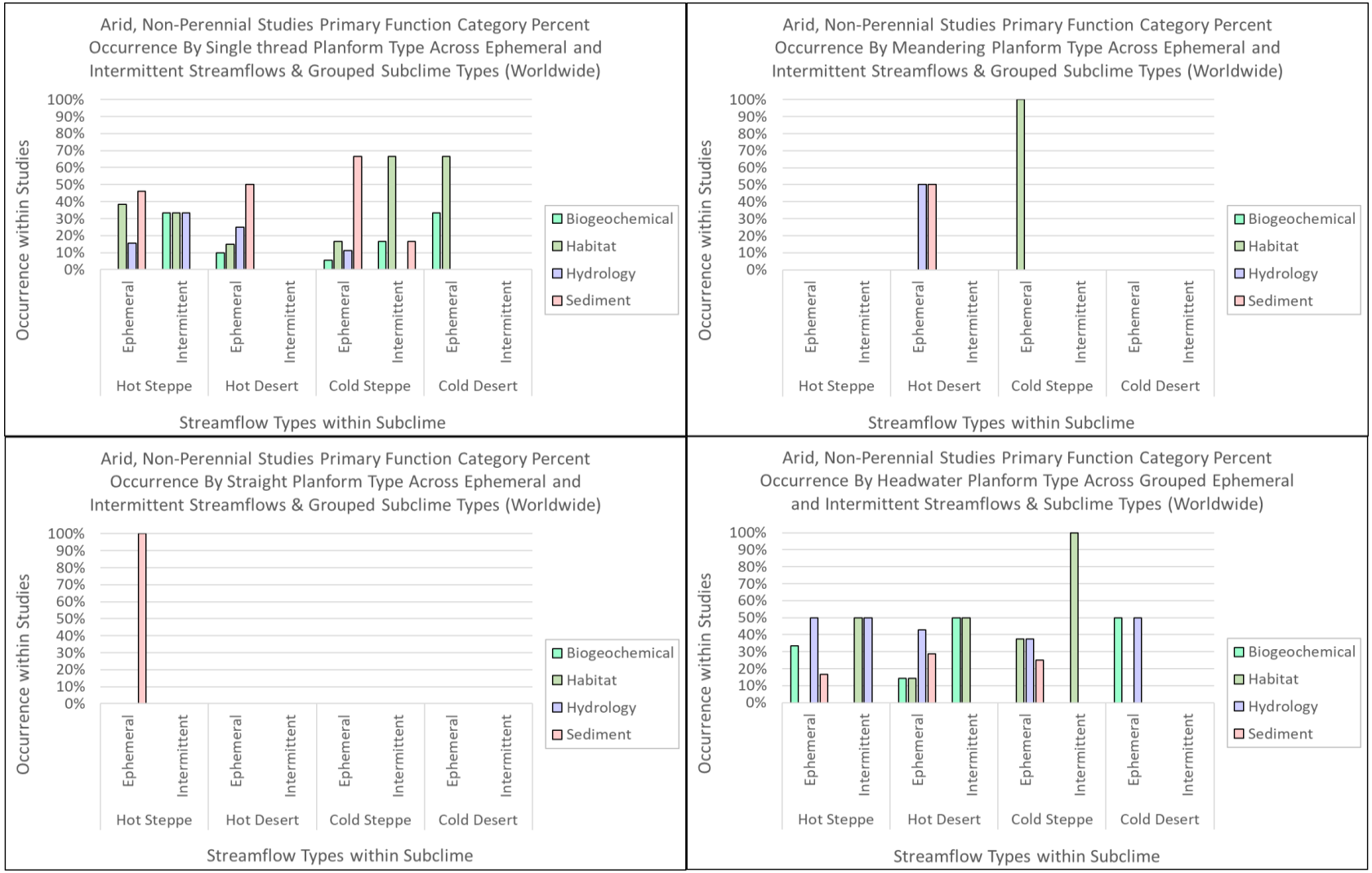


Figure 114. Sampling of each Group 1 condensed planform type across primary broad function categories by subclimes and known ephemeral and intermittent streamflow types, within global arid non-perennial stream literature.

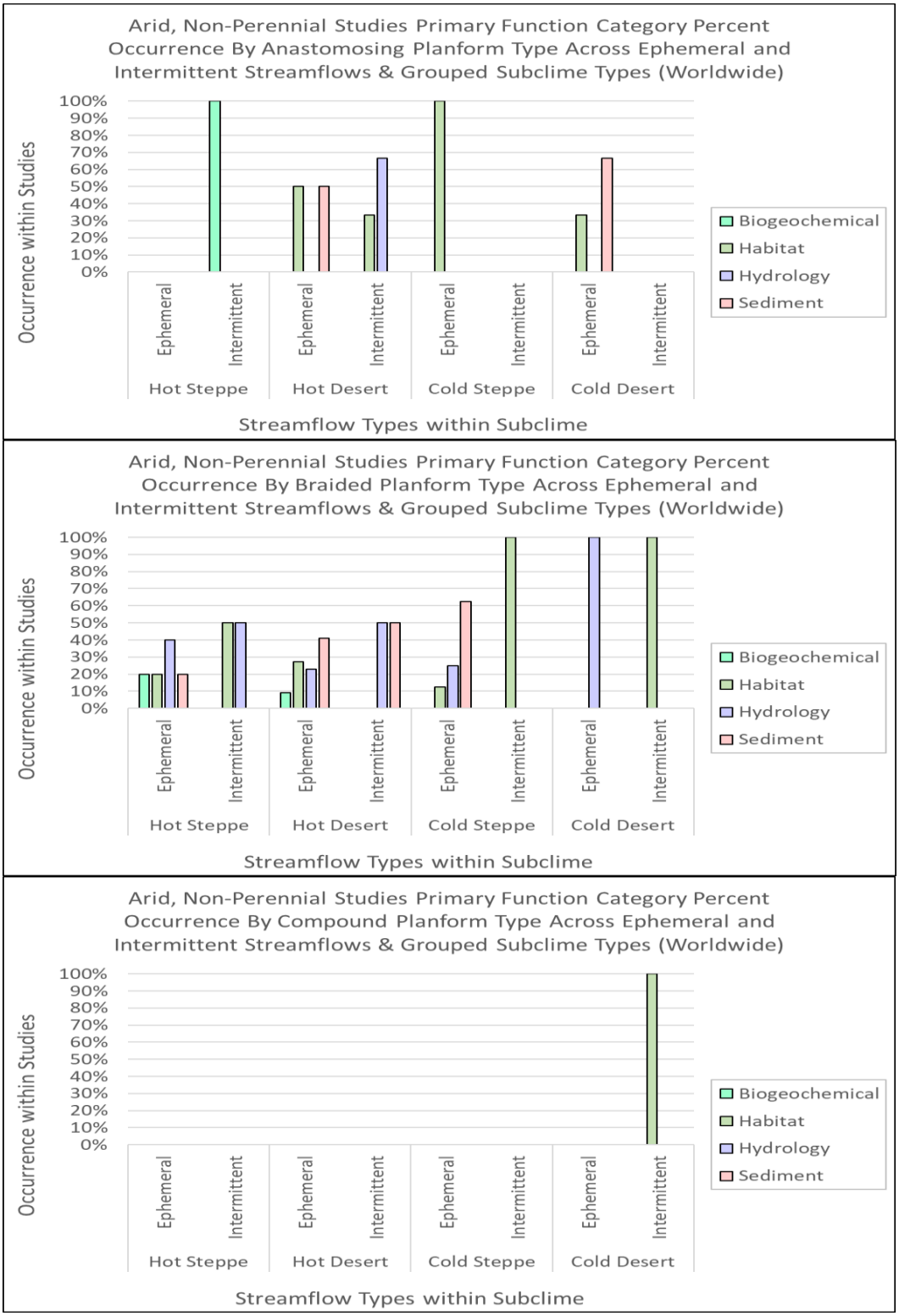


Figure 115. Sampling of each Group 2 condensed planform type across primary broad function categories by subclimes and known ephemeral and intermittent streamflow types, within global arid non-perennial stream literature.

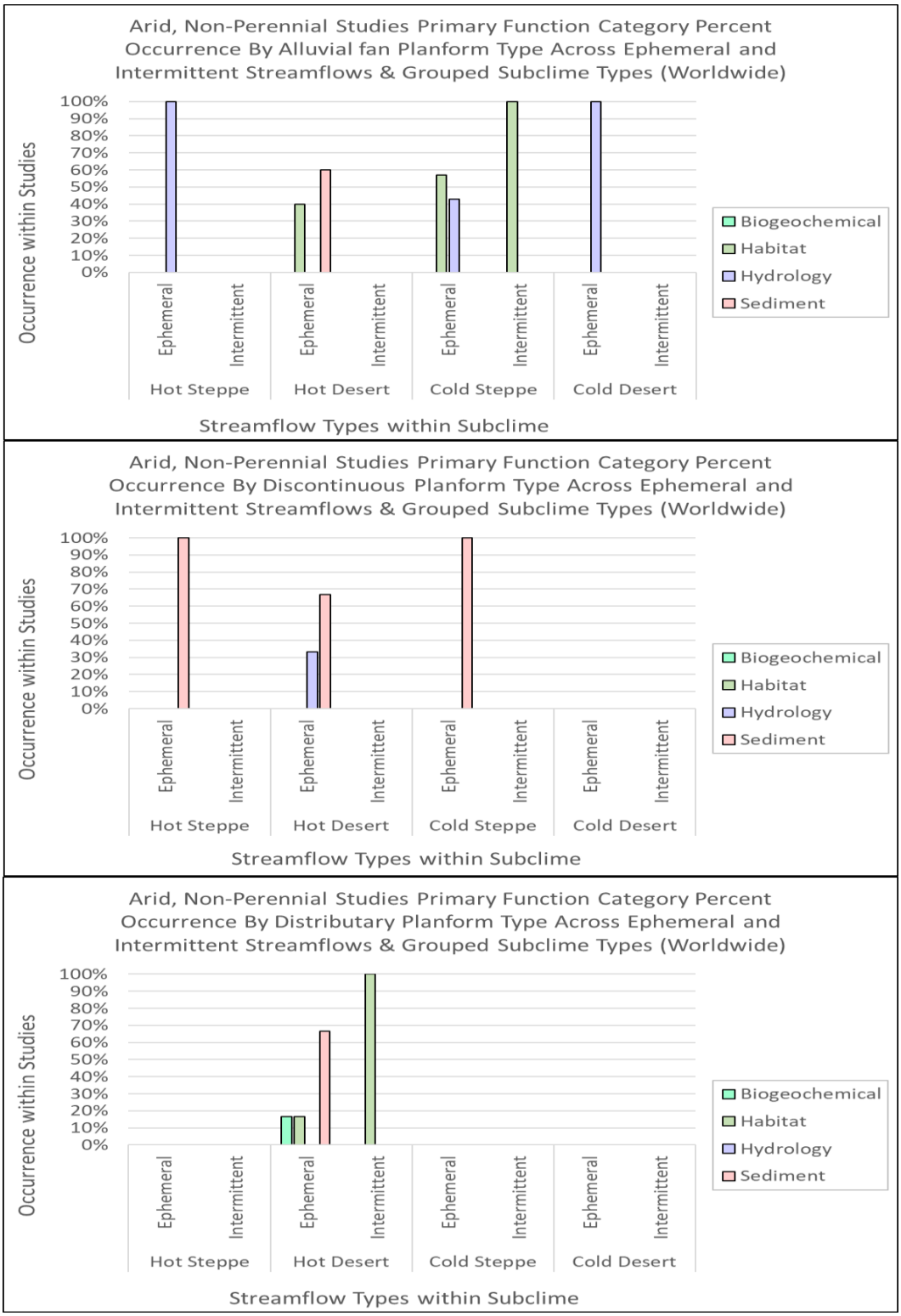


Figure 116. Sampling of each Group 3 condensed planform type across primary broad function categories by subclimes and known ephemeral and intermittent streamflow types, within global arid non-perennial stream literature.

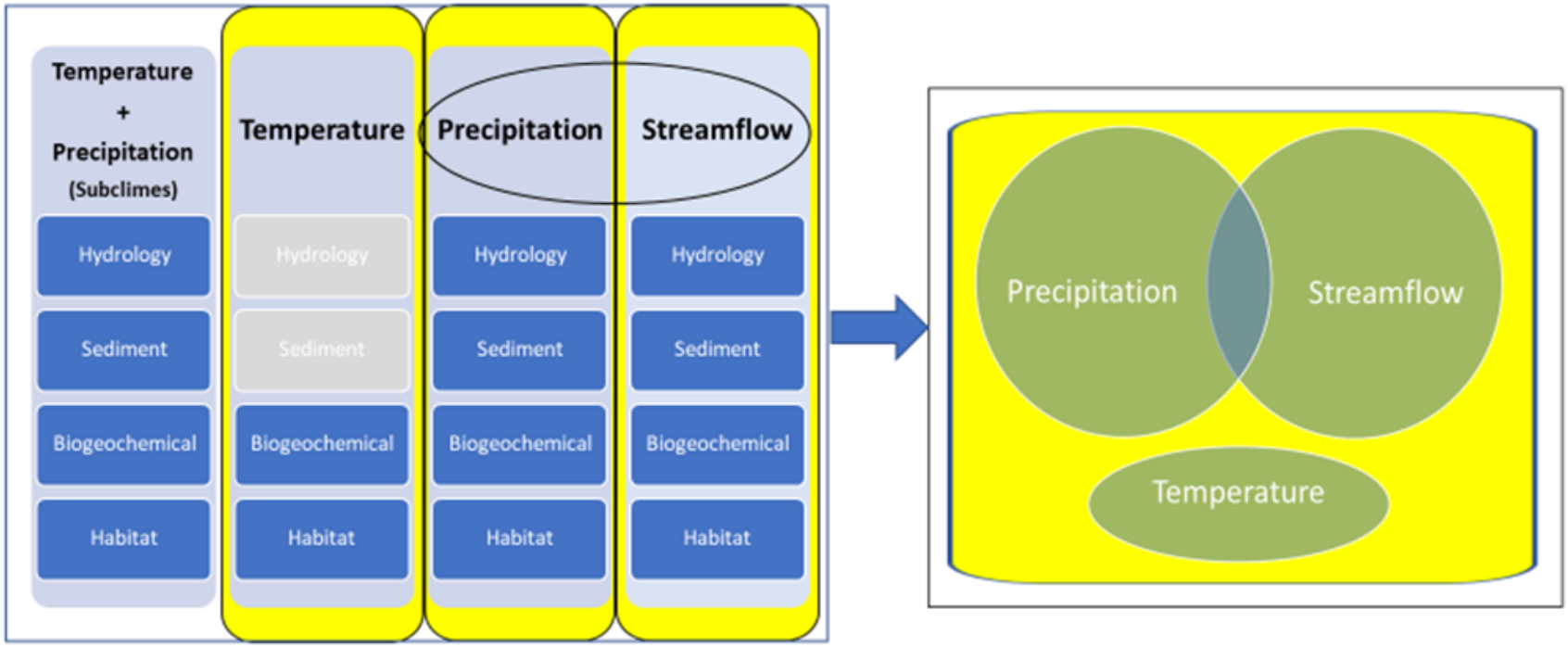


Figure 117. The conceptual relations and hierarchies of subclime components (temperature and precipitation types) and hydrology (inherent precipitation and streamflow types) factors and their influence on broad stream function categories.



Figure 118. Sampling of Biogeochemical and Habitat function categories across condensed planform and known streamflow types, by temperature and precipitation types, within global arid non-perennial stream literature.

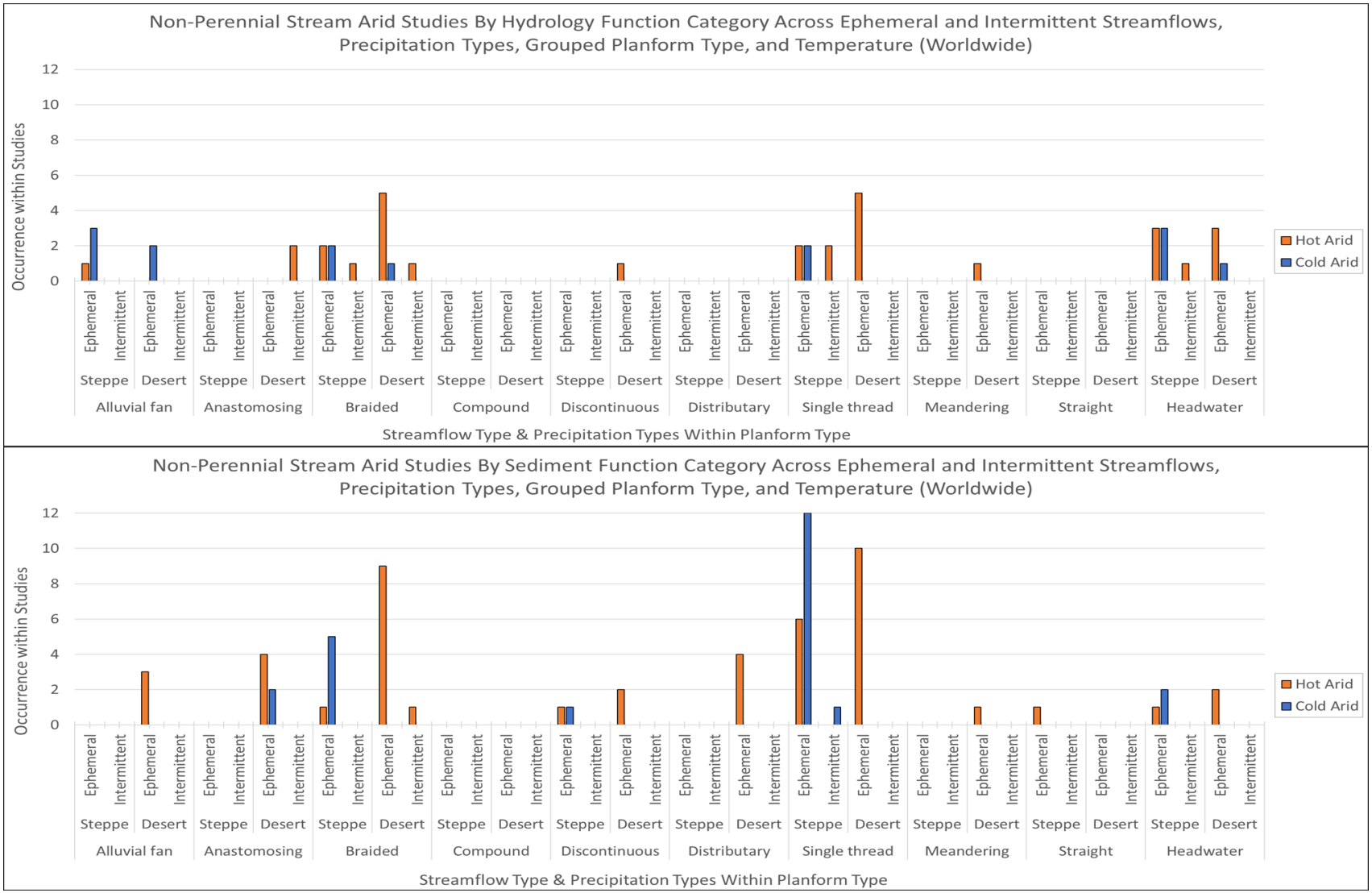


Figure 119. Sampling of Hydrology and Sediment function categories across condensed planform and known streamflow types, by temperature and precipitation types, within global arid non-perennial stream literature.

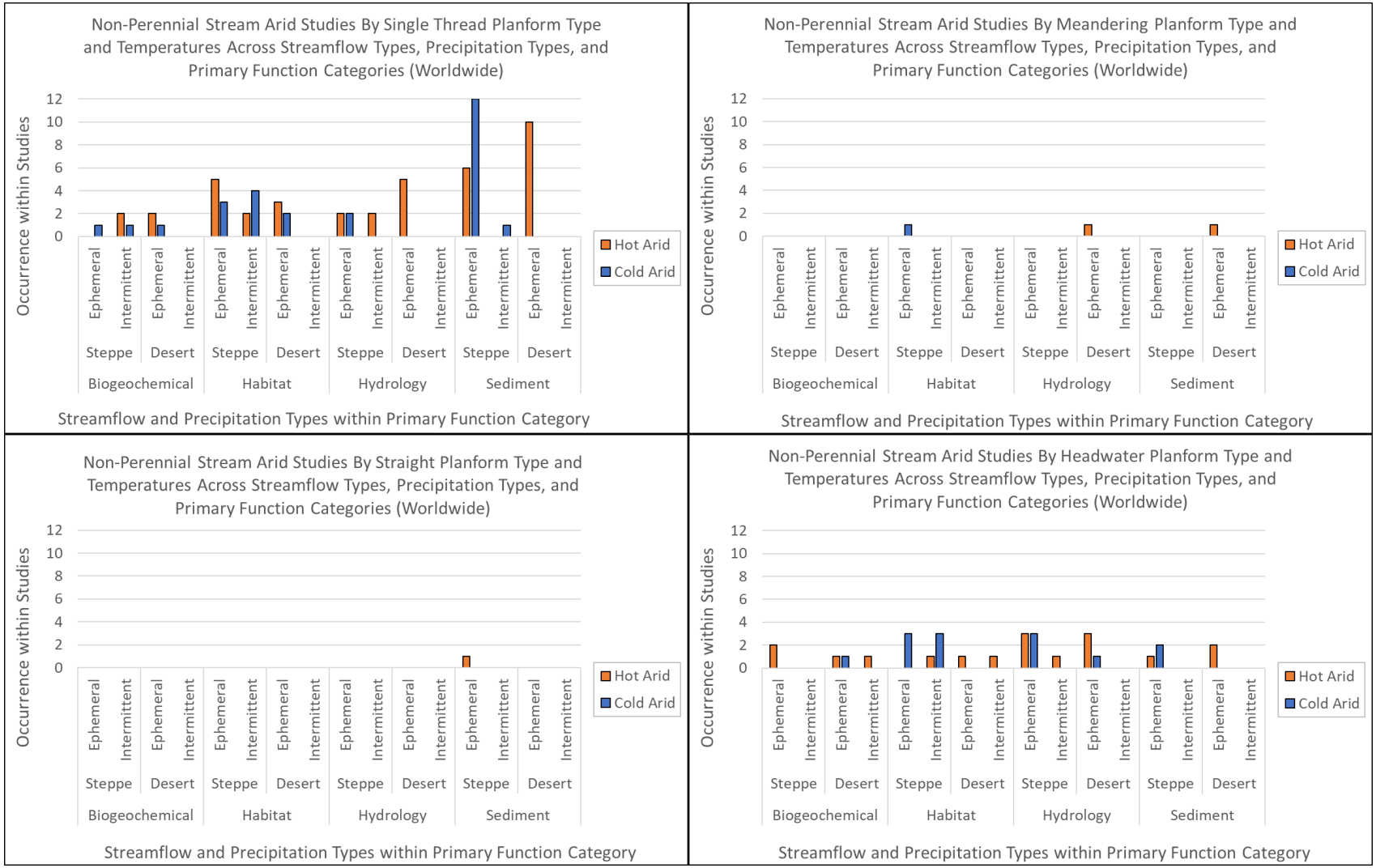


Figure 120. Sampling of each Group 1 stream planform type across primary broad function categories and temperatures, by precipitation and known streamflow types, within global arid non-perennial stream literature.

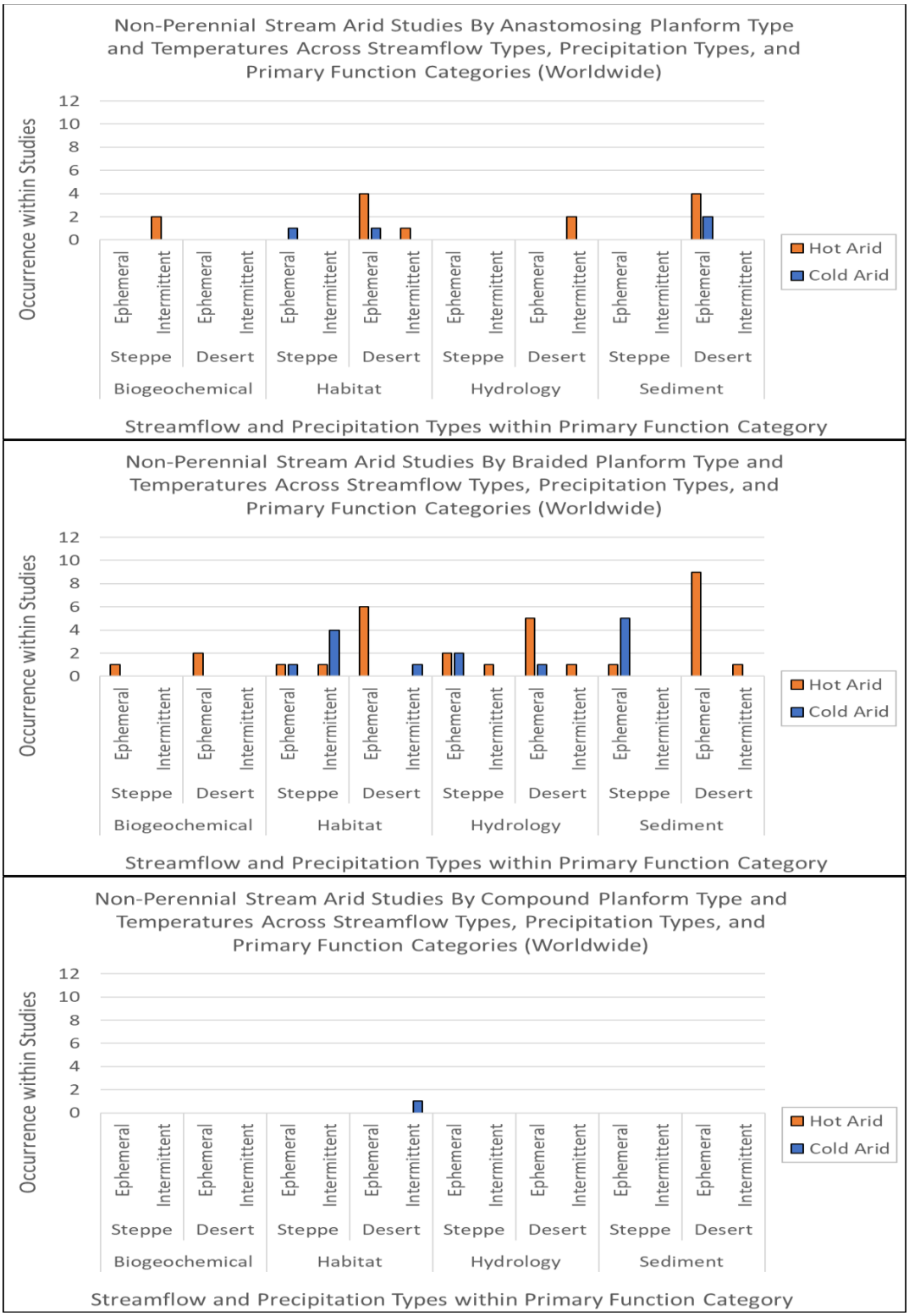


Figure 121. Sampling of each Group 2 stream planform type across primary broad function categories and temperatures, by precipitation and known streamflow types, within global arid non-perennial stream literature.

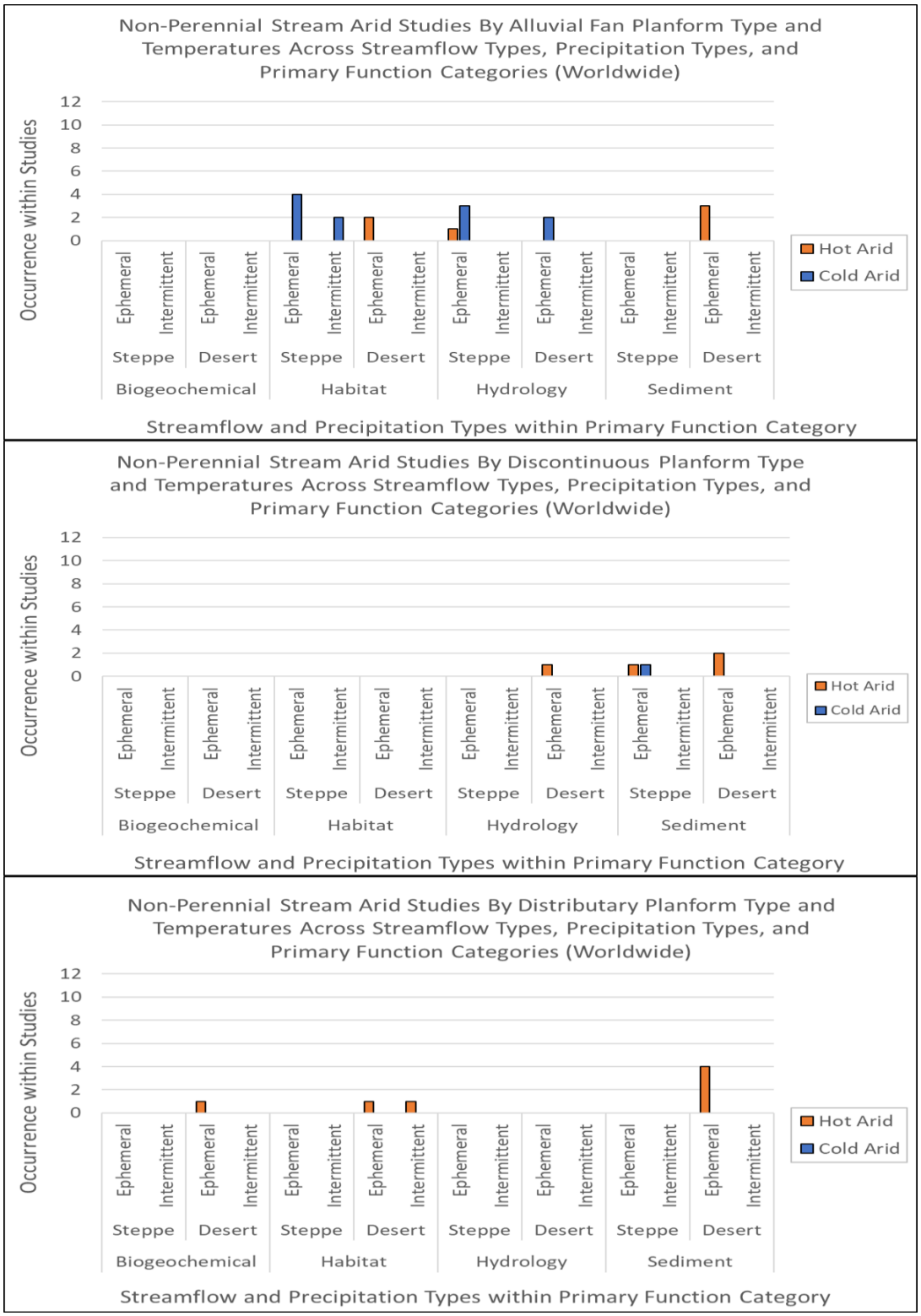


Figure 122. Sampling of each Group 3 stream planform type across primary broad function categories and temperatures, by precipitation and known streamflow types, within global arid non-perennial stream literature.

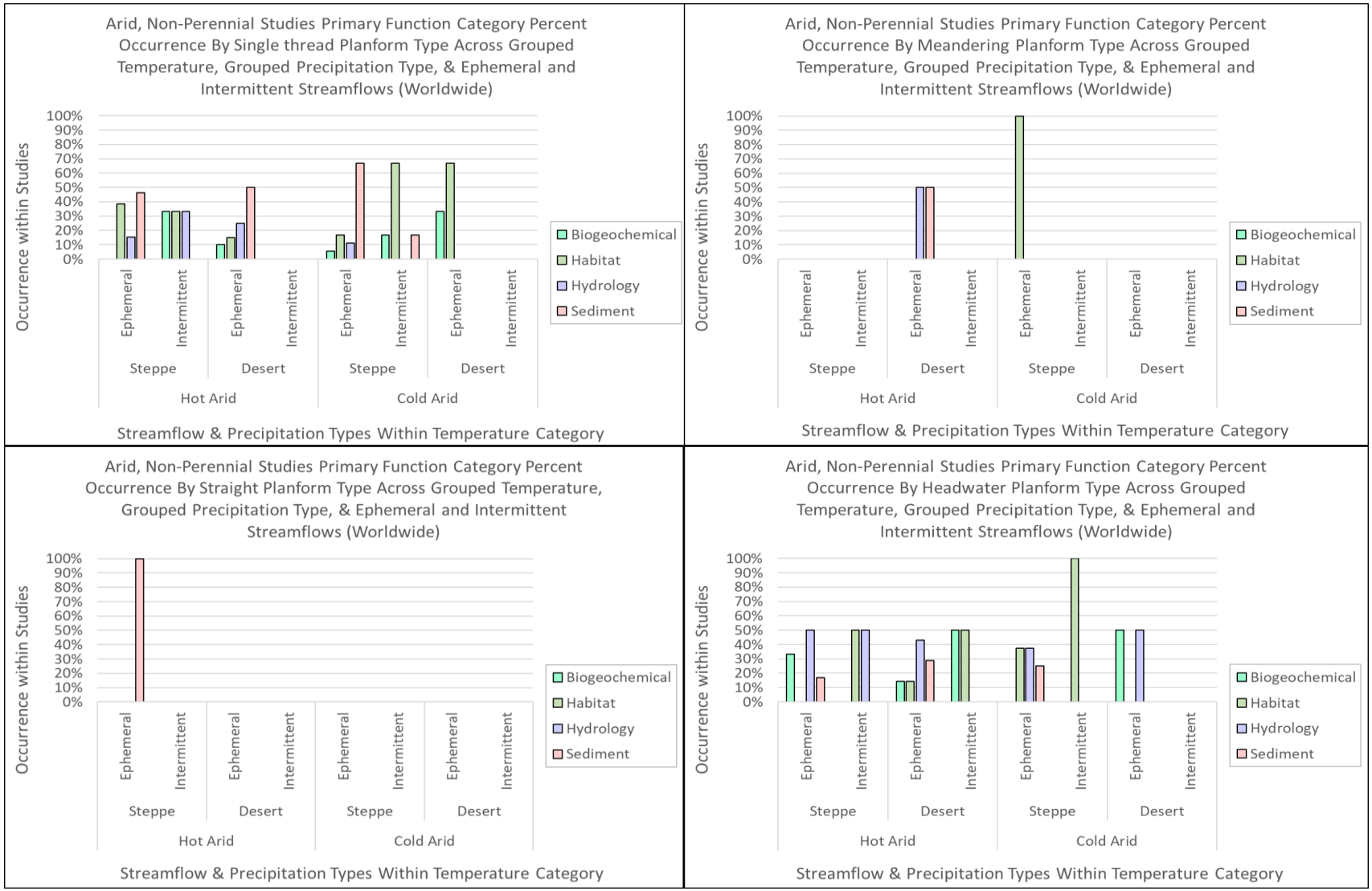


Figure 123. Sampling of each Group 1 stream planform type across primary broad function categories by temperatures, and by precipitation and known streamflow types, within global arid non-perennial stream literature.

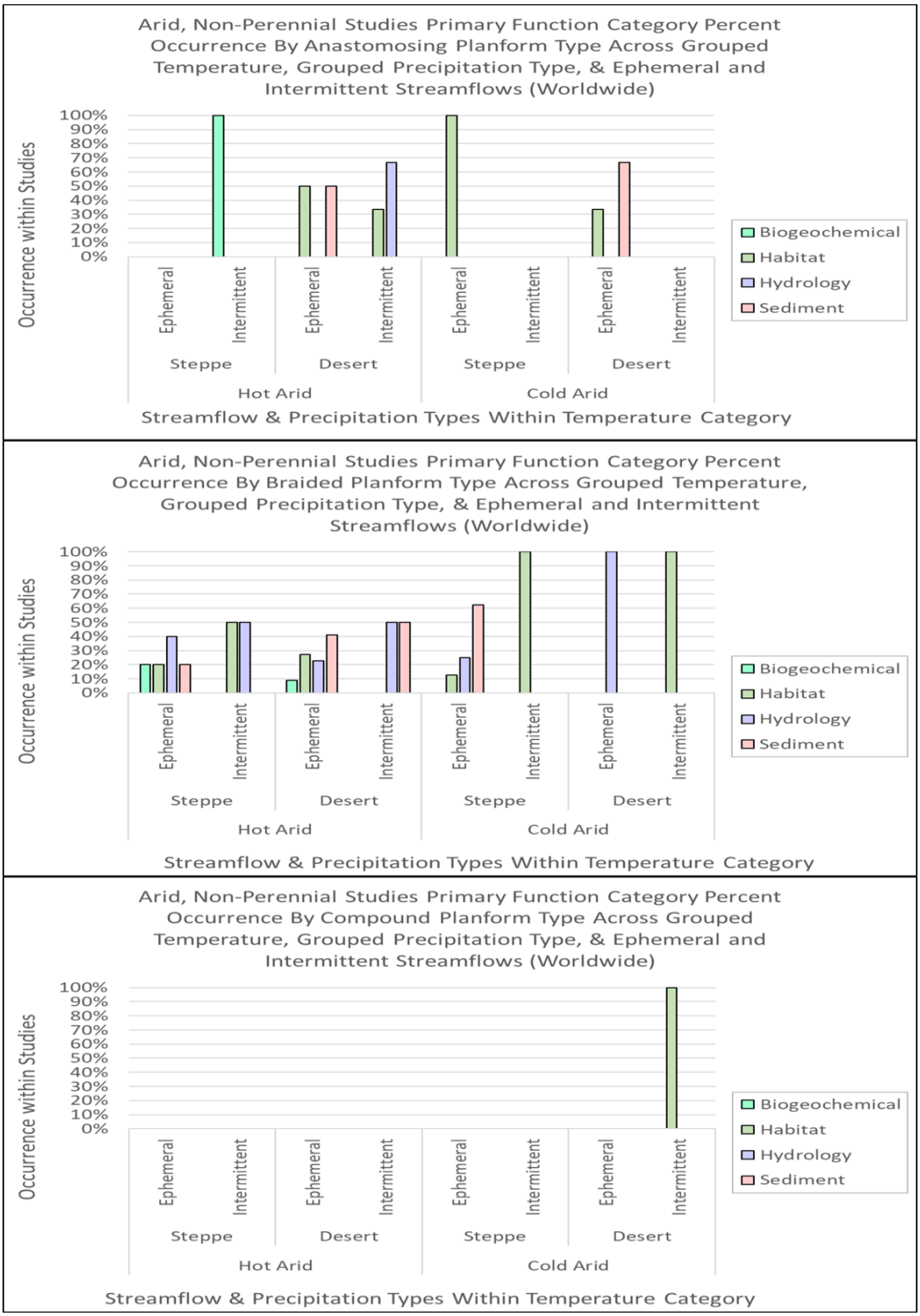


Figure 124. Sampling of each Group 2 stream planform type across primary broad function categories by temperatures, and by precipitation and known streamflow types, within global arid non-perennial stream literature.

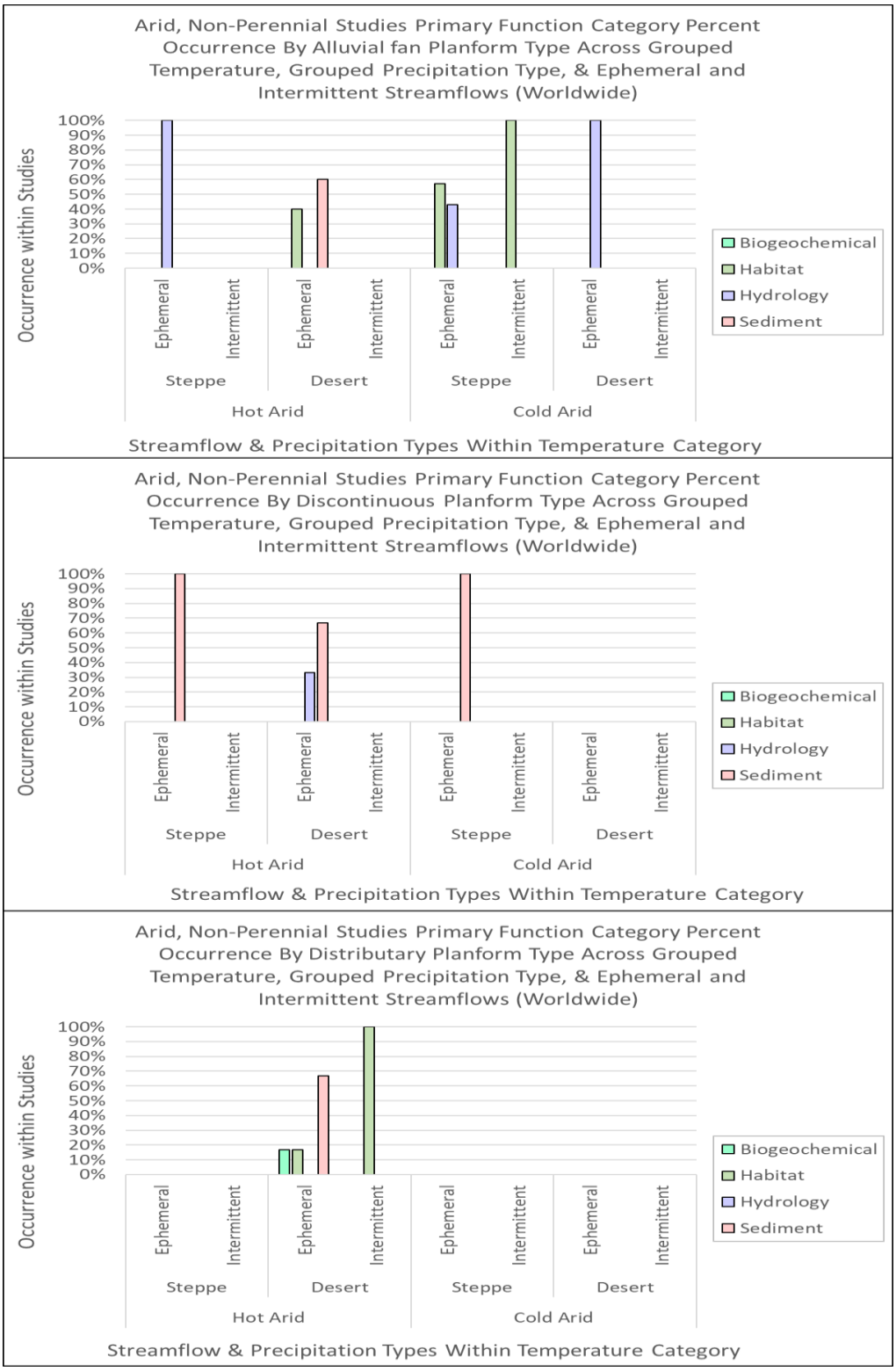


Figure 125. Sampling of each Group 3 stream planform type across primary broad function categories by temperatures, and by precipitation and known streamflow types, within global arid non-perennial stream literature.

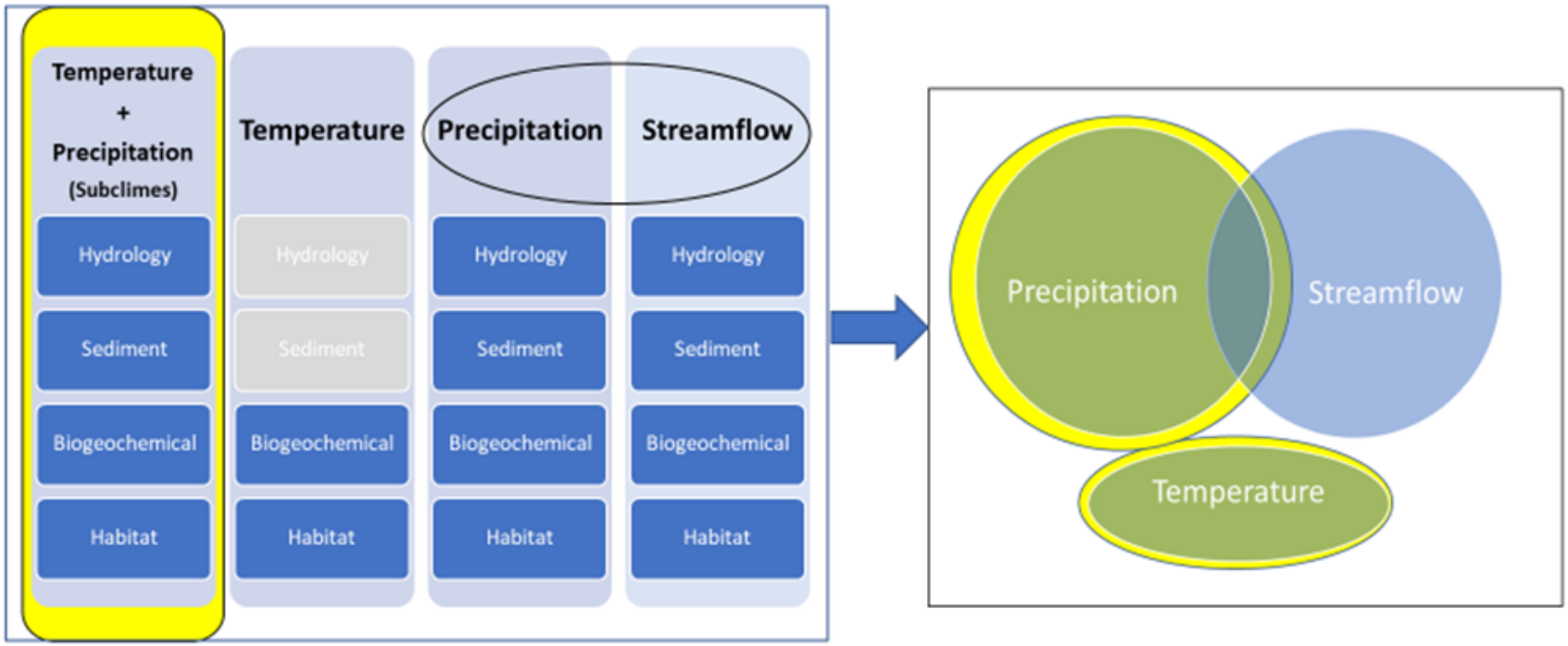


Figure 126. The conceptual relations and hierarchies of subclimes (combined temperature and precipitation types) factors and an inherent hydrology component (precipitation types) factor and their influence on broad stream function categories.

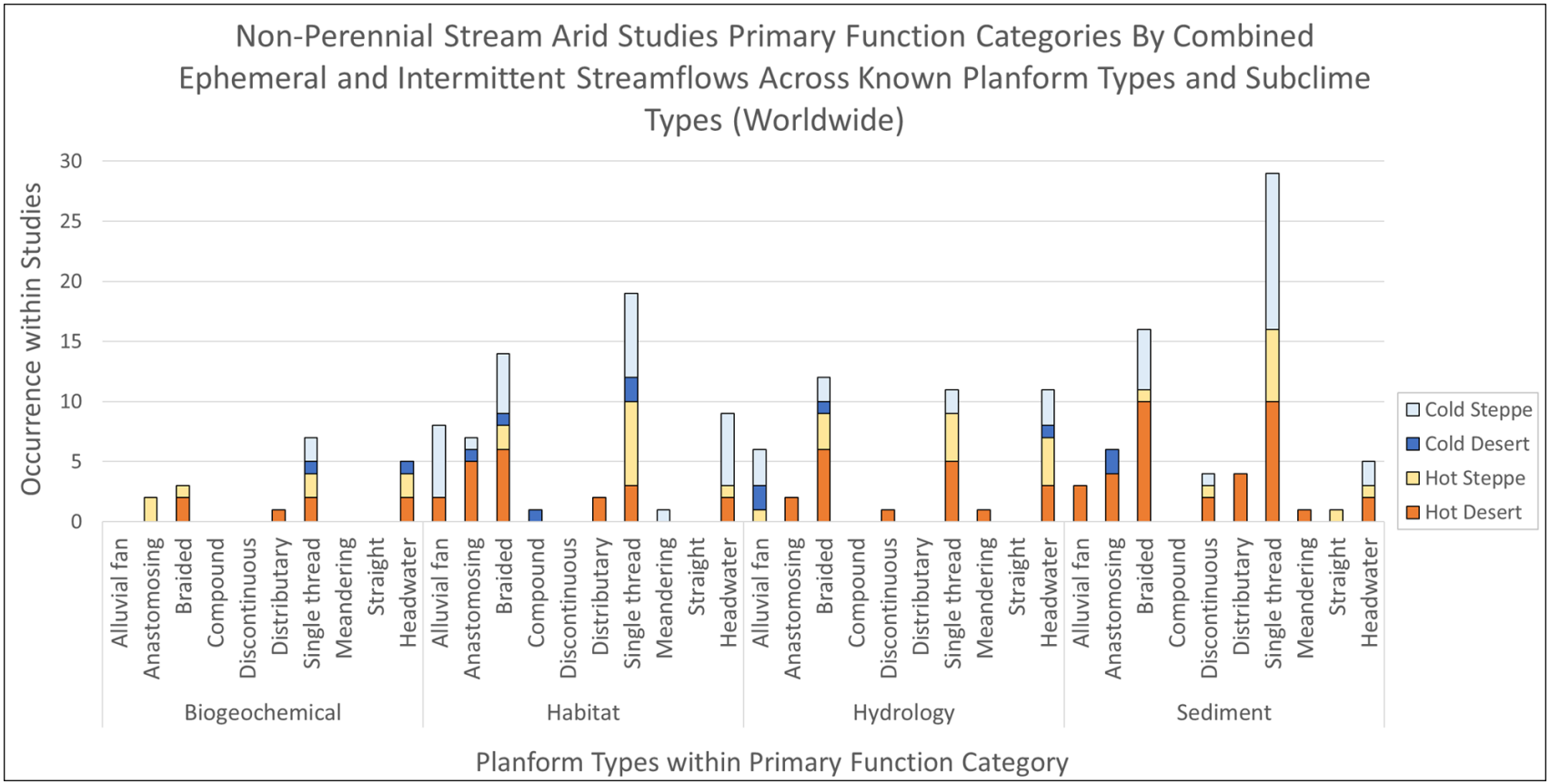


Figure 127. Sampling of primary broad function categories across condensed planform types by subclimes, within global arid non-perennial stream literature.

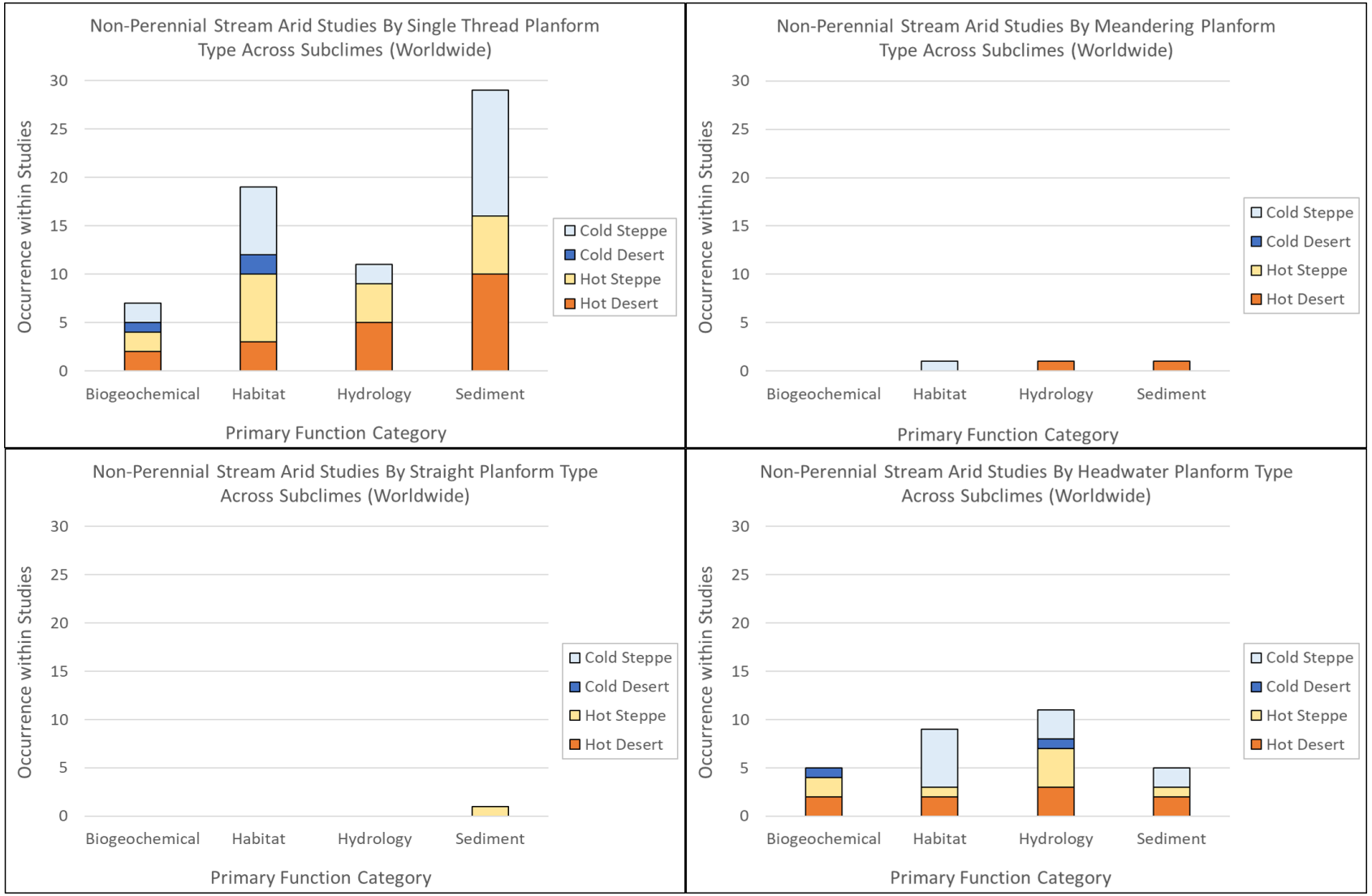


Figure 128. Sampling of each Group 1 planform type across primary broad function categories and subclimes, within global arid non-perennial stream literature.

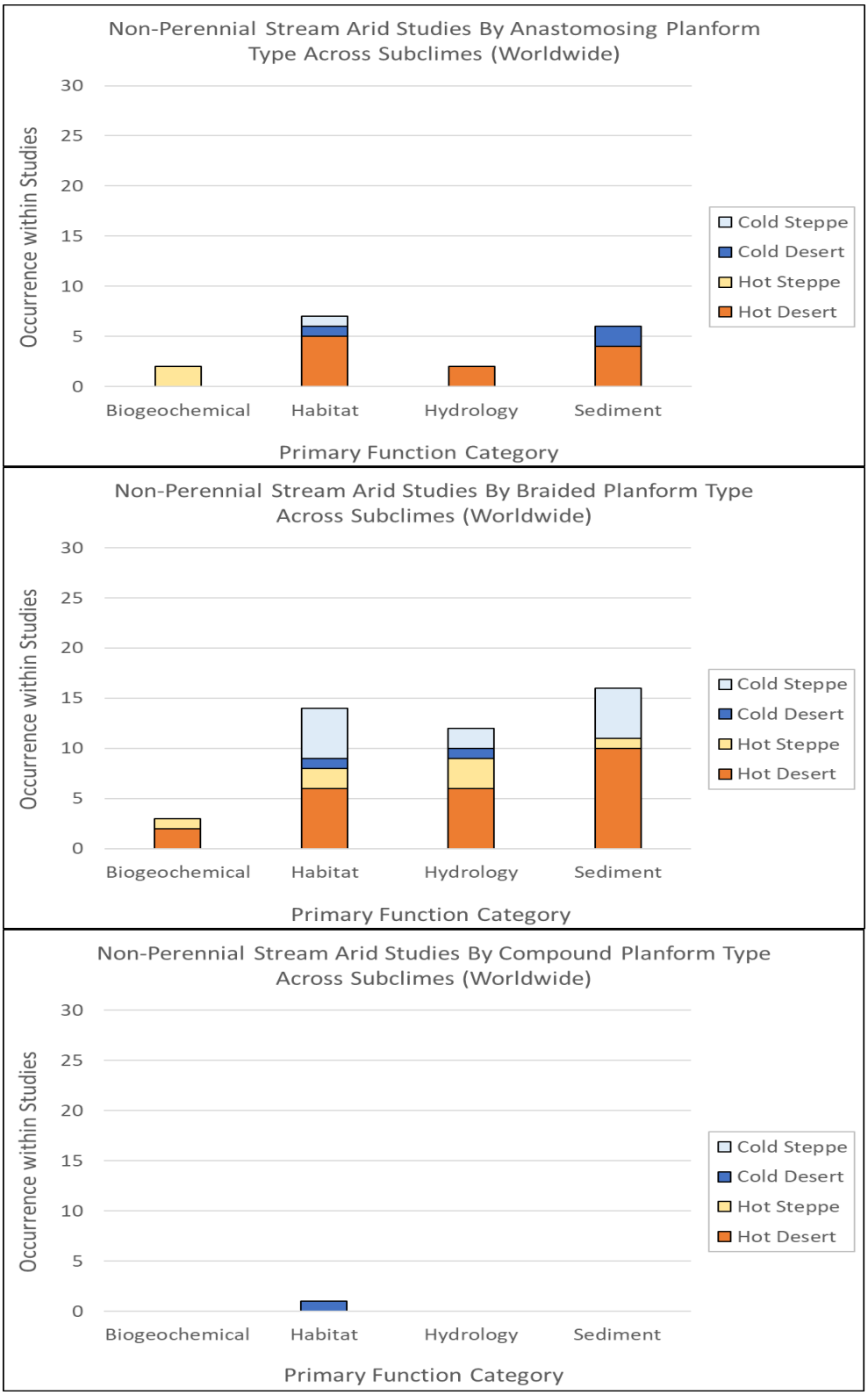


Figure 129. Sampling of each Group 2 planform type across primary broad function categories and subclimes, within global arid non-perennial stream literature.

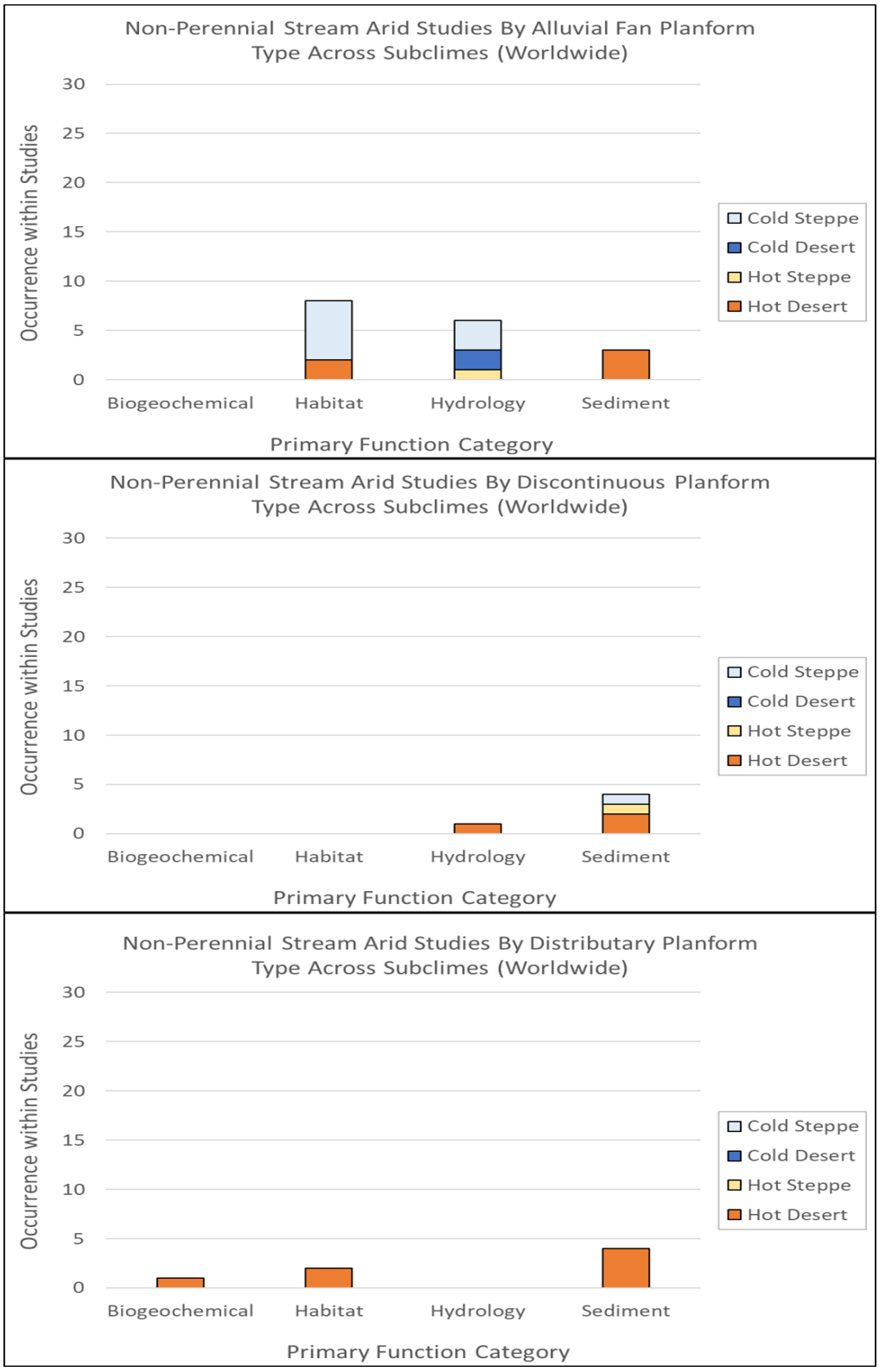


Figure 130. Sampling of each Group 3 planform type across primary broad function categories and subclimes, within global arid non-perennial stream literature.

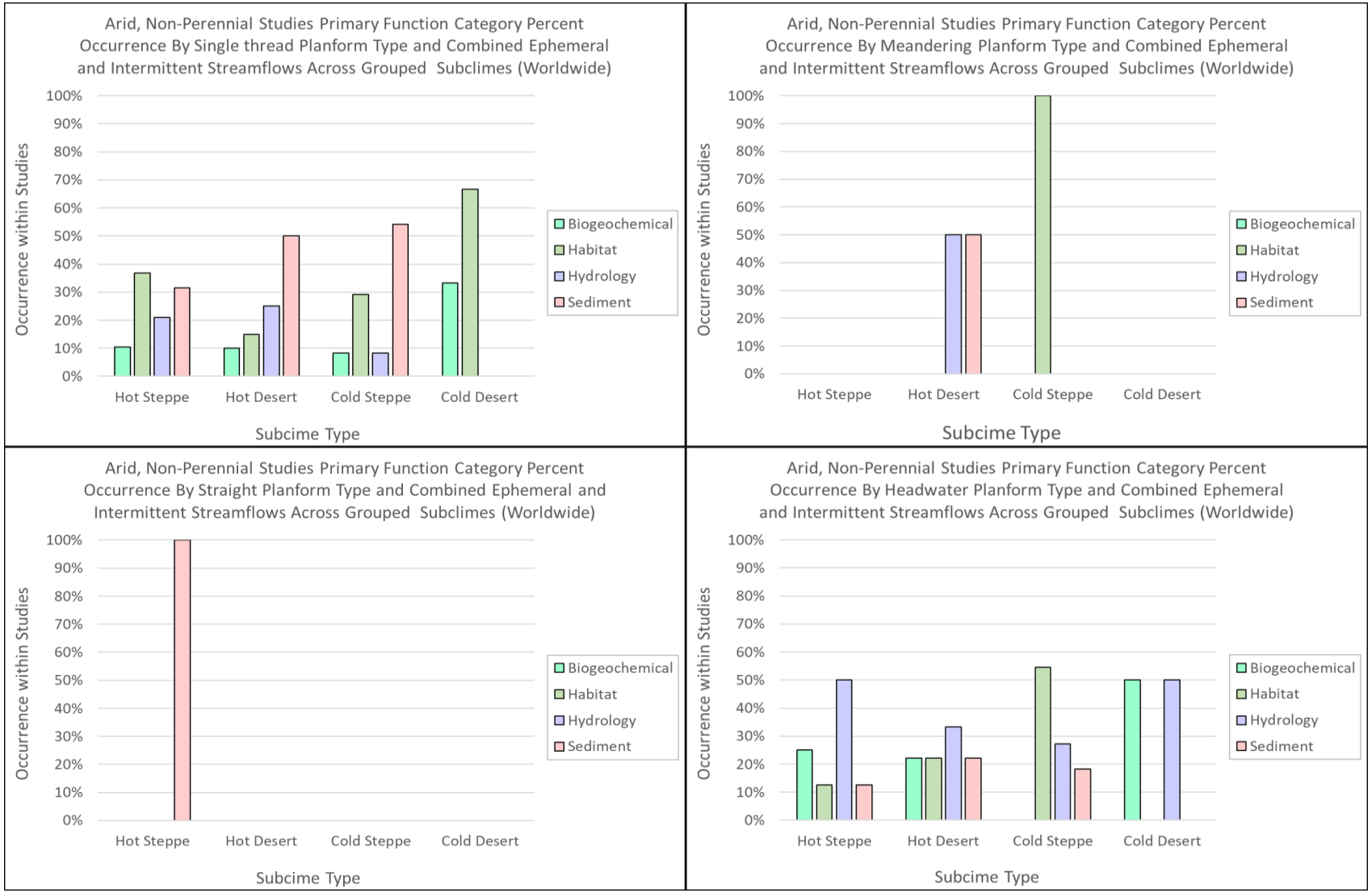


Figure 131. Sampling of each Group 1 planform type across primary broad function categories by subclimes, within global arid non-perennial stream literature.

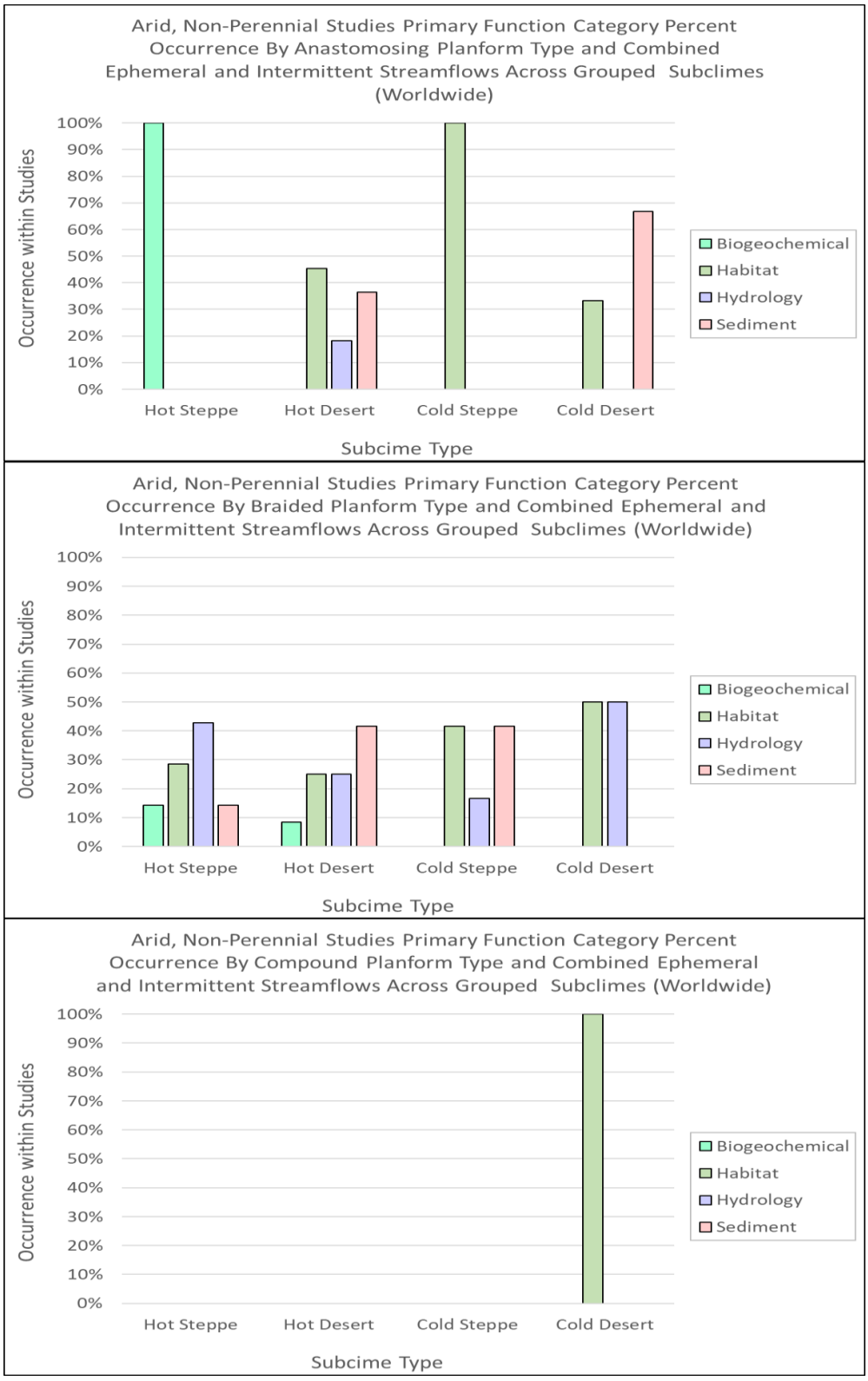


Figure 132. Sampling of each Group 2 planform type across primary broad function categories by subclimes, within global arid non-perennial stream literature.



Figure 133. Sampling of each Group 3 planform type across primary broad function categories by subclimes, within global arid non-perennial stream literature.

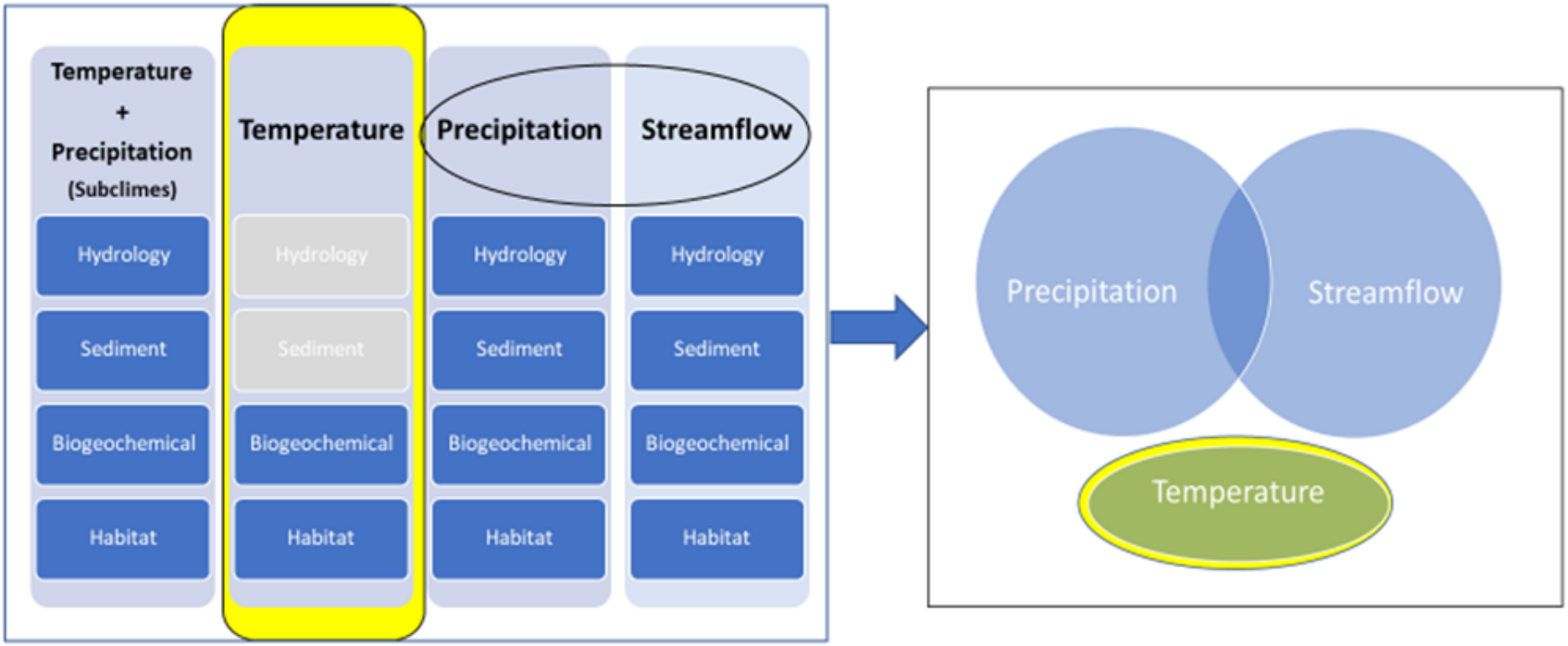


Figure 134. The conceptual relations and hierarchies of a subclime component (temperature) factor and its influence on broad stream function categories.

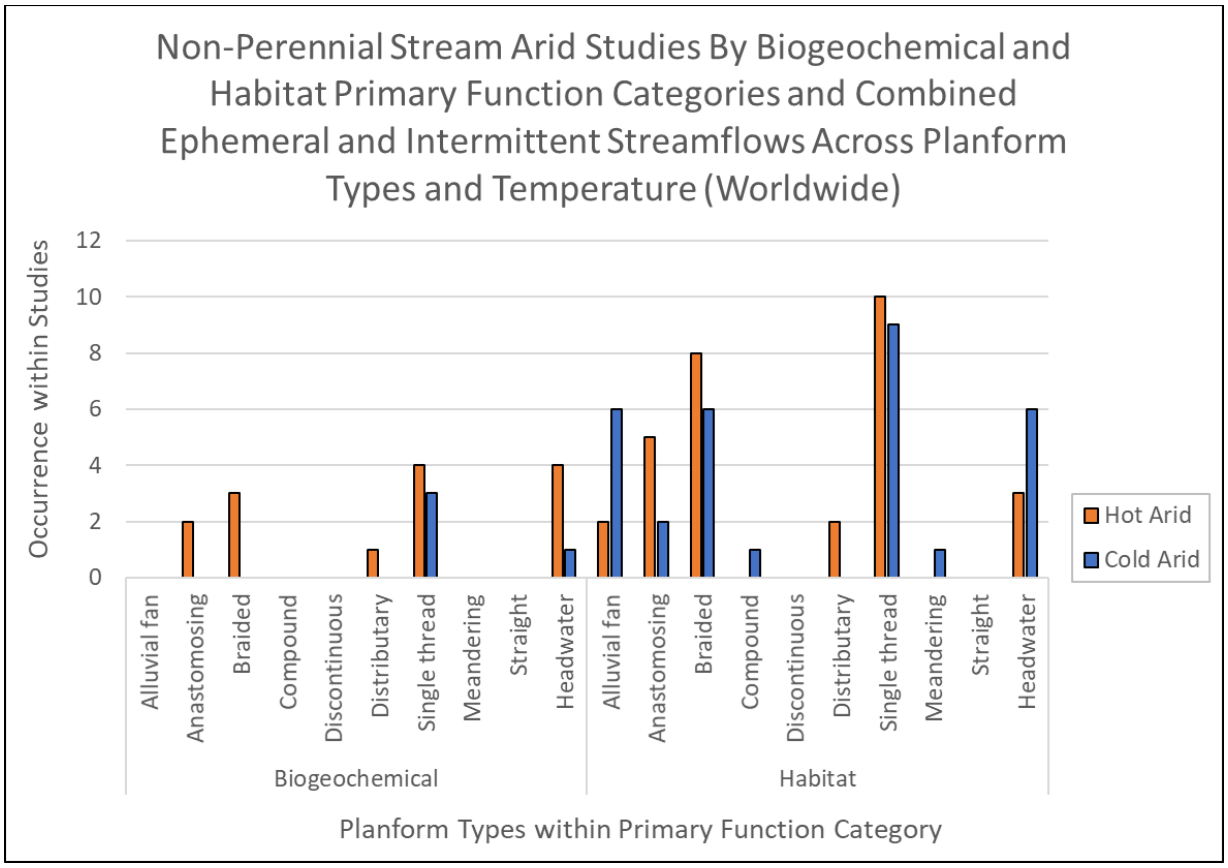


Figure 135. Sampling of Biogeochemical and Habitat primary broad function categories across condensed planform types and temperatures, within global arid non-perennial stream literature.

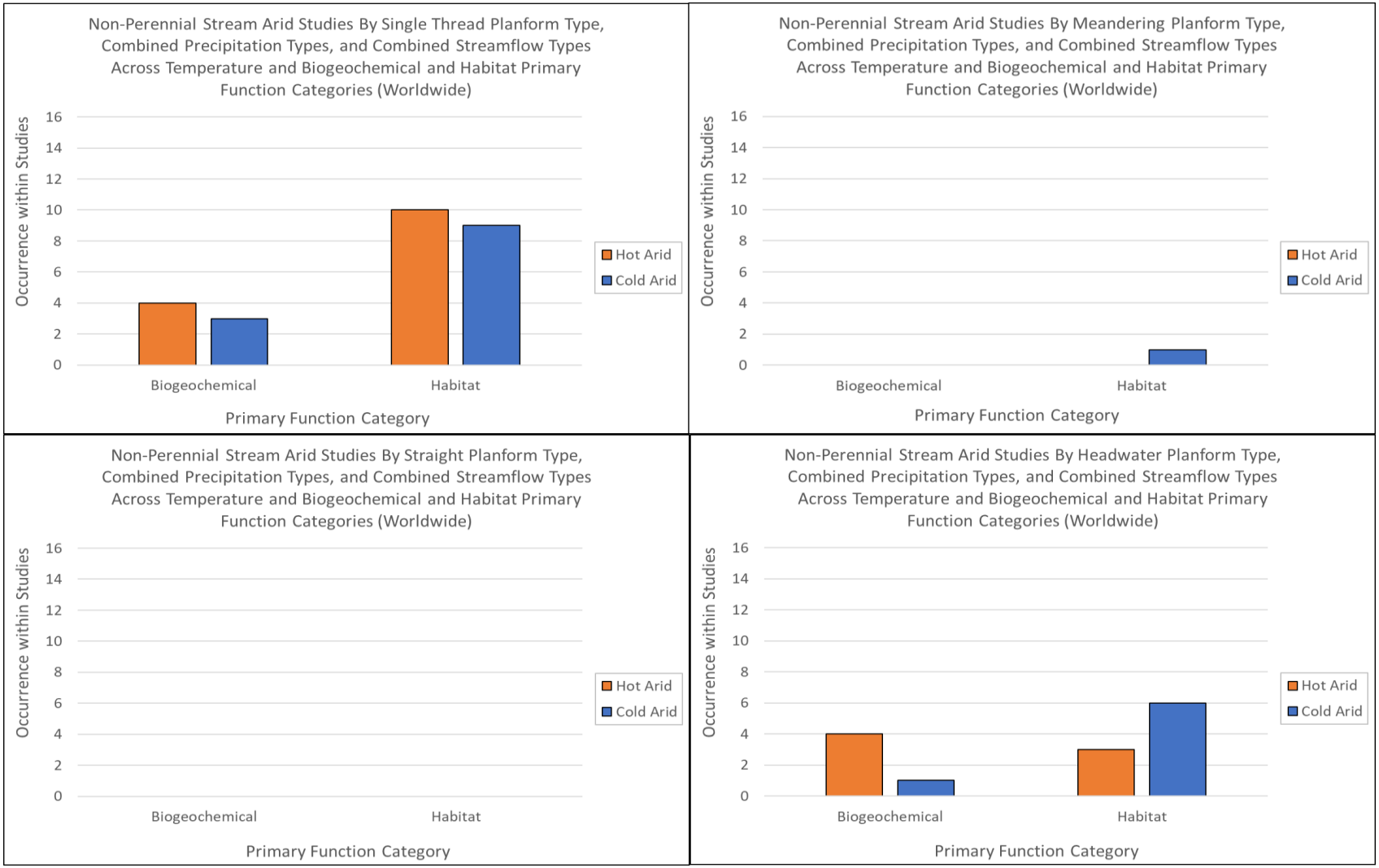


Figure 136. Sampling of each Group 1 planform type across Biogeochemical and Habitat primary broad function categories and temperatures, within global arid non-perennial stream literature.

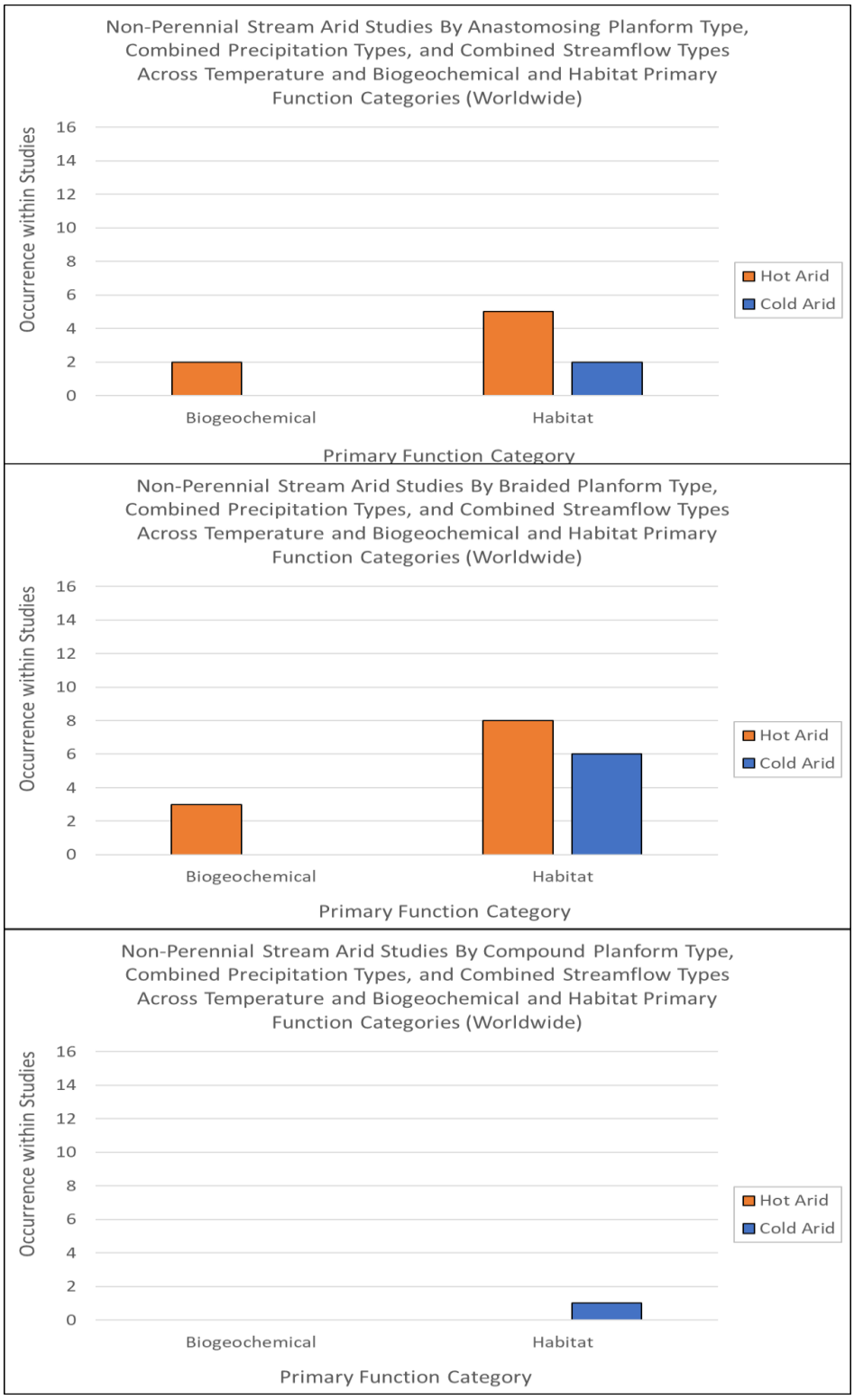


Figure 137. Sampling of each Group 2 planform type across Biogeochemical and Habitat primary broad function categories and temperatures, within global arid non -perennial stream literature.

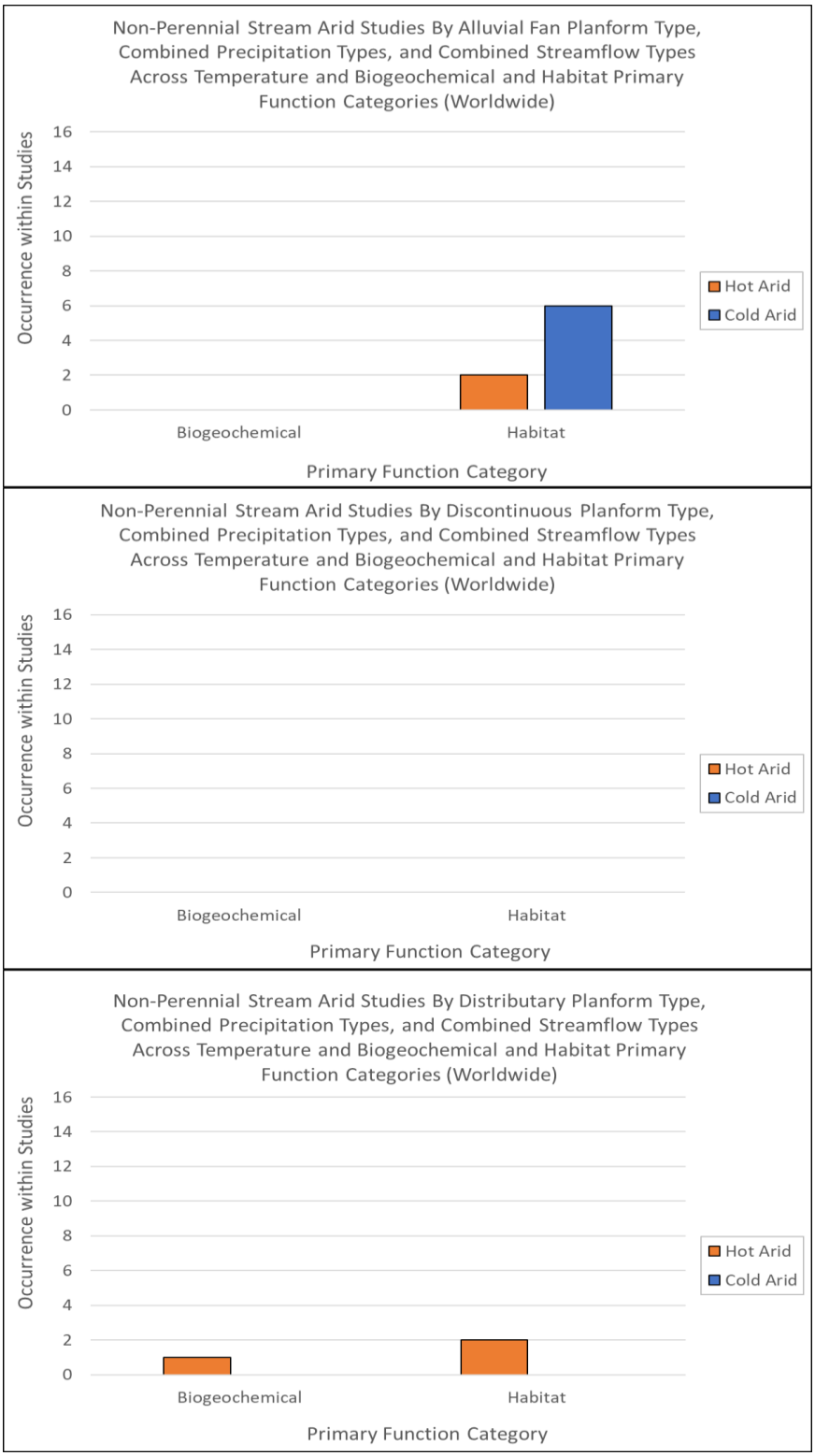


Figure 138. Sampling of each Group 3 planform type across Biogeochemical and Habitat primary broad function categories and temperatures, within global arid non -perennial stream literature.

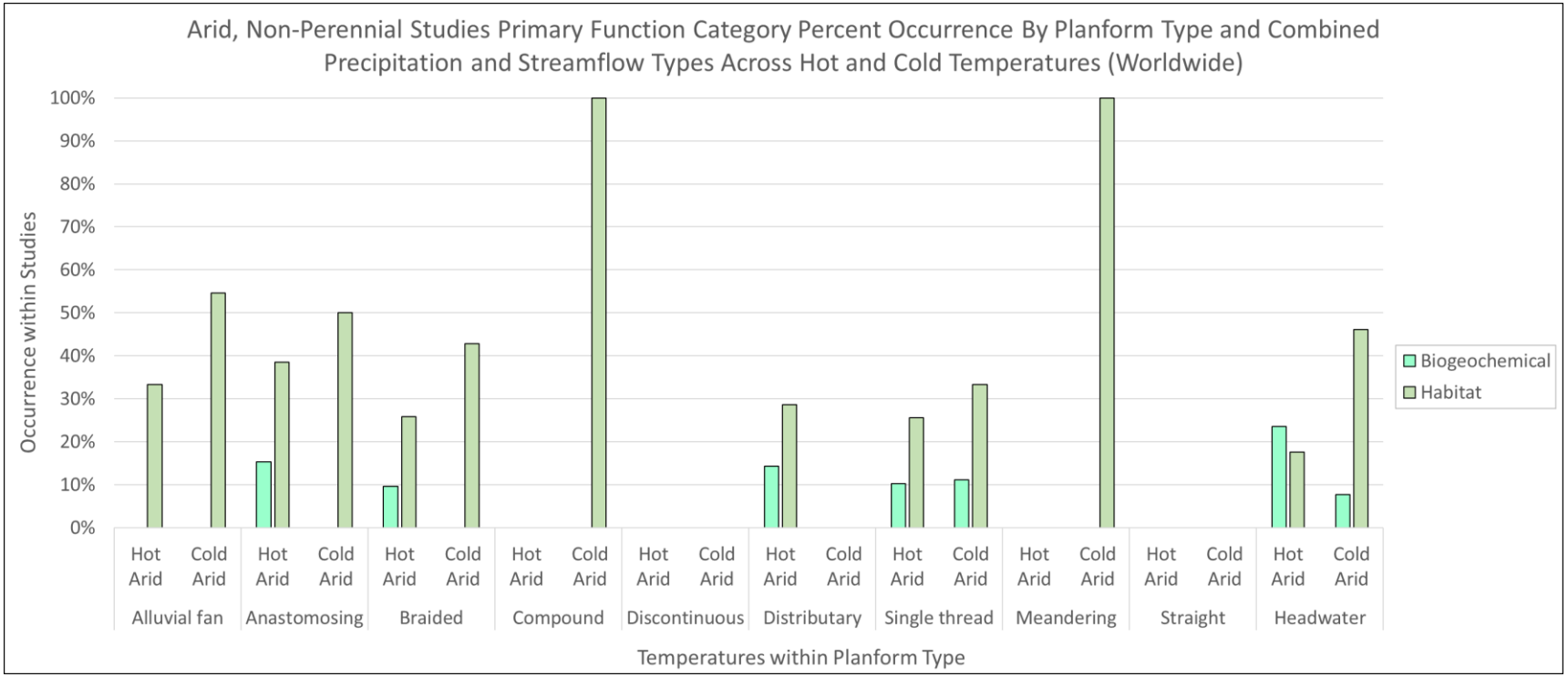


Figure 139. Sampling of planform types across Biogeochemical and Habitat primary broad function categories by temperatures, within global arid non-perennial stream literature.

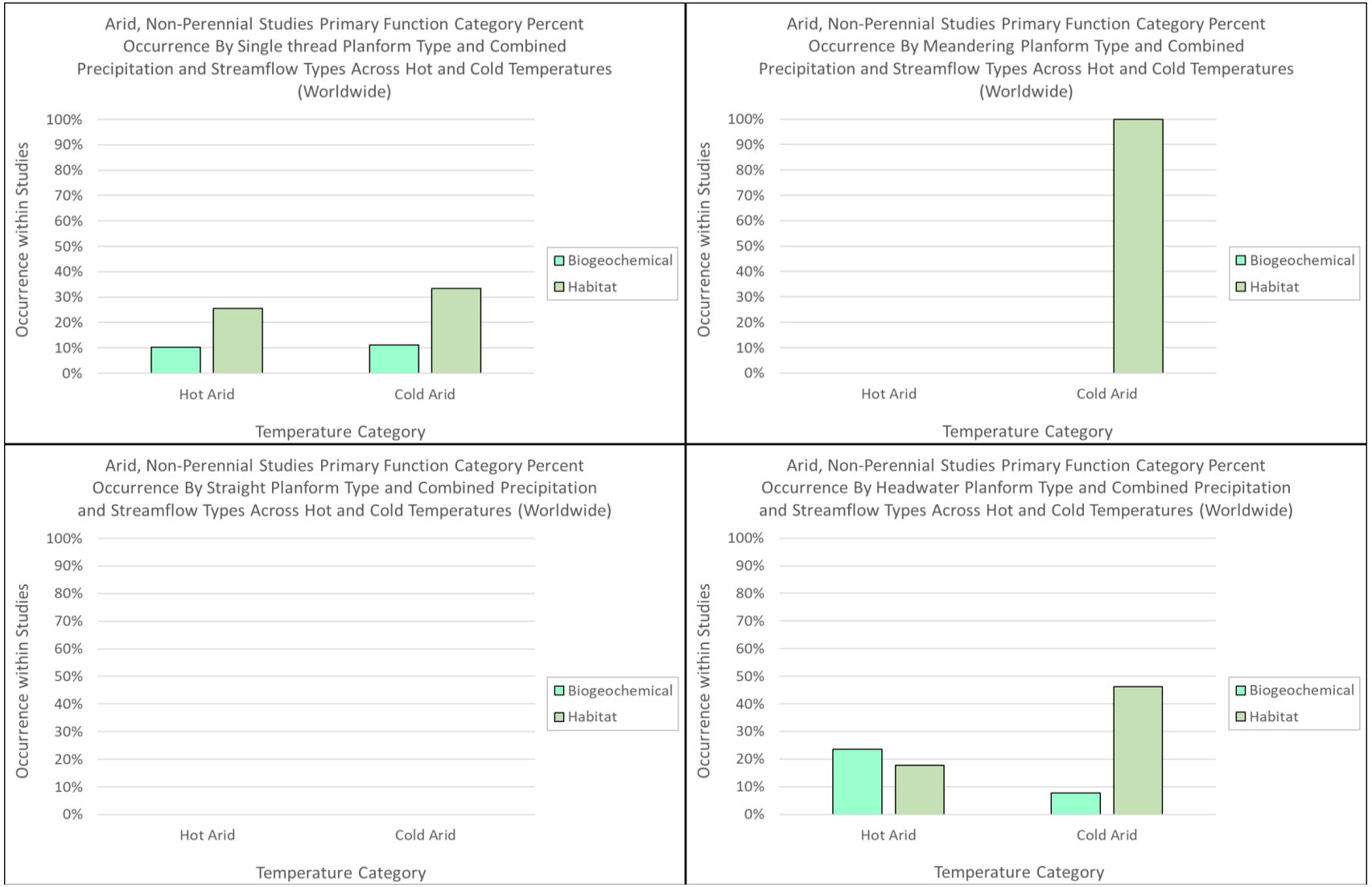


Figure 140. Sampling of each Group 1 planform type across Biogeochemical and Habitat primary broad function categories by temperatures, within global arid non-perennial stream literature.



Figure 141. Sampling of each Group 2 planform type across Biogeochemical and Habitat primary broad function categories by temperatures, within global arid non-perennial stream literature.

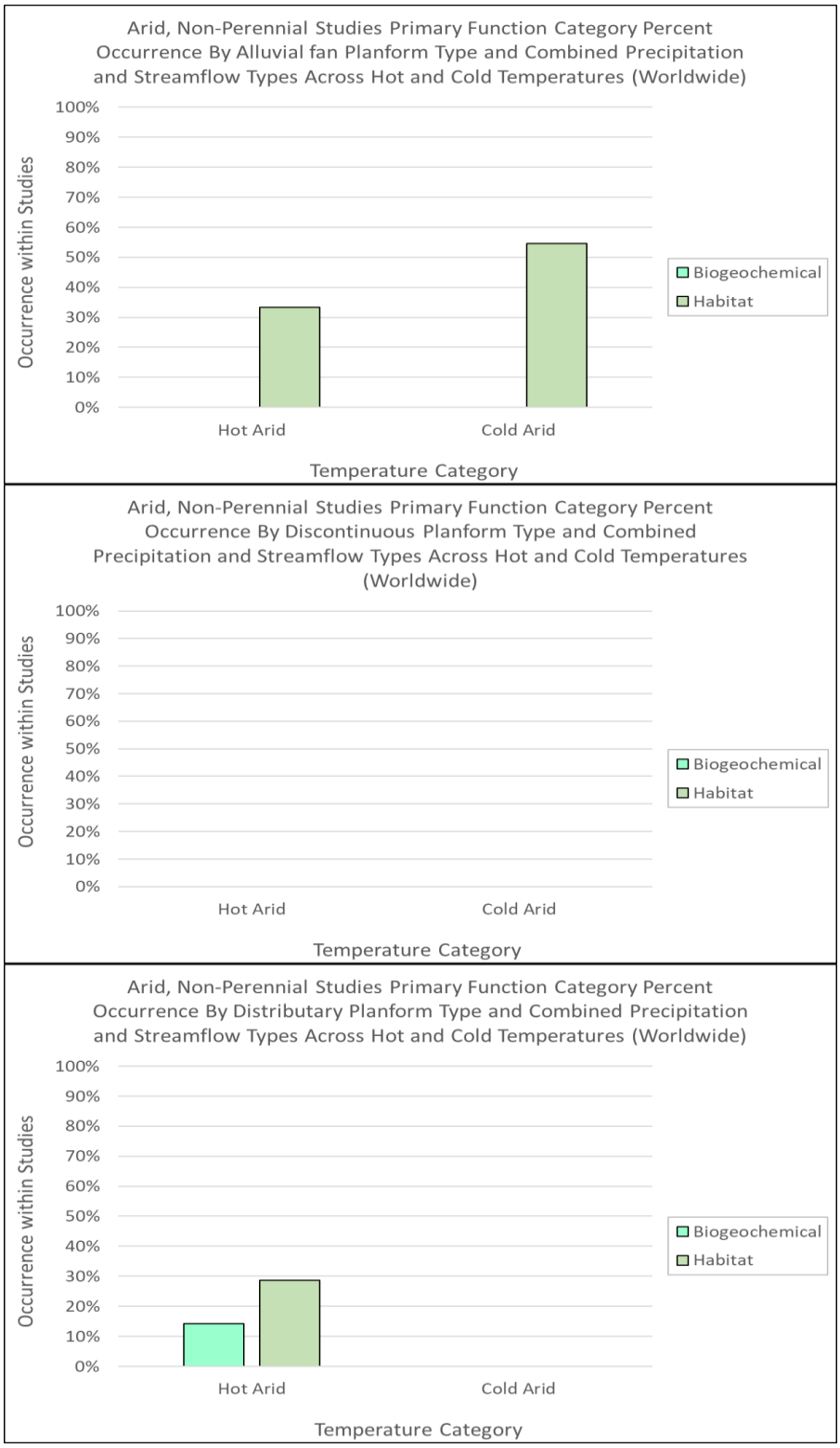


Figure 142. Sampling of each Group 3 planform type across Biogeochemical and Habitat primary broad function categories by temperatures, within global arid non-perennial stream literature.

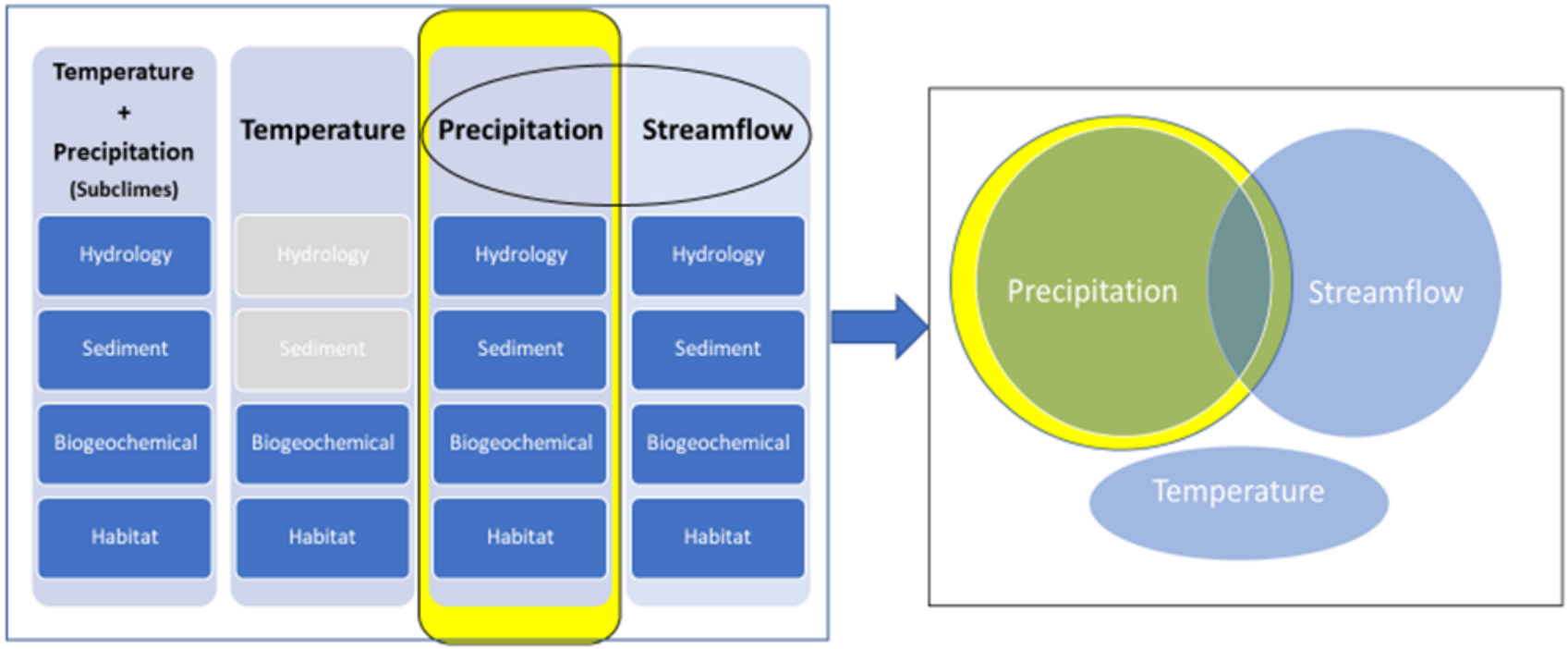


Figure 143. The conceptual relations and hierarchies of a subclime component (precipitation types) and an inherent hydrology component (precipitation types) factor and its influence on broad stream function categories.

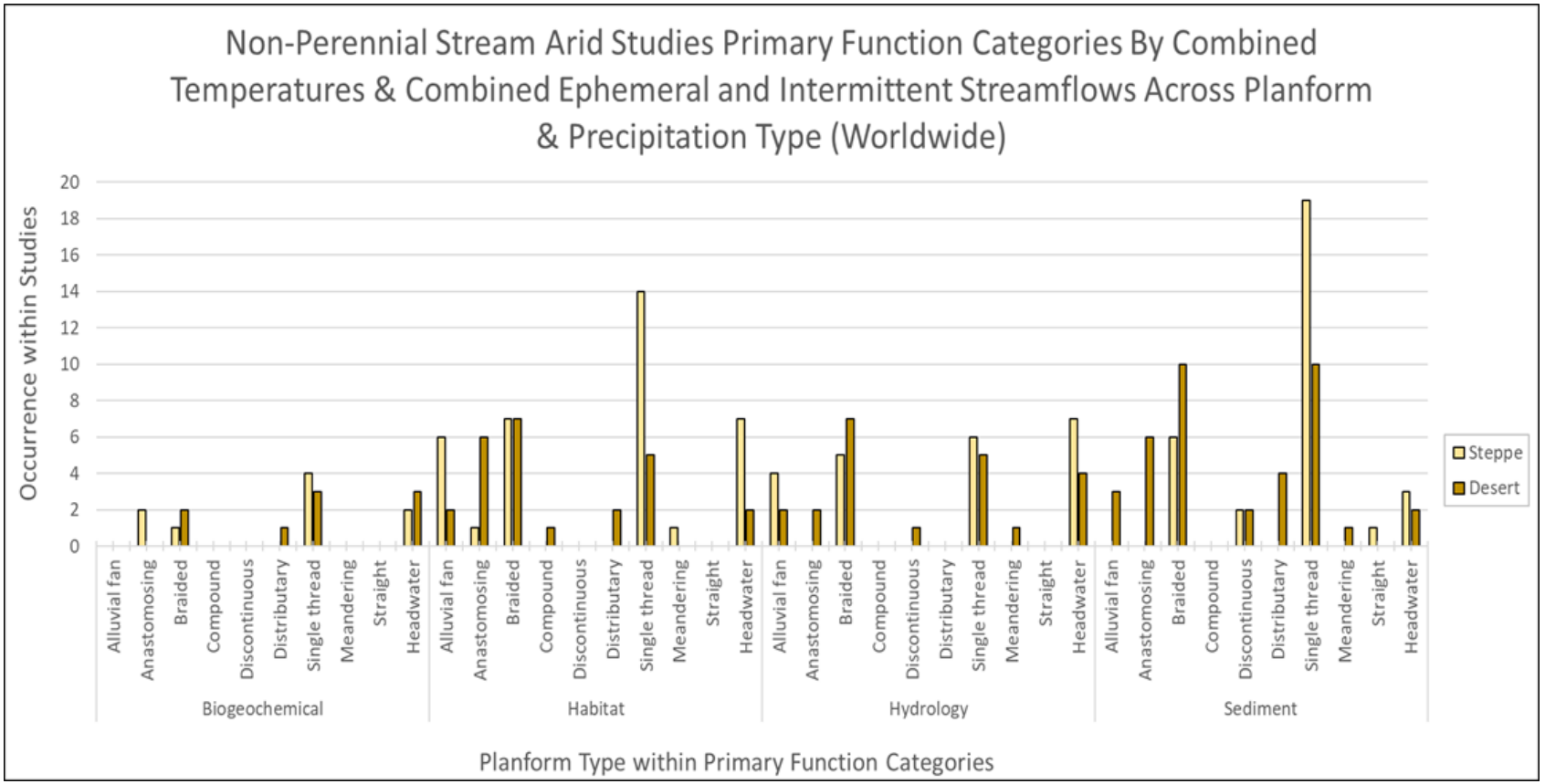


Figure 144. Sampling of primary broad function categories across condensed planform types and precipitation types, within global arid non-perennial stream literature.

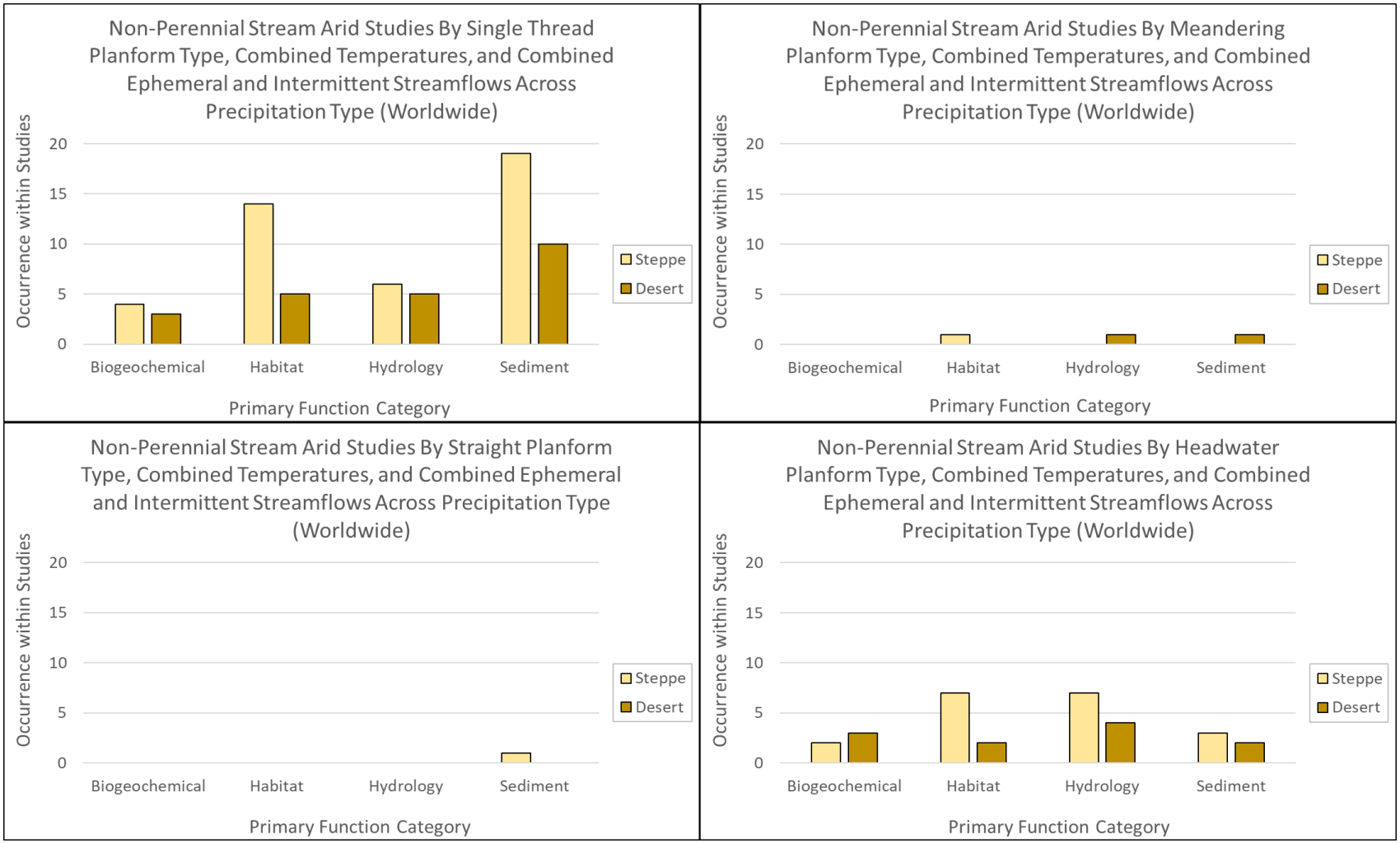


Figure 145. Sampling of each Group 1 condensed planform type across primary broad function categories and precipitation types, within global arid non-perennial stream literature.

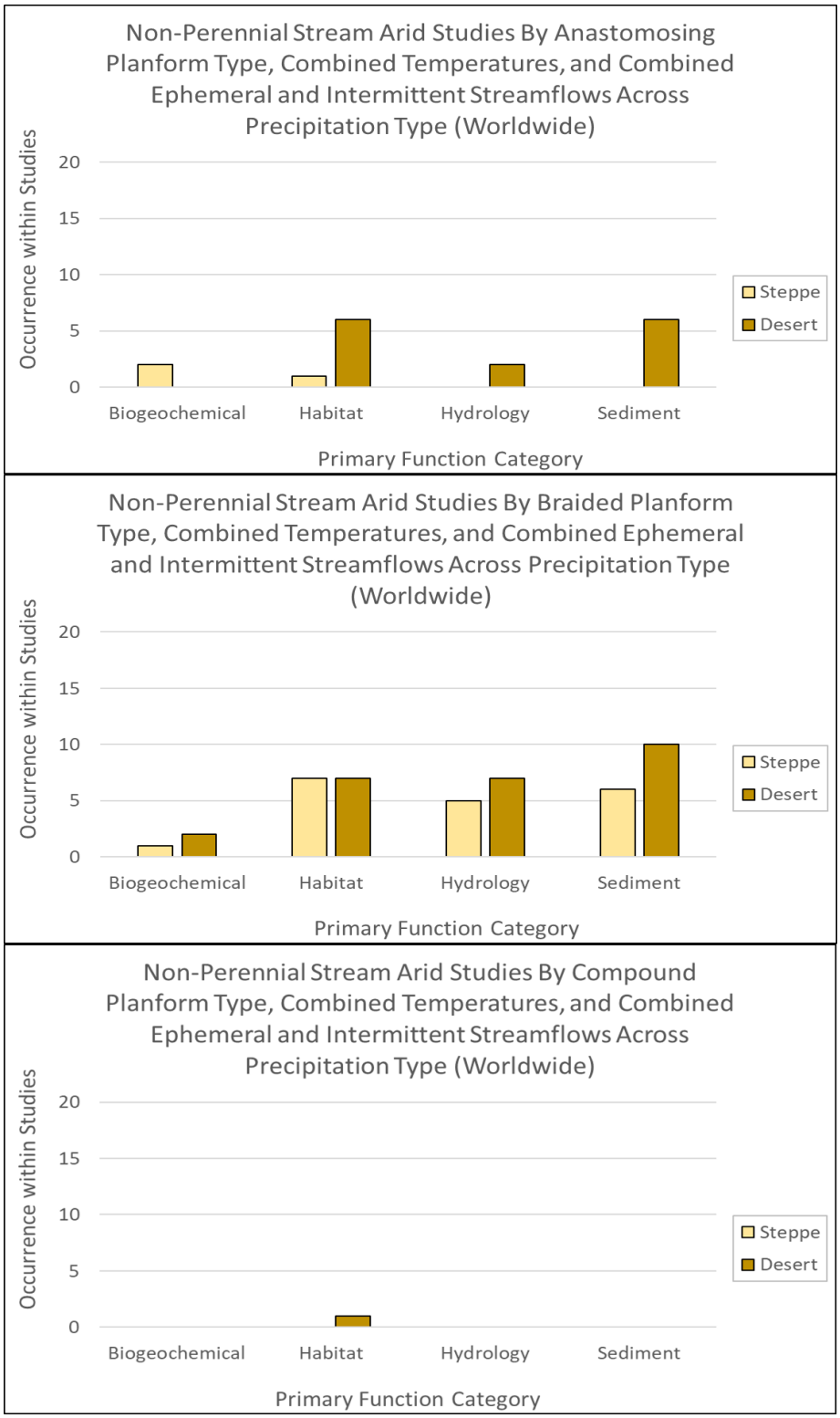


Figure 146. Sampling of each Group 2 condensed planform type across primary broad function categories and precipitation types, within global arid non-perennial stream literature.

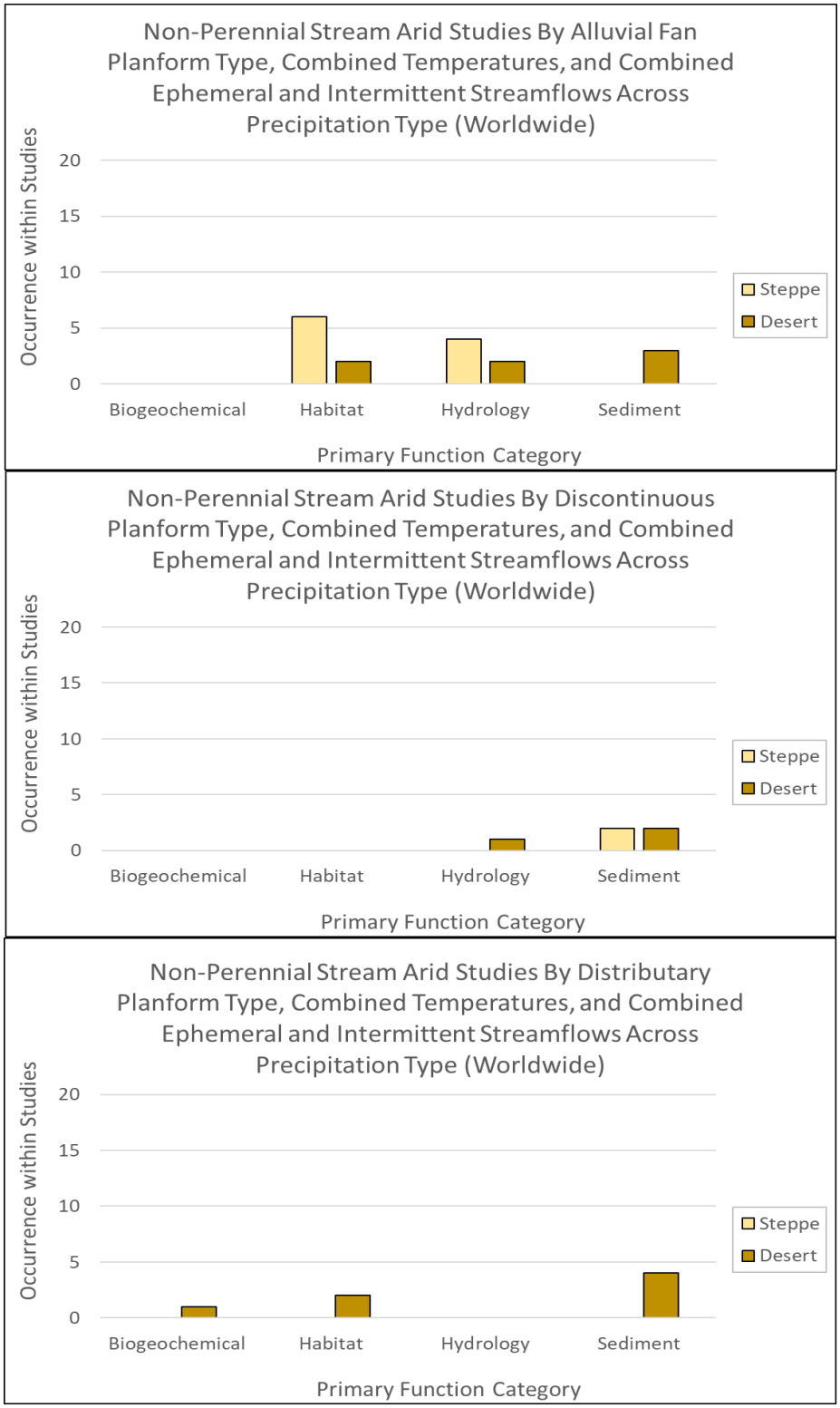


Figure 147. Sampling of each Group 3 condensed planform type across primary broad function categories and precipitation types, within global arid non-perennial stream literature.

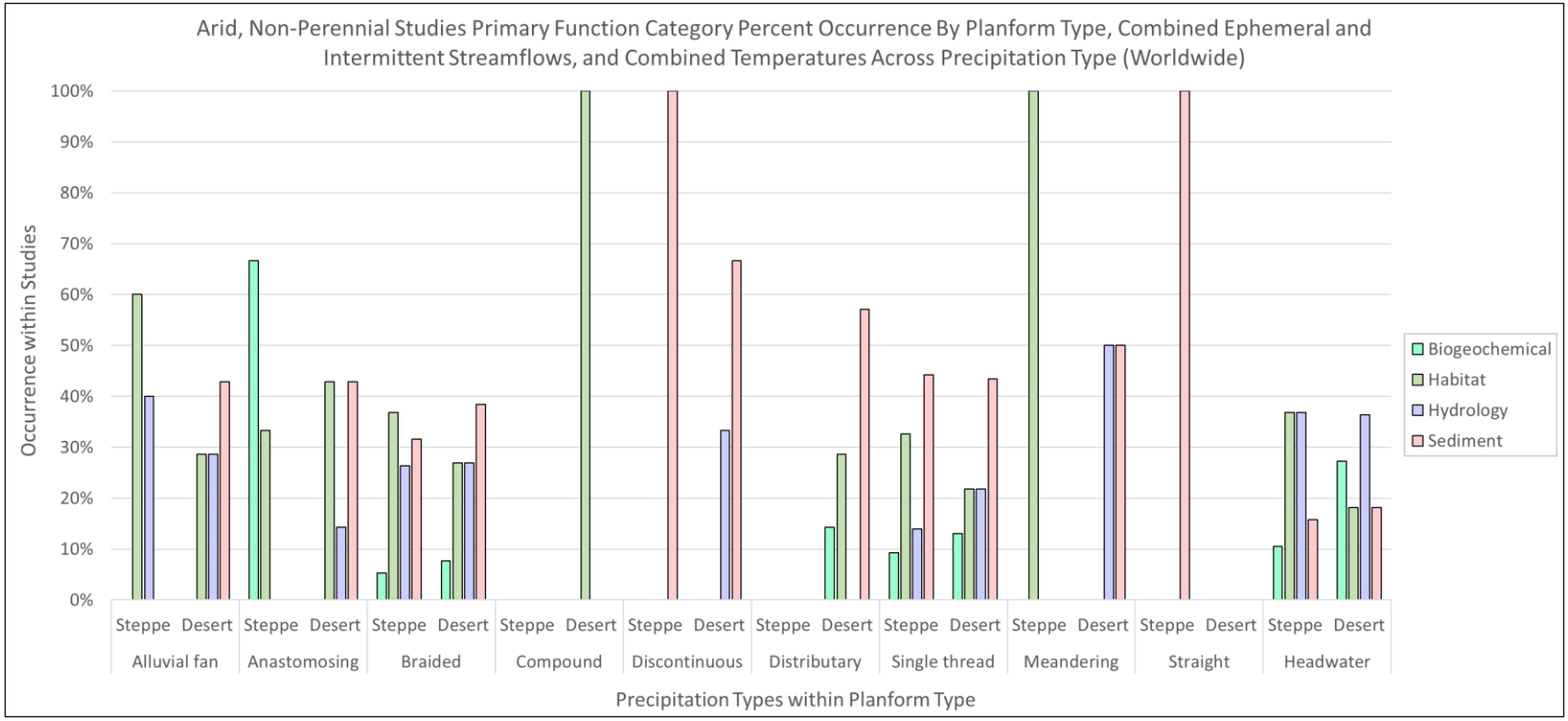


Figure 148. Sampling of primary broad function categories across condensed planform types by precipitation types, within global arid non-perennial stream literature.

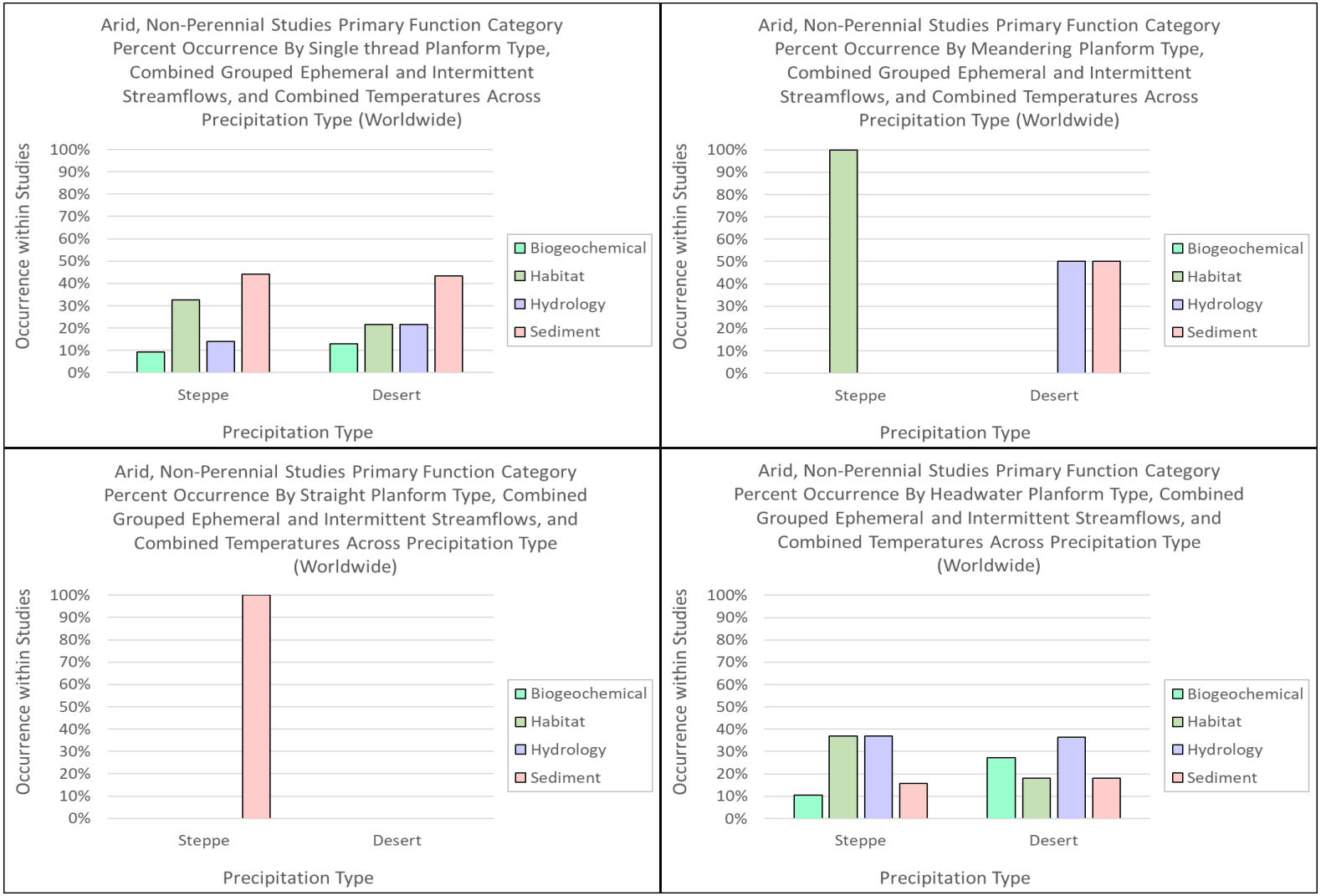


Figure 149. Sampling of primary broad function categories within each Group 1 condensed planform type across precipitation types, within global arid non-perennial stream literature.

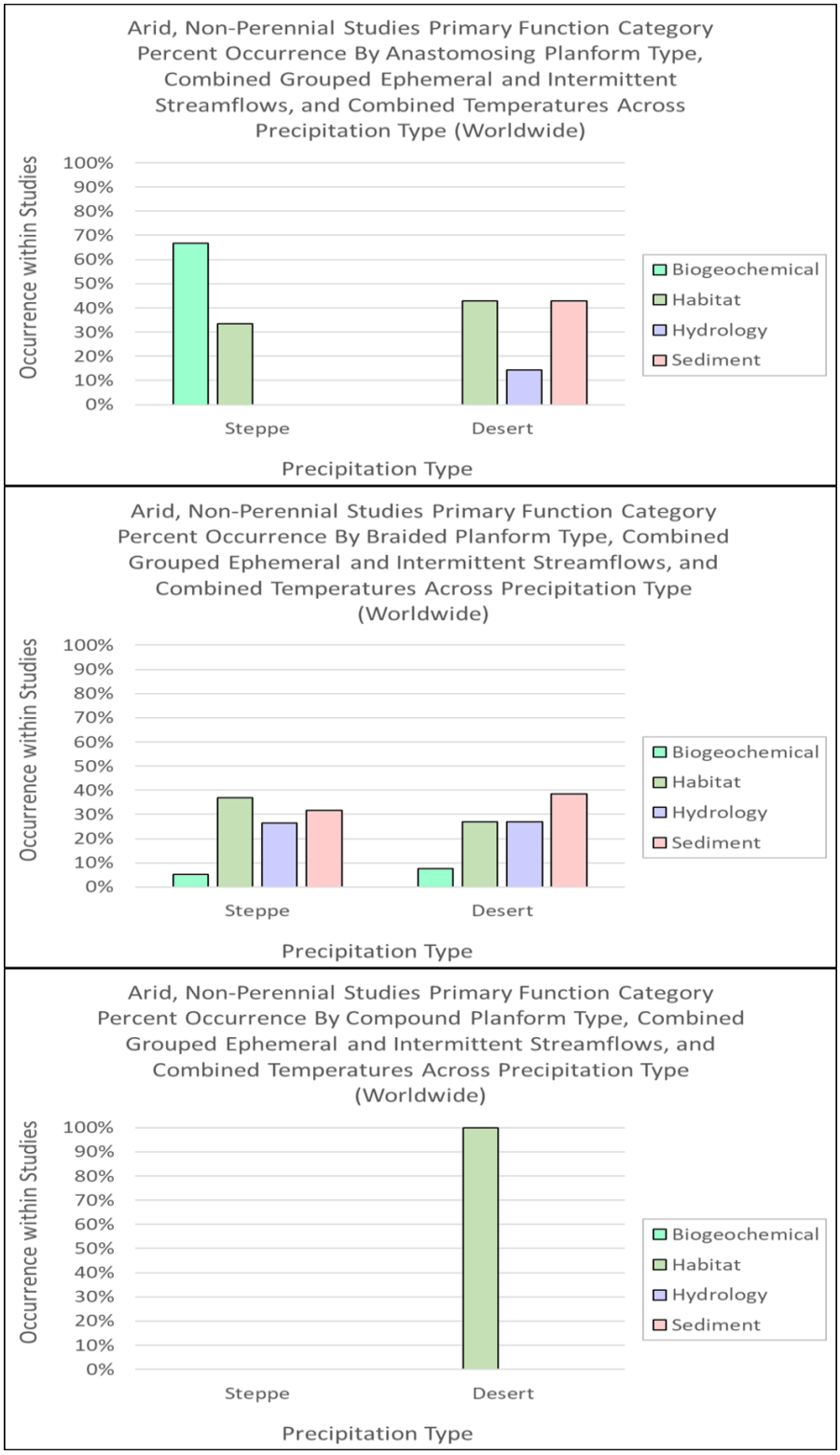


Figure 150. Sampling of primary broad function categories within each Group 2 condensed planform type across precipitation types, within global arid non-perennial stream literature.

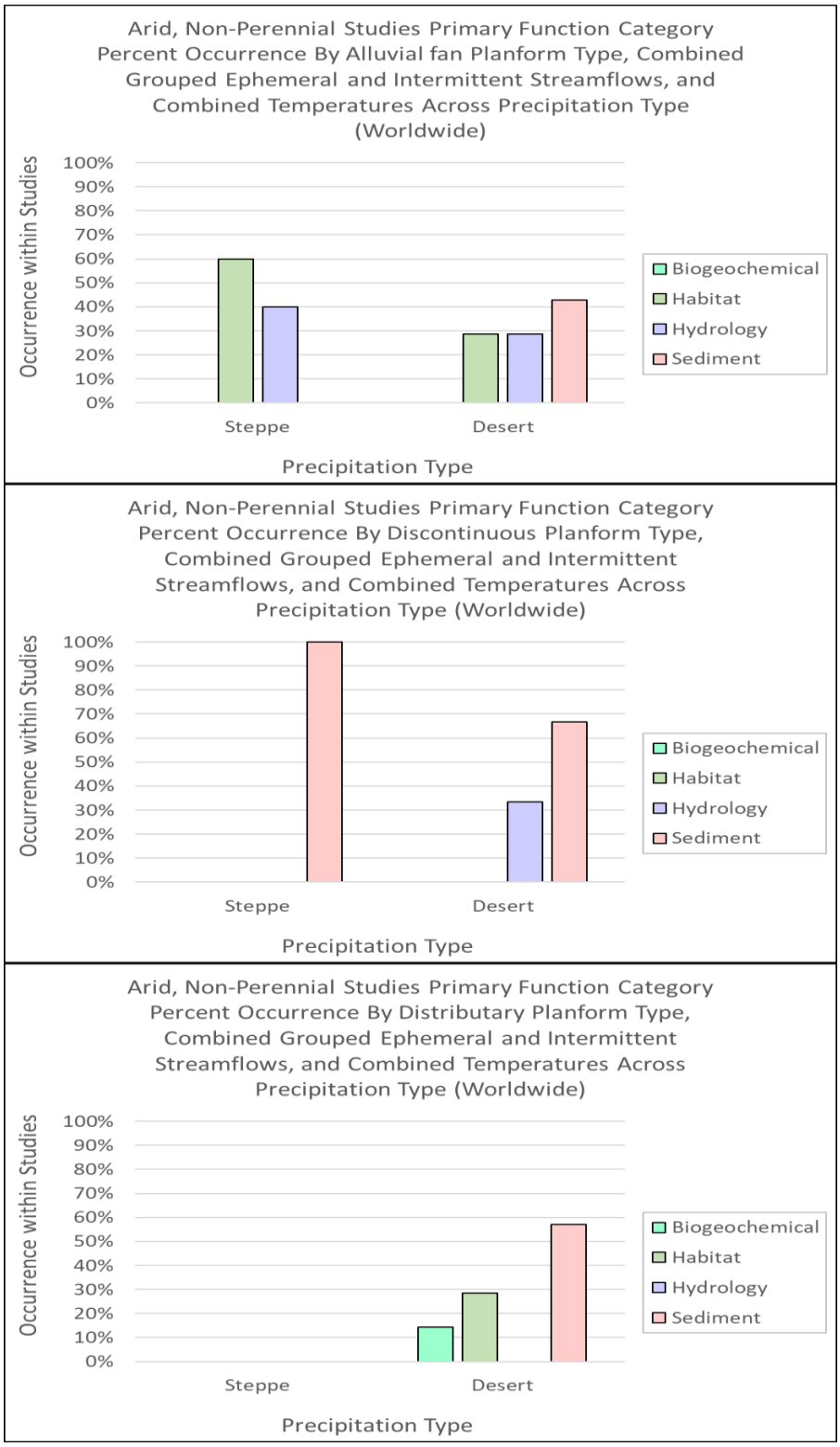


Figure 151. Sampling of primary broad function categories within each Group 3 condensed planform type across precipitation types, within global arid non-perennial stream literature.

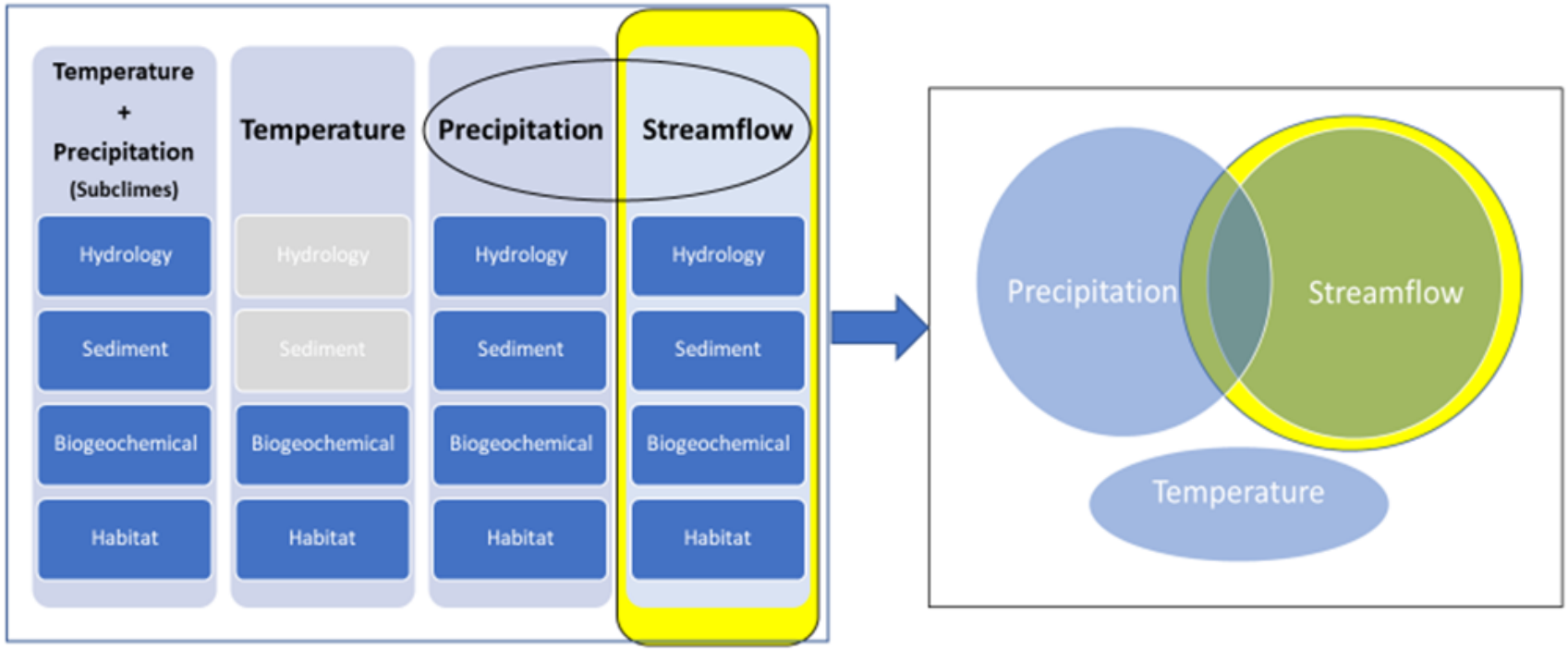


Figure 152. The conceptual relations and hierarchies of a hydrology component (streamflow types) factor and its influence on broad stream function categories.

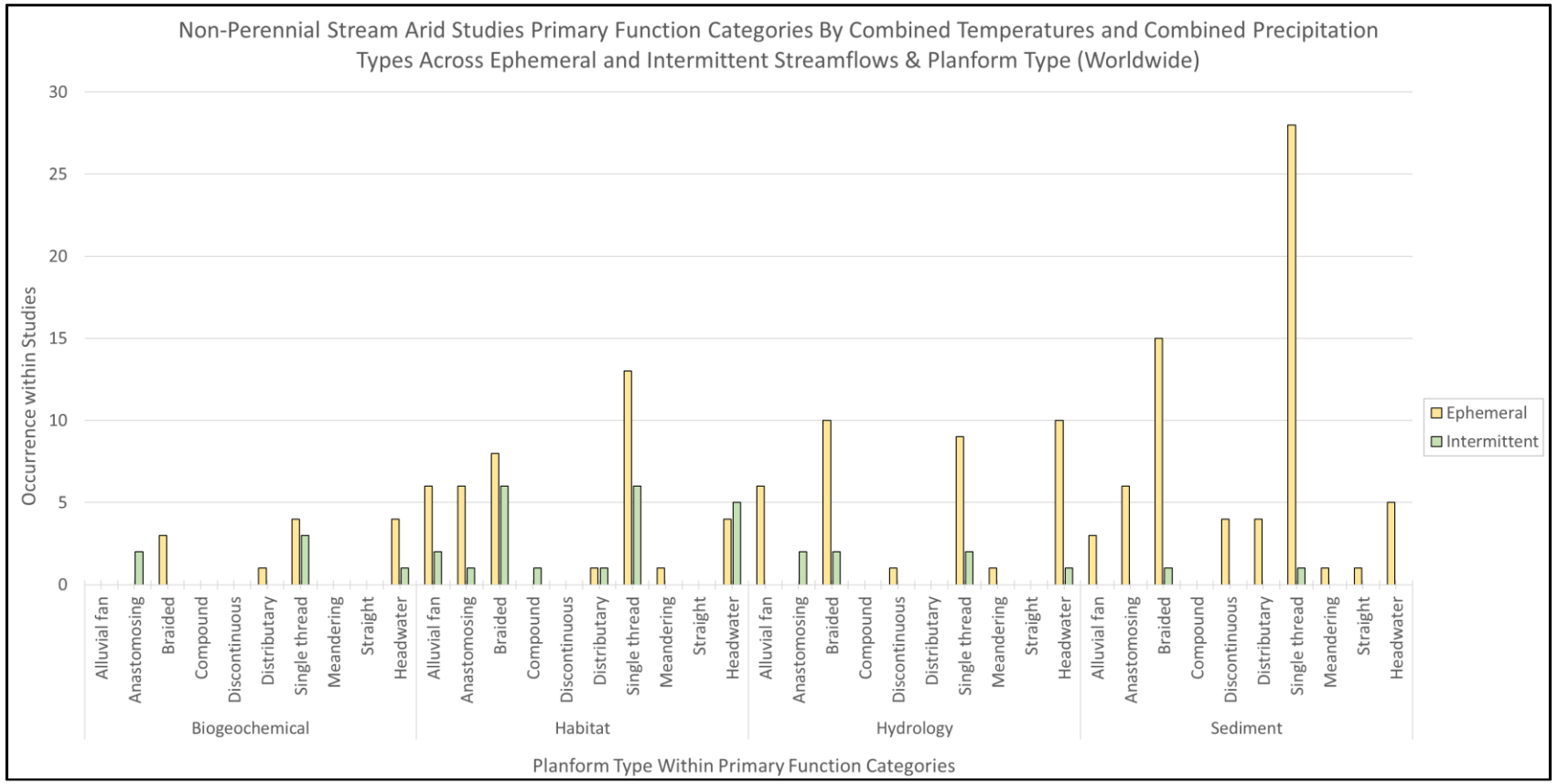


Figure 153. Sampling of primary broad function categories across condensed planform types by ephemeral and intermittent streamflow types, within global arid non-perennial stream literature.

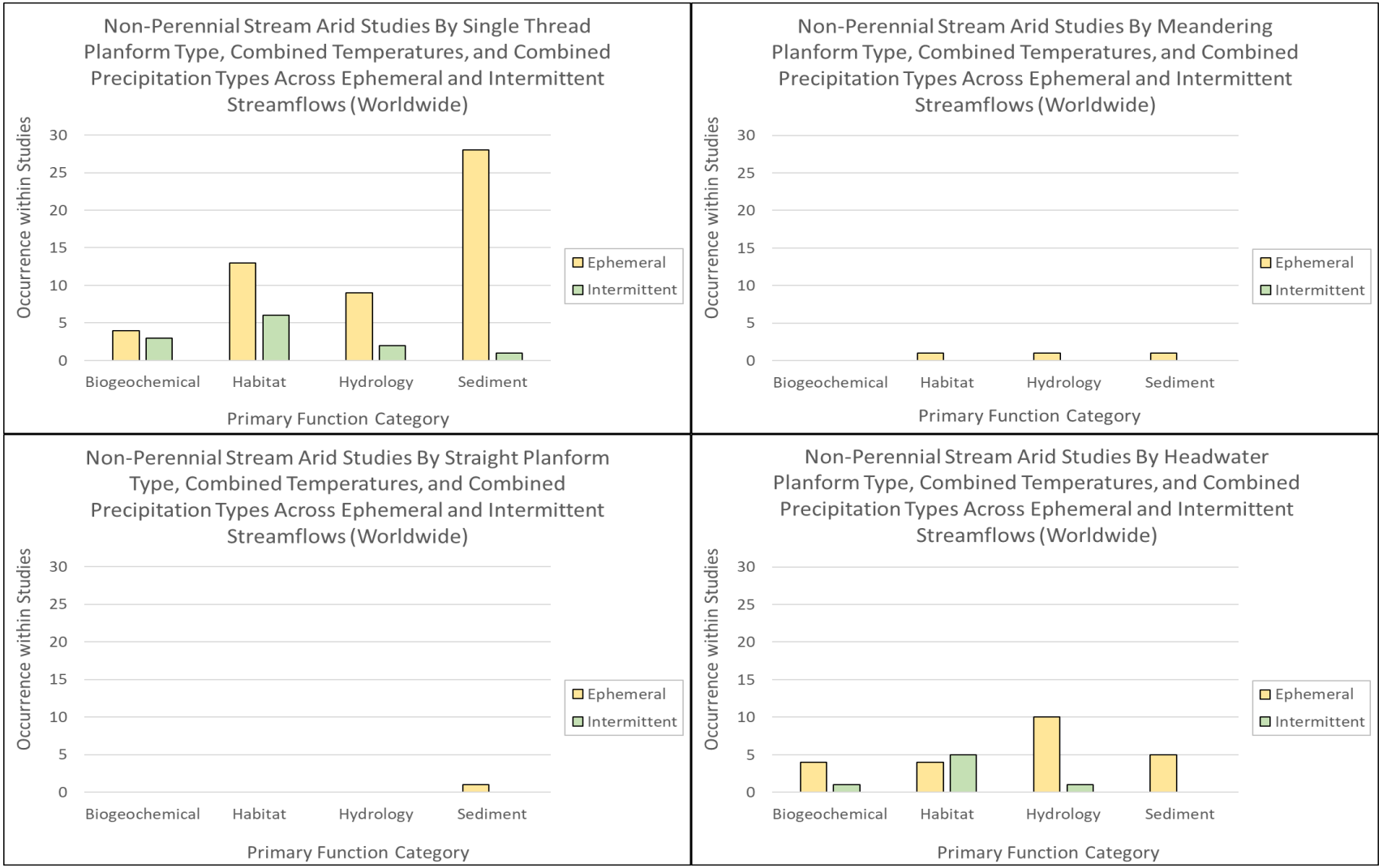


Figure 154. Sampling of each Group 1 condensed planform type across primary broad function categories and ephemeral and intermittent streamflow types, within global arid non-perennial stream literature.

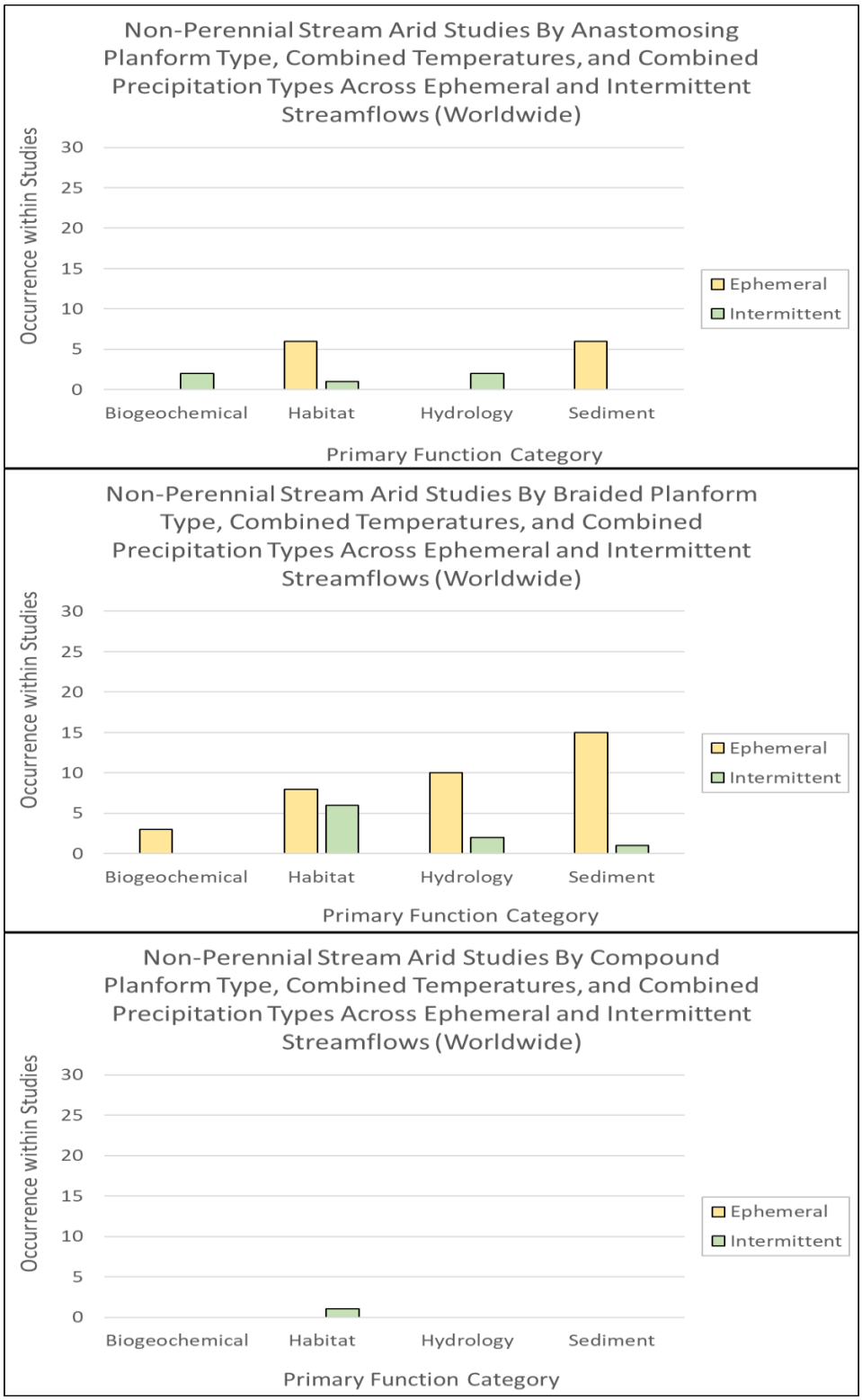


Figure 155. Sampling of each Group 2 condensed planform type across primary broad function categories and ephemeral and intermittent streamflow types, within global arid non-perennial stream literature.

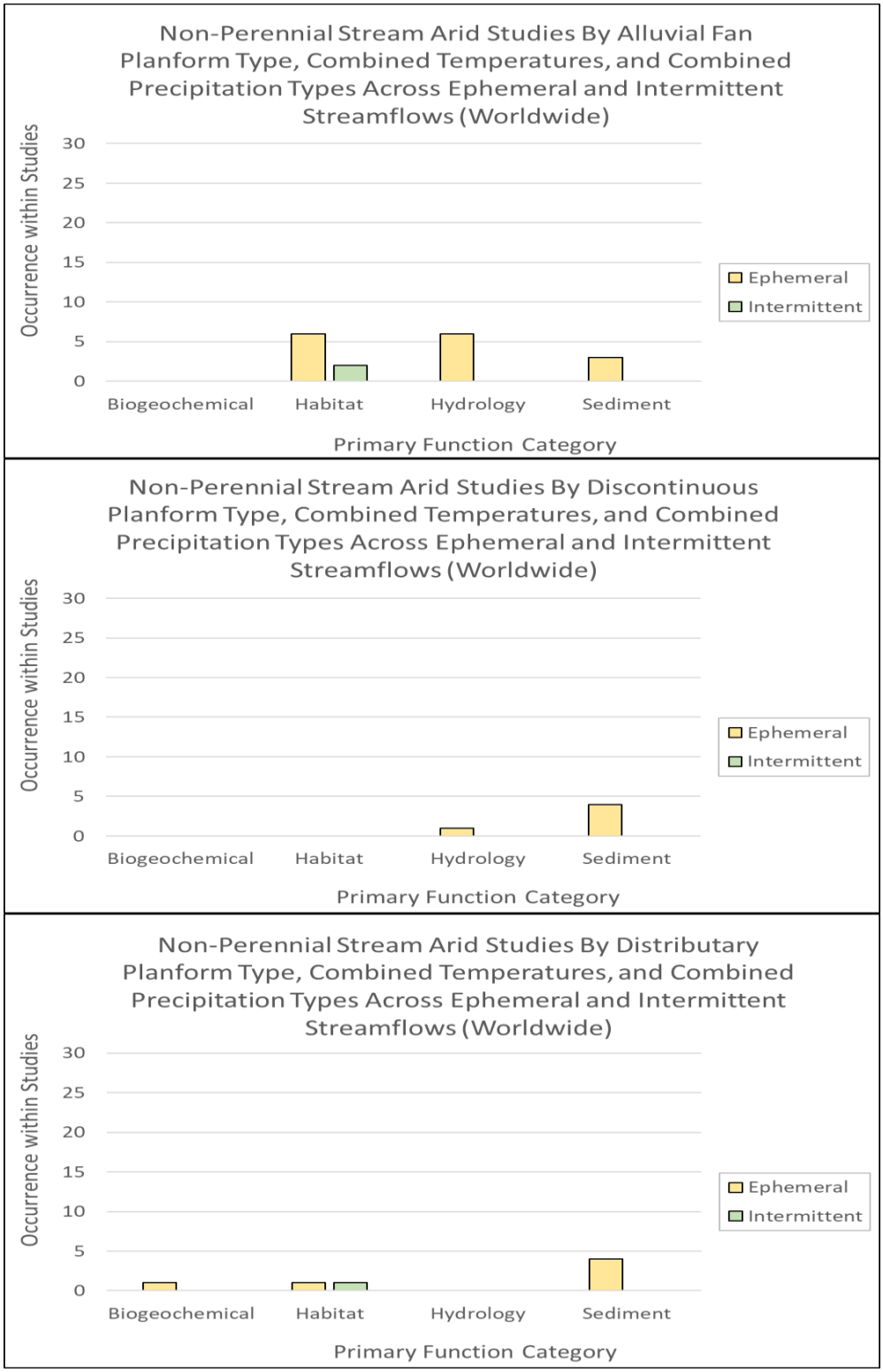


Figure 156. Sampling of each Group 3 condensed planform type across primary broad function categories and ephemeral and intermittent streamflow types, within global arid non-perennial stream literature.

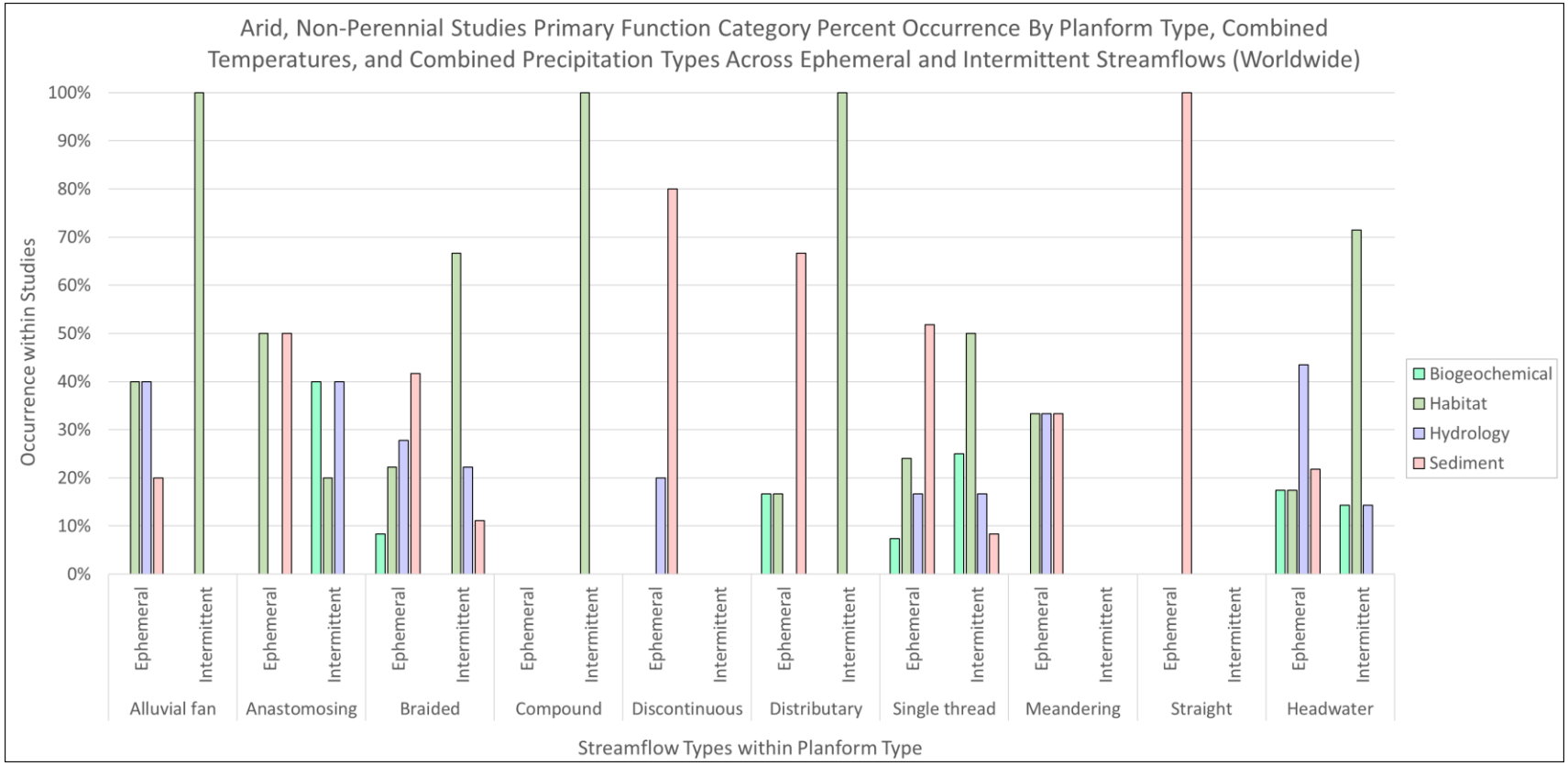


Figure 157. Sampling by condensed planform types across primary broad function categories and ephemeral and intermittent streamflow types, within global arid non-perennial stream literature.

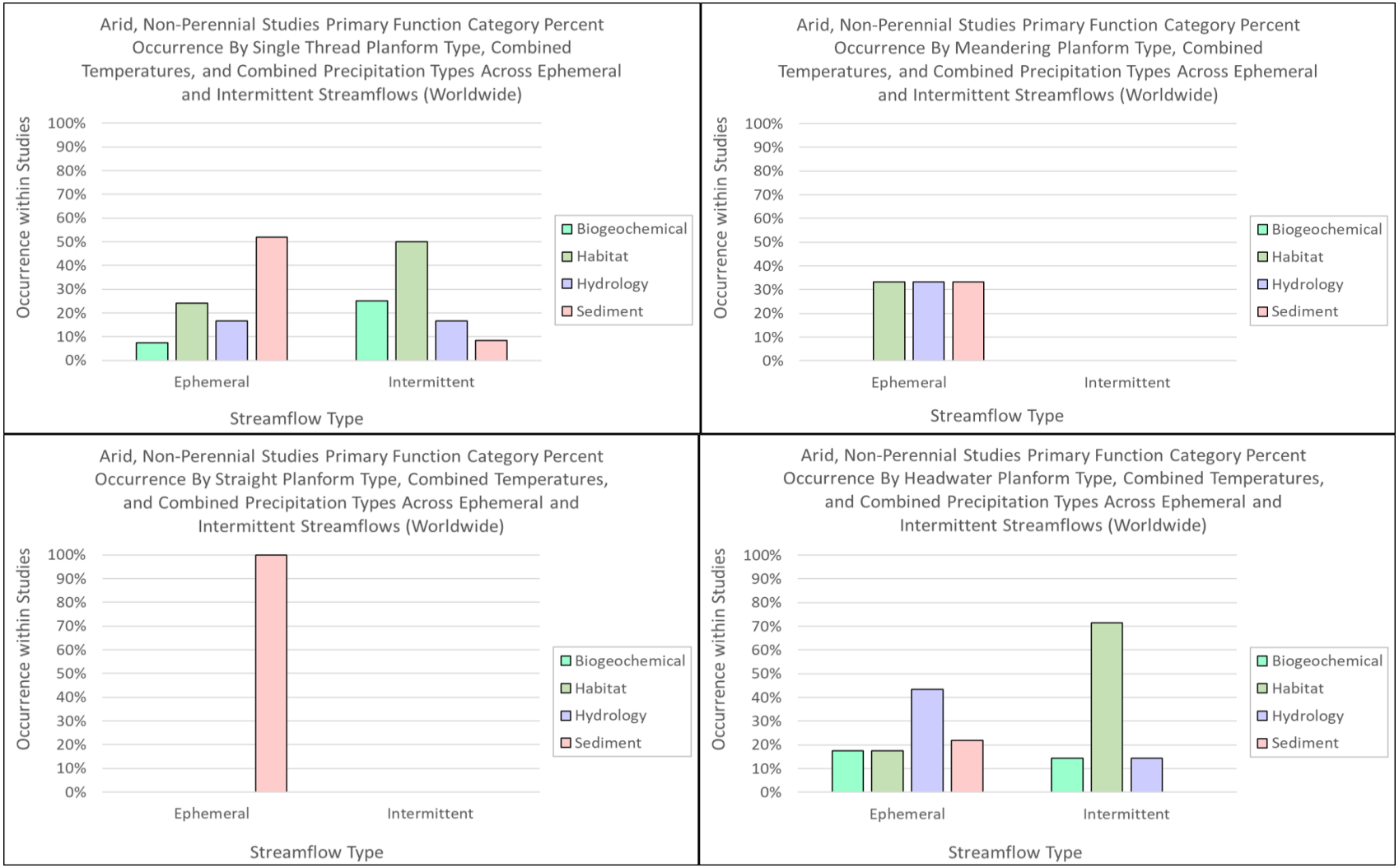


Figure 158. Sampling of primary broad function categories within each Group 1 condensed planform type across ephemeral and intermittent streamflow types, within global arid non-perennial stream literature.

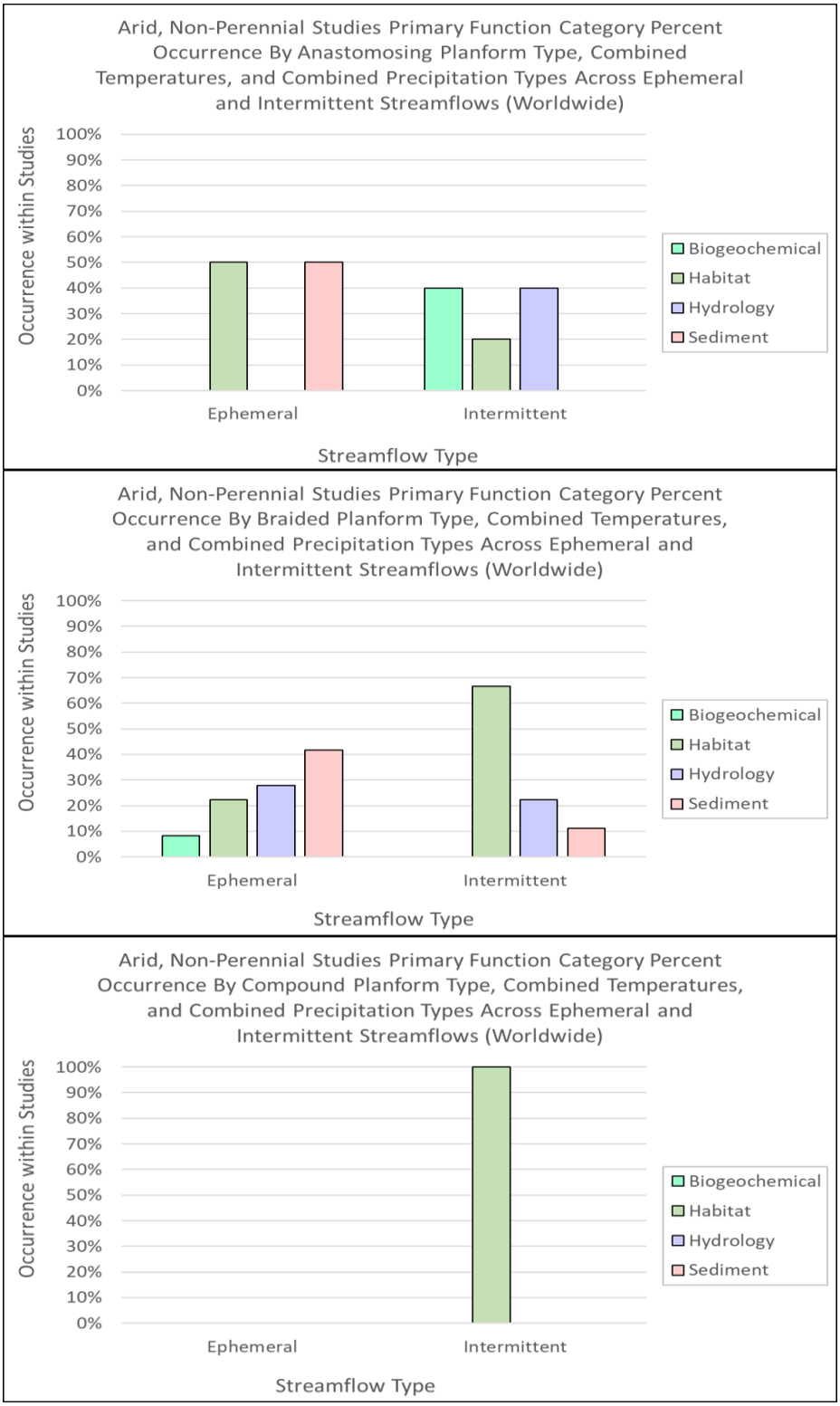


Figure 159. Sampling of primary broad function categories within each Group 2 condensed planform type across ephemeral and intermittent streamflow types, within global arid non-perennial stream literature.

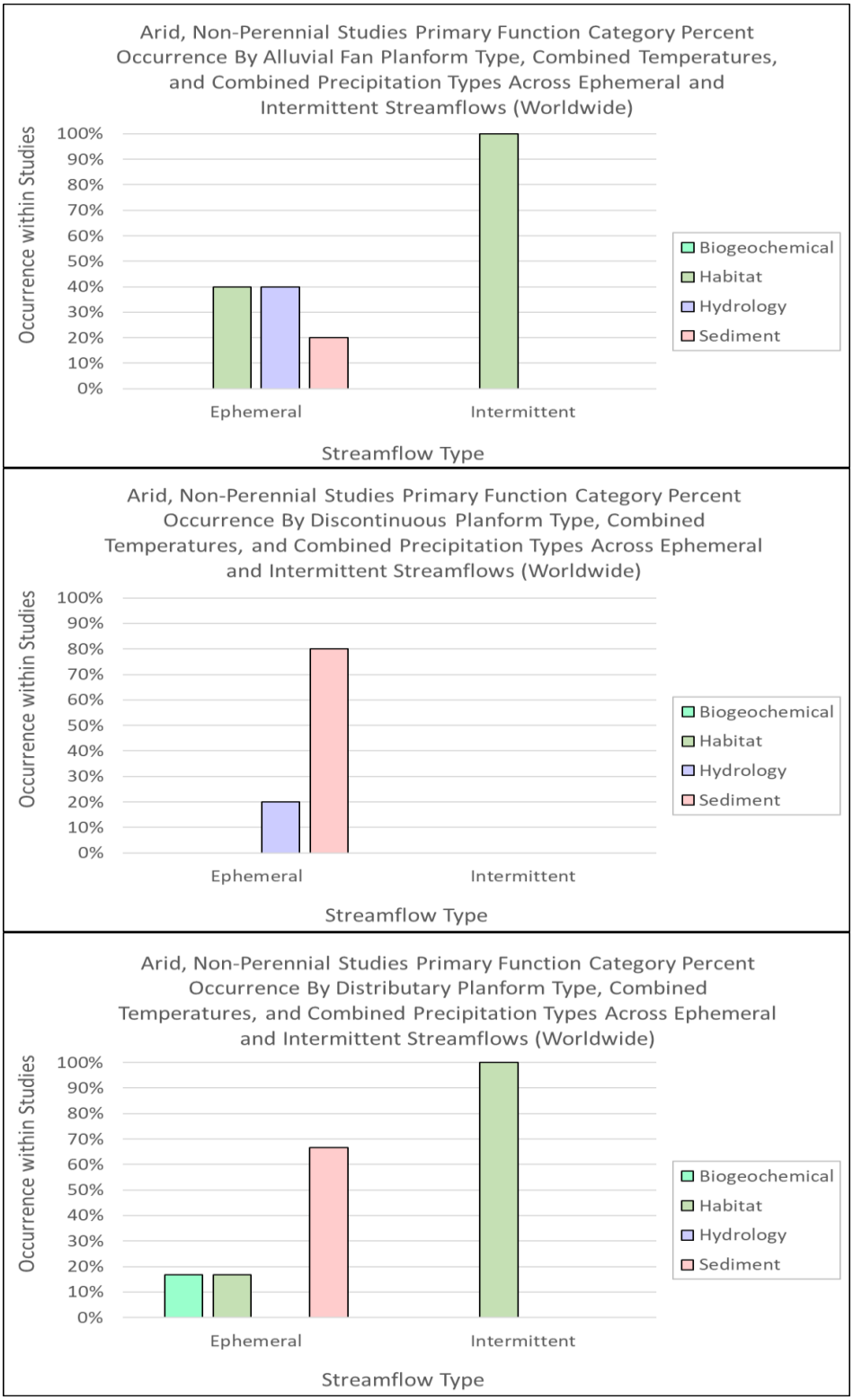


Figure 160. Sampling of primary broad function categories within each Group 3 condensed planform type across ephemeral and intermittent streamflow types, within global arid non-perennial stream literature.

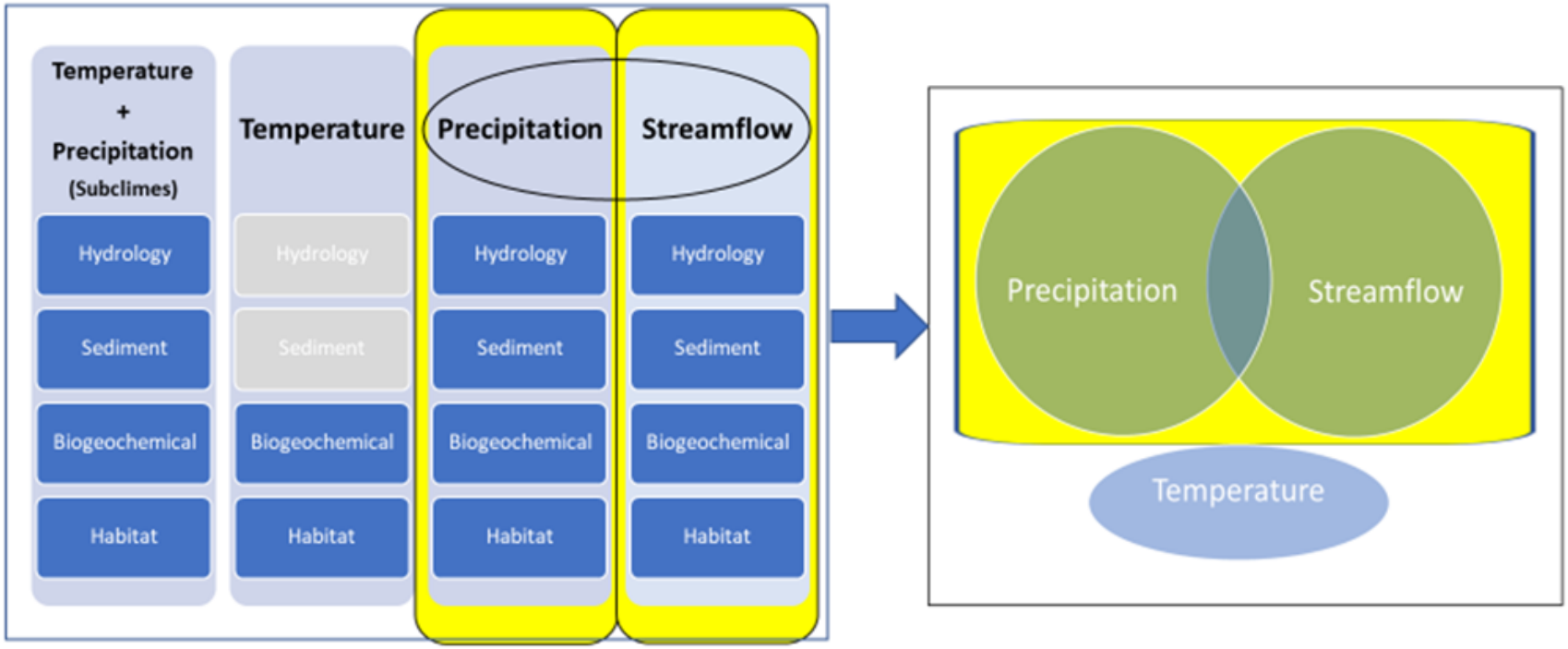


Figure 161. The conceptual relations and hierarchies of hydrology (precipitation and streamflow types) factors and their influence on broad stream function categories.

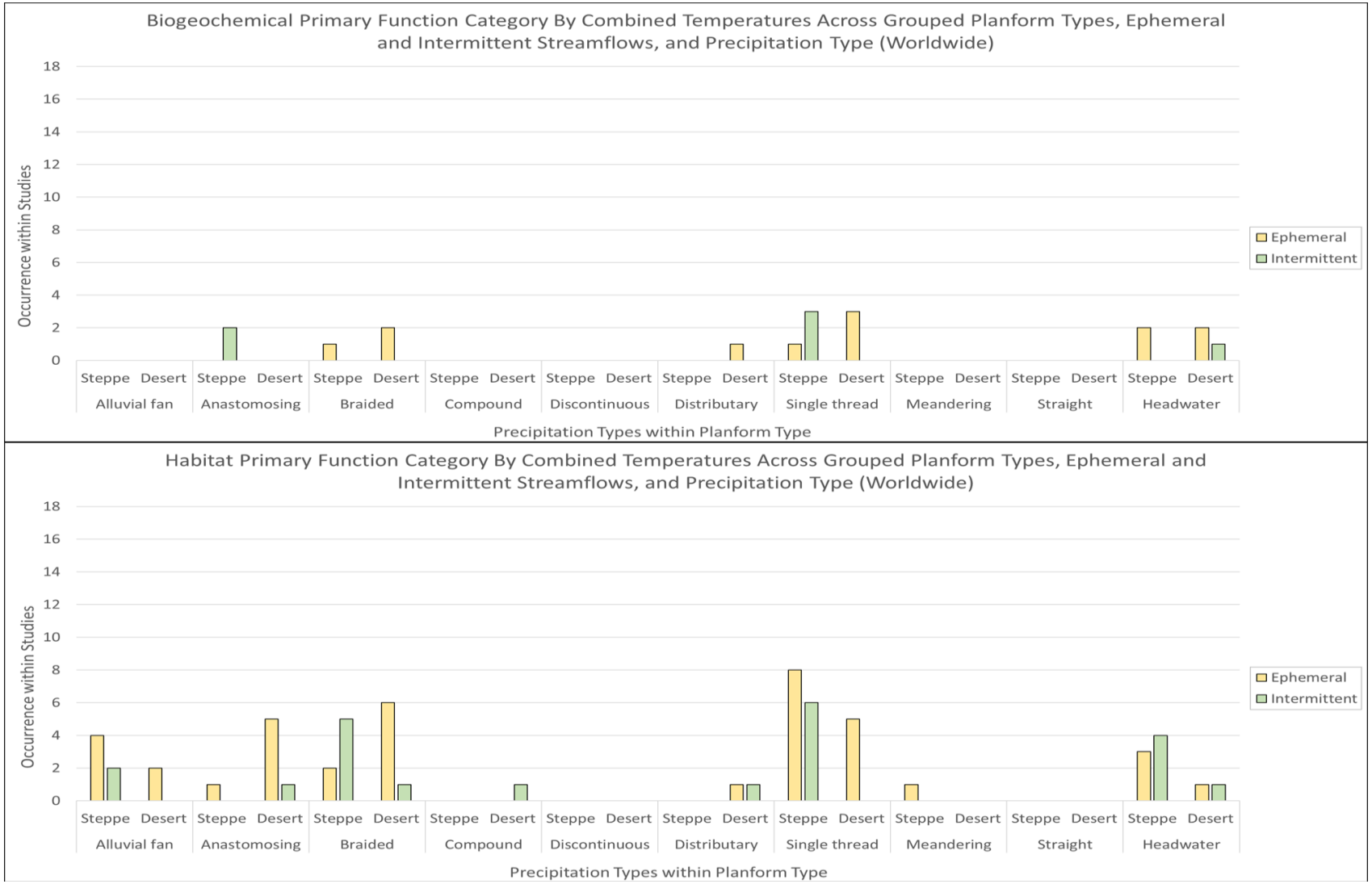


Figure 162. Sampling of Biogeochemical and Habitat function categories by condensed planform types across precipitation types and ephemeral and intermittent streamflow types, within global arid non-perennial stream literature.

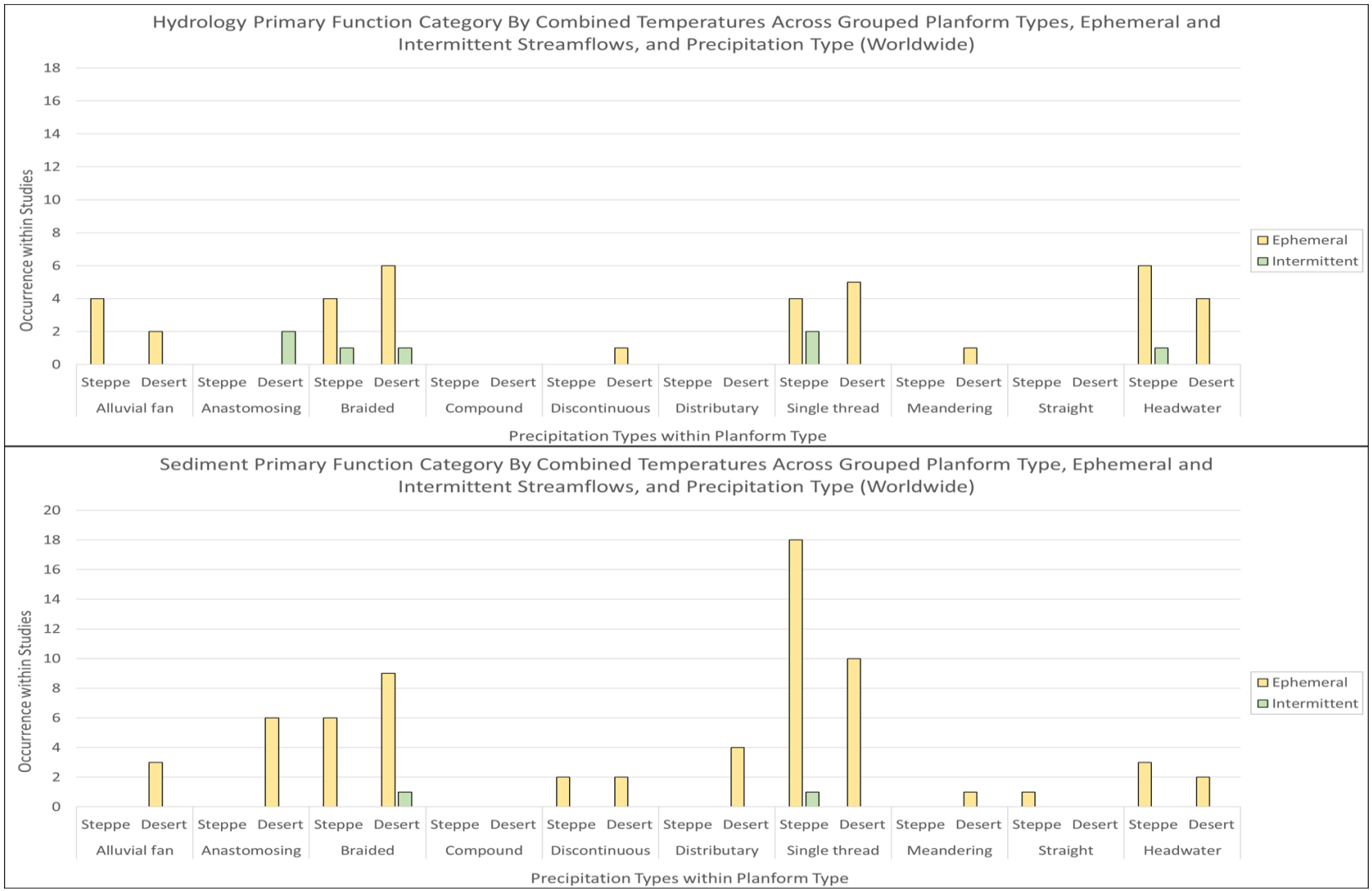


Figure 163. Sampling of Hydrology and Sediment function categories by condensed planform types across precipitation types and ephemeral and intermittent streamflow types, within global arid non-perennial stream literature.

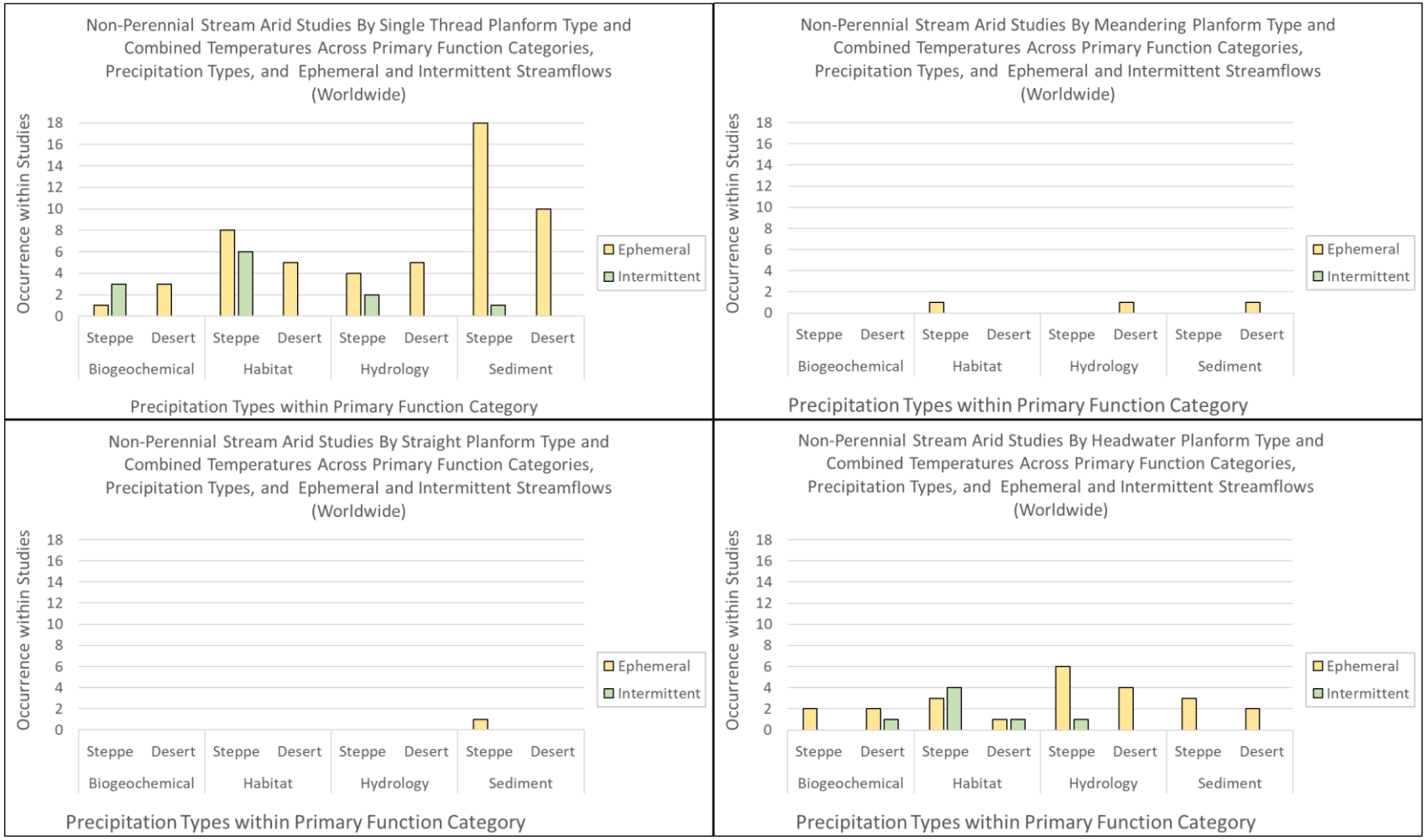


Figure 164. Sampling of primary broad function categories by each Group 1 condensed planform type across precipitation types and ephemeral and intermittent streamflows, within global arid non-perennial stream literature.

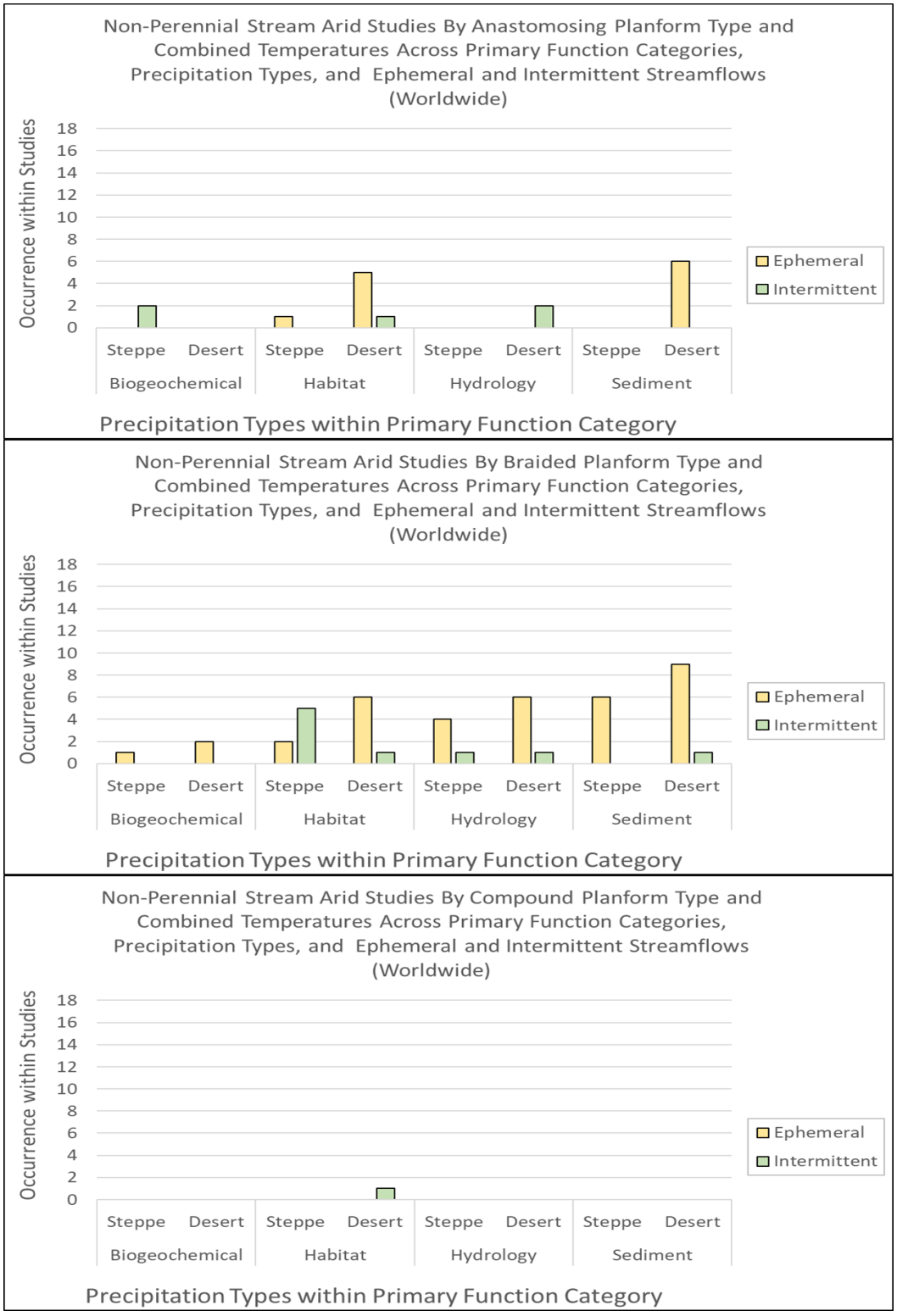


Figure 165. Sampling of primary broad function categories by each Group 2 condensed planform type across precipitation types and ephemeral and intermittent streamflows, within global arid non-perennial stream literature.

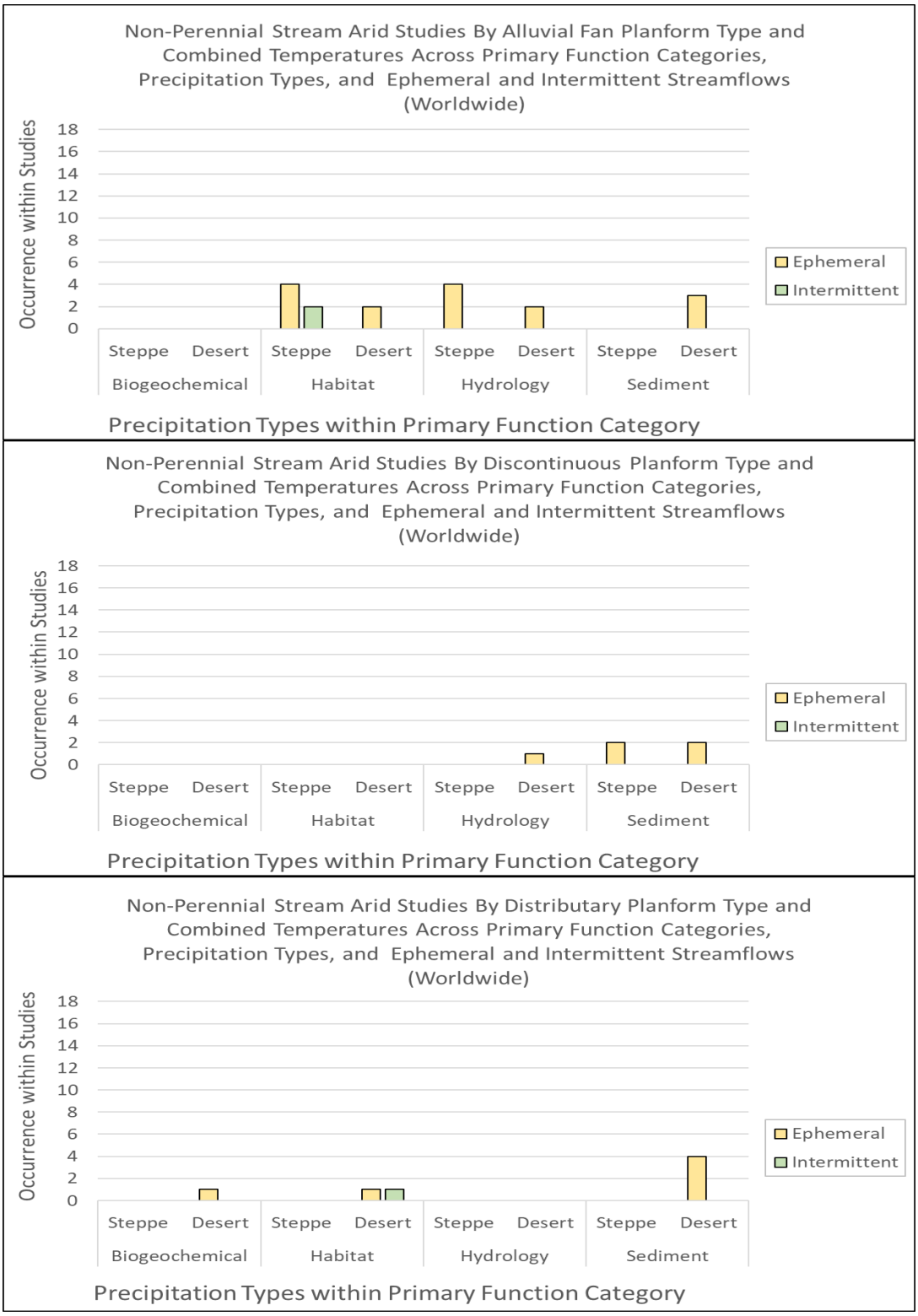


Figure 166. Sampling of primary broad function categories by each Group 3 condensed planform type across precipitation types and ephemeral and intermittent streamflows, within global arid non-perennial stream literature.

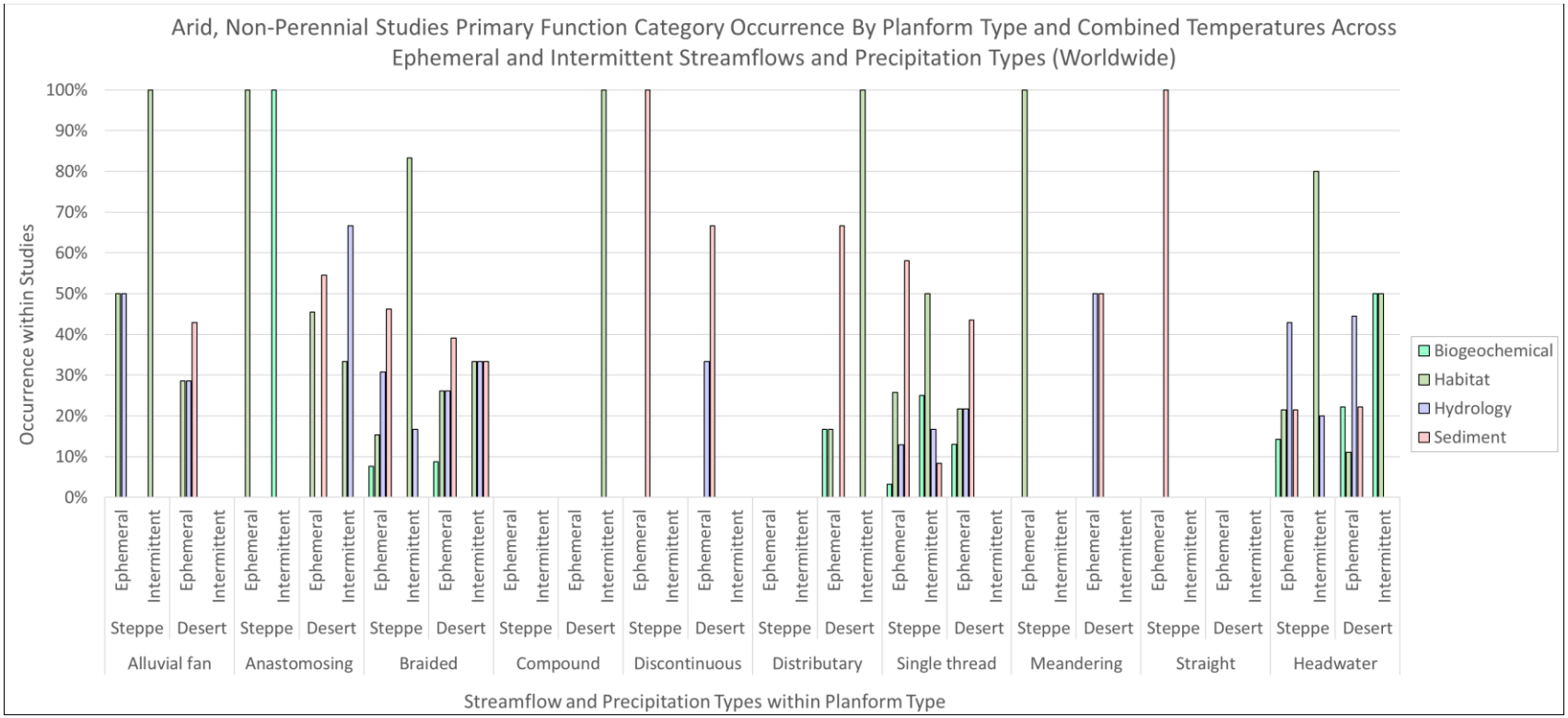


Figure 167. Sampling by condensed planform types across primary broad function categories, ephemeral and intermittent streamflow types, and precipitation types, within global arid non-perennial stream literature.

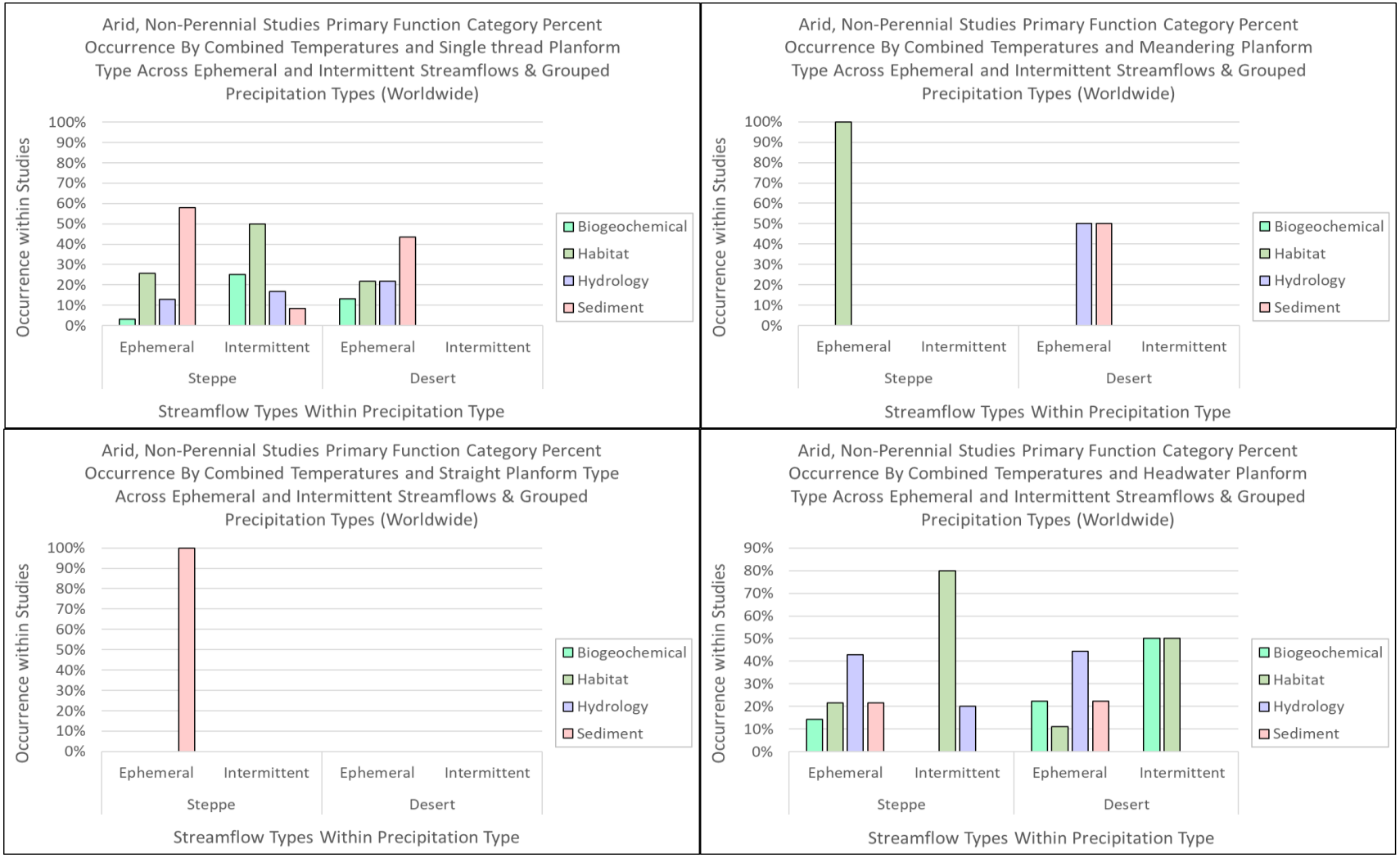


Figure 168. Sampling of each Group 1 condensed planform type across primary broad function categories by precipitation types and ephemeral and intermittent streamflows, within global arid non-perennial stream literature.

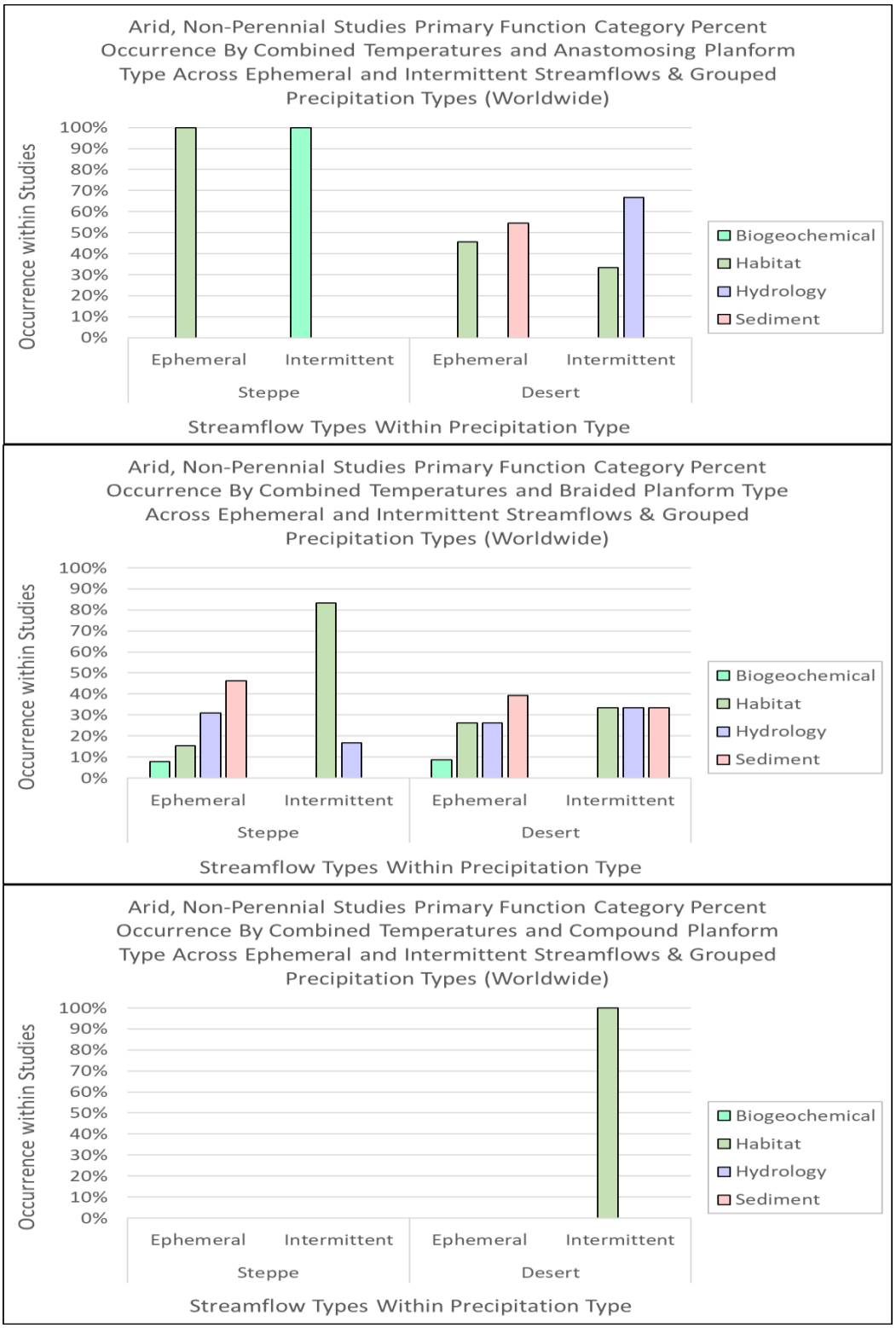


Figure 169. Sampling of each Group 2 condensed planform type across primary broad function categories by precipitation types and ephemeral and intermittent streamflows , within global arid non-perennial stream literature.

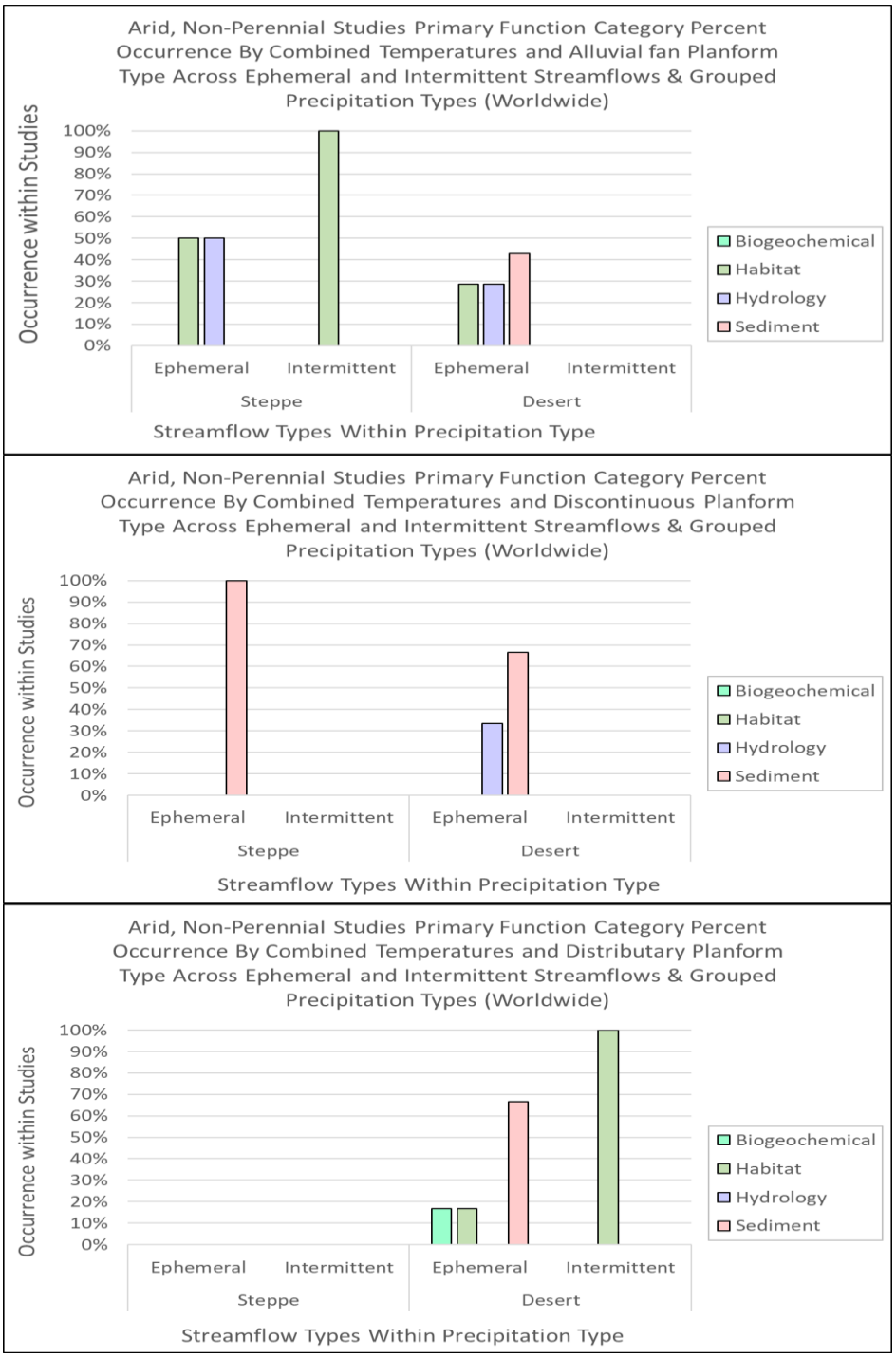


Figure 170. Sampling of each Group 3 condensed planform type across primary broad function categories by precipitation types and ephemeral and intermittent streamflows , within global arid non-perennial stream literature.

Functions and Sampling Location Parameter

The specific functions and level of functions a stream may provide are in context of the environmental settings, including the consideration of the riverine corridor and different hydrogeomorphic surfaces or subareas, herein referred to as sampling locations (Figure 171). Similar to stream classifications, differentiating the various macro- and micro-subareas within the river corridor is a means by which to group similarly situated and typically smaller-scale stream site subareas, and thus functions (Fisher et al., 2007; Meitzen et al., 2013), based on prevailing hydrological and geomorphic characteristics (Harman et al., 2012; Meitzen et al., 2013; Wohl et al., 2016). Studies have noted differences in Habitat, Hydrology, Sediment and Biogeochemical functions by different zones within the cross section of river corridors (Harvey & Gooseff, 2015; Poff et al., 1997; J. Stromberg et al., 2015; Wohl et al., 2016). It is also relatively common for studies to specifically focus on within stream, low-flow areas, and other macro-diverse zones of the larger stream corridor, which will differ in various hydrology, sediment, and vegetation characteristics (Mersel et al., 2014; Wohl et al., 2016). Yet studies still note the lack of collective functions information across channels of different flow regimes and channel subareas, including for Biogeochemical functions (Lohse et al., 2020; J. Stromberg et al., 2015). Moreover, not much is collectively known how and to what extent the Habitat, Biogeochemical, Hydrology and Sediment primary function categories have been documented among these different subareas of stream systems. This information is also important for the development and evaluation of stream assessment, management, regulation and other purposes (David et al., 2021; Fischenich, 2006; Mersel et al., 2014). Therefore, the river corridor site

location where stream functions data is generated is an important environmental parameter for consideration in stream functions (D.E. Somerville, 2010; James H. Thorp et al., 2010), in addition to streamflow regimes and climactic factors (Mersel et al., 2014).

Unlike watershed position and stream planform types, the arid non-perennial stream sampling location(s) of the primary function categories were listed or otherwise discernable for all global and U.S. studies. The different sampling locations originally recorded included: “stream”, “in-stream waterhole”, “in-stream stock pond”, “in-stream riffle”, “in-stream reservoir”, “in-stream pool”, “floodplain waterhole”, “floodplain”, “catchment scale”, and “basin scale” (Table 32) (Figure 172). For practicality of data analyses, equivalent sampling locations were further condensed into the eight subcategories of: “in-stream riffle”, “in-stream reservoir”, “in-stream pool”, “stream”, “floodplain waterhole”, “floodplain”, “catchment scale”, and “basin scale” subcategories (Figure 173), capturing all study sampling scales and site subarea detail (as best ascertained). For the most part, the documented study sampling locations represent the various subareas encountered along the lateral portion, or cross sections, of streams. Furthermore, as there are some general, broad similarities among the various sampling location types, results were typically organized within the three general groupings of (1) “catchment scale”, and “basin scale”, (2) “floodplain” and “floodplain waterhole”, and (3) “stream”, “in-stream pool”, “in-stream reservoir”, and “in-stream riffle”. The first grouping has the commonality of larger scale settings of stream system sampling. The second grouping is linked as riverine corridor subareas primarily situated outside of the stream proper, while the third grouping is broadly portrayed as within-channel subareas. As U.S. studies data comprised a significant portion of all global studies and overall data trends were similar between both, except

for the basic overview of stream functions with sampling location types described below, all other sampling location are herein presented only for the global literature set.

Both global and U.S. studies exhibited the highest representation of sampling locations within streams (>50%) followed by floodplains (>20%) across all Biogeochemical, Habitat, Hydrology and Sediment function studies (Figure 173) (Table 33). These results are interesting, especially in terms of the Habitat functions category, as arid non-perennial streams can lack in-channel vegetation (i.e. Habitat functions category) compared to surrounding upland areas such as floodplains, due to storm flow scour and deposition disturbances within channel (J. C. Stromberg et al., 2007). In terms of the opposite perspective, focusing on the sampling location subcategories and the coverage of all stream function categories within each (Figure 174), the overall global studies covered the Habitat function category the most, followed by Sediment, Biogeochemical, and Hydrology function studies. Though U.S. studies followed general global patterns of the level of the primary functions covered within the dominant stream and floodplain areas and other sampling areas, the overall coverage of all four functions deviated from global stream planform studies with a predominance of Habitat function coverage, followed by Biogeochemical, Sediment, and Hydrology functions. It's interesting that overall coverage of the primary function categories across stream sampling types within only global studies are not consistent with the pattern of the overall studies coverage of the primary function categories (Figure 23), where representation from highest to lowest is Habitat, Biogeochemical, Sediment and Hydrology functions. For global studies, there is a slight difference of greater Sediment compared to Hydrology function categories coverage.

The next steps of global data layering included all climate and hydrology aspects, in addition to that of the primary function categories with sampling location subcategories (Figure 175). As detailed within Figure 176, the broad function categories of arid non-perennial studies were examined in terms of overall climate (e.g., subclimes) with all hydrology components (inherent precipitation types and specific streamflow regimes). This data layering represented the most influence on the function categories, as it combined both system hydrology components along with temperature. When examining the distribution of Koppen-Geiger subclimes, sampling location subcategories, and ephemeral and intermittent streamflow regimes across each primary function category, there is an general pattern of predominance of ephemeral stream coverage across all sampling location types within the hot desert subclime, followed by coverage of intermittent streams within cold steppe subclime (Figure 177, Figure 178) (Table 34). Also, least represented across all sampling location types and primary function categories were intermittent studies within cold desert subclimes. This is mostly consistent with the overall data pattern of greater coverage of ephemeral vs intermittent streams for all functions other than the Habitat category (Figure 32), although here Habitat stream sampling location studies were also dominated by both ephemeral and intermittent stream studies. There was an interesting trend specifically with the Hydrology functions category, where study coverage departed from the predominant stream and floodplain sampling locations also reflecting dominant coverage within the function categories, as was the case for the Habitat, Biogeochemical, and Sediment functions. In this instance, second only to the stream sampling location type, across both streamflow regimes the Sediment function studies tended to be spread out more evenly across the majority of other sampling locations. Somewhat different patterns emerge in terms of the overall three

groupings of sampling location types and their proportional representation of the primary function categories (Figure 179, Figure 180, Figure 181), where the Habitat function category is most represented by sampling areas both within riverine corridor subareas outside of and within-channel, and Hydrology functions have the highest coverage within larger scale stream system sampling. In terms of the opposite perspective, focusing on the percent contribution of primary function categories within studies covering a specific sampling location type, subclime, and streamflow regime, these same patterns were more clearly evident (Figure 182, Figure 183, Figure 184). Most function categories coverage across all sampling location types were primarily within ephemeral stream studies, higher representation of Sediment and Habitat functions were evident across all sampling locations, and especially those with limited data. The highest percentage coverage of the least well represented Biogeochemical function primarily occurred within most subclimes of stream and floodplain studies, and the least coverage of all functions across all subclimes and streamflow types occurred within in-stream reservoirs, in-stream riffles and basin scale sampling locations. This may likely be due to a very small sampling size, as the highest represented sampling locations of streams and floodplains also had the greatest coverage of all function categories across subclime and streamflow types.

Similar to the above global data analyses, the subclimes data were subdivided into the separate temperature and precipitation components, which were also examined with streamflow regime types among the primary function categories and sampling location subcategories (Figure 185). Figure 186 and Figure 187 depict these data layerings in terms of each primary function category, while Figure 188, Figure 189, and Figure 190 provide a similar global data set comparison in terms of the three groupings of the stream sampling location types. Likely

influenced by overall studies coverage of precipitation (Figure 46), streamflow regime (Figure 32), and arid temperatures (Figure 42), the overall trend across global studies was an equal or greater coverage of steppe precipitation, ephemeral streams, and hot arid temperatures across all stream sampling location types (Table 35). Across all primary function categories and sampling locations, ephemeral stream studies in hot desert areas dominated, while generally ephemeral stream studies within cold desert areas were least represented. And in comparison to the patterns when sampling location types being overlain with subclime and all other data layers, there were no other additional distinct data patterns to those when examining the sampling location types across the three general groupings (Figure 188, Figure 189, Figure 190). In terms of the opposite perspective, focusing on the percent contribution of all primary function categories within a specific sampling location, temperature, arid precipitation, and streamflow regime type (Figure 191, Figure 192, Figure 193), the results were the same as those above addressing subclimes (Figure 182, Figure 183, Figure 184). Most function categories coverage across all sampling location types were primarily within ephemeral stream studies, higher representation of Sediment and Habitat functions were evident across all sampling locations, and the highest percentage coverage of the least well represented Biogeochemical function primarily occurred within most subclimes of subclimes of stream and floodplain studies (the second and third sampling location groups).

In beginning to separate out the hydrology components, by not including specific streamflow regimes, studies coverage of the primary functions categories were layered with only subclimes (temperature and inherent precipitation) and sampling location subcategories (Figure 194). Within global studies across all sampling location types, the overall trend is similar with a

predominance of all primary functions coverage within the hot desert subclime, except for the Biogeochemical and Habitat function categories that were most represented within hot steppe and cold steppe subclimes, respectively (Figure 195) (Table 36). There was also the least coverage of all function categories within the cold desert subclime. When examining the data by individual sampling location type across all primary function categories, most sampling location types deviated from the overall trend with higher representation within cold steppe subclimes (Figure 196, Figure 197, Figure 198). In terms of the opposite perspective, focusing on the percent contribution of all primary function categories within studies covering a specific sampling location and subclime type, the general trend continued to be a predominance of Habitat functions coverage across all sampling location types and by sampling location groups, except for the first grouping (catchment and basin scales) that mainly consisted of Hydrology function studies (Figure 199, Figure 200, Figure 201). For the least overall represented Hydrology and Biogeochemical function studies, the highest relative percent occurrence among the other function categories was within studies of the predominant stream, floodplain, and in-stream pool sampling types within hot desert and hot steppe subclimes.

Similar to the above data analyses, and in continuing to separate out the literature data among separate climate and hydrology components, the subclimes were further subdivided into and separately evaluated as the temperature (Figure 202) and then precipitation (Figure 211) components among the function categories they primarily influence and among sampling location types, in the absence of streamflow regime contributions. Similar to all global studies exhibiting an overall pattern of predominance within hot arid areas (Figure 42), this was mirrored within all stream sampling location types for Biogeochemical studies and most stream

sampling location types for Habitat studies (Figure 203) (Table 37). There was a noted shift in global Habitat studies with equal or greater sampling occurrences within cold arid areas among sampling location types, occurring within basin and catchment scales, in-stream pool, and in-stream riffle sampling types (Figure 204, Figure 205, Figure 206). Additionally, there was a complete lack of representation for both Biogeochemical and Habitat functions coverage within basin scale sampling areas, as well as no representation of Biogeochemical functions within at least a third of each sampling location type grouping and half of all stream sampling location types (basin scale, floodplain waterhole, in-stream reservoir, in-stream riffle areas). In terms of the opposite perspective, focusing on the percent contribution of Biogeochemical and Habitat function studies covered within a specific sampling location and arid temperature type, global studies had a strong pattern of Habitat studies outpacing Biogeochemical studies across sampling location types and hot and cold arid temperatures (Figure 207). Out of only half of stream sampling location types that did include a small percentage of Biogeochemical functions coverage, most were situated within hot arid temperature areas with smaller representation within cold arid temperatures (catchment scale, floodplain, stream, and in-stream pool areas) (Figure 208, Figure 209, Figure 210). When subsequently examining the other half component of both subclimes and hydrology, or precipitation type, in the absence of streamflow regime contributions (Figure 211), a majority of all study occurrences were within steppe precipitation areas across the primary function categories and sampling location types (Figure 212) (Table 38). This is consistent with the overall global studies primarily occurring within steppe precipitation areas (Figure 46). Only one of the individual sampling location types (floodplains) exhibited a dominant occurrence within desert precipitation areas across the function categories (Figure 213,

Figure 214, Figure 215). Moreover, all primary function categories had a clear majority of study occurrences within steppe precipitation areas (over all sampling location types). In terms of the opposite perspective, focusing on the percent contribution of primary function categories within a specific sampling location and precipitation type, there was only global coverage of all functions across both precipitation types within two of the sampling location areas, the predominant stream and floodplain sampling types (Figure 216). On the other end of the spectrum, basin scale, in-stream reservoir and in-stream riffle sampling locations had the least coverage of all function categories (including absence of Biogeochemical functions) across both precipitation types (Figure 217, Figure 218, Figure 219). Following overall sampling location study trends (Figure 182, Figure 183, Figure 184), Habitat functions studies were most represented across most sampling location types and by within-channel and outside channel sampling location type groups (Figure 217, Figure 218, Figure 219). Likewise, only the first grouping of sampling location types (basin and catchment scales), had a predominance within Hydrology studies. Furthermore, there was a slight predominance of Hydrology studies occurring within desert precipitation areas for 38% (catchment scale, floodplain, and floodplain waterholes) of all sampling location types.

In a similar fashion to the above sections, in terms of regarding individual contributions of precipitation and temperature, the individual contribution of streamflow regimes absent any other hydrology and climate components was examined in concert with the function categories and stream sampling location types (Figure 220). The overall pattern of a predominance of ephemeral stream coverage over intermittent streams (Figure 32) generally carried through all stream sampling location types across global Biogeochemical, Hydrology, and Sediment studies

(Figure 221) (Table 39). Nonetheless, except for catchment, in-stream reservoir, and in-stream riffle sampling types, there was a noted alteration from that general pattern for Habitat studies, where there continued to be a predominance of ephemeral over intermittent stream studies for most stream planform types (Figure 222, Figure 223, Figure 224). Similar to precipitation types, as overall hydrology is a critical factor in arid water-limited stream systems influencing the spectrum of primary function categories, it would be beneficial for future studies across all sampling location types and primary function categories to provide an increased focus on arid intermittent stream studies. In terms of the opposite perspective, focusing on the percent contribution of primary function categories within a specific sampling location and streamflow type, there was global coverage of all primary function categories across both streamflow regimes only for the stream sampling type. On the other end of the spectrum, basin scale, in-stream reservoir and in-stream riffle sampling locations had the least coverage of all primary function categories (including absence of Biogeochemical functions) across both streamflow types (Figure 225). Following overall sampling location study trends (Figure 182, Figure 183, Figure 184), Habitat functions studies were most represented across most sampling location types and by within- and outside channel sampling location type groups (Figure 226, Figure 227, Figure 228). Likewise, only the first grouping of sampling location types (basin and catchment scales), had a predominance within Hydrology studies. Furthermore, as with the other primary function categories the predominant Habitat function studies occurred mainly within ephemeral streams, over all sampling location types.

The last, and arguably most overall influential ecosystem control for arid stream systems addressed herein are the combined overall hydrology components, precipitation and streamflow

regime, in concert with stream sampling location areas among the primary function categories (Figure 229). The general overarching patterns of a predominance of ephemeral stream studies and steppe precipitation studies carried through most global studies, summed across all stream sampling types and primary function categories (Figure 230, Figure 231) (Table 40). Intermittent stream desert studies were the least well represented across all primary function categories. In terms of coverage by number of sampling location types. When regarding the data by the number of individual sampling location types representing a primary function category, Habitat function studies had the most coverage (seven) of sampling location types, whereas Biogeochemical function studies trended the least (three). Also, by individual sampling location types, basin scale, floodplain waterhole, in-stream reservoir, and in-stream riffle sampling locations had the least coverage of all primary functions across both precipitation and streamflow regimes (Figure 232, Figure 233, Figure 234). Lastly, in terms of the opposite perspective, focusing on the percent contribution of all primary function categories within a specific sampling location, precipitation, and streamflow type, there was coverage only complete coverage of all function categories across both streamflow regime types for stream sampling location studies within steppe precipitation areas. On the other end of the spectrum, basin scale, in-stream reservoir, and in-stream riffle sampling location types had the least coverage of all functions (including absence of Biogeochemical functions) across both streamflow and precipitation types (Figure 235). Following overall sampling location study trends (Figure 182, Figure 183, Figure 184), Habitat functions studies were most represented coverage summed across all sampling location types and sampling location groups (Figure 236, Figure 237, Figure 238), where only Hydrology functions were predominantly covered by large scale stream system sampling (catchment and basin

scales). Overall, the lack of even coverage across the primary function categories, including differences in coverage among sampling location types, streamflow and precipitation types, could be benefitted by future studies concentrating more in these key areas.

Tables

Table 32. Primary function categories of arid non-perennial literature by streamflow regime and stream corridor subarea without subclimates worldwide, including the U.S.

Streamflow Type	Sampling Location Type	Biogeochemical		Habitat		Hydrology		Sediment		TOTAL (WW)	TOTAL (U.S.)	% TOTAL (U.S.)	% Sampling Location/All Locations & Streamflow Streamflow Types (WW)	% Sampling Location/All Locations & Streamflow Streamflow Types (U.S.)
		WW	U.S.	WW	U.S.	WW	U.S.	WW	U.S.					
Non-perennial	basin scale	0	0	0	0	2	0	0	0	2	0	0%	2%	0%
	catchment scale	0	0	2	1	1	0	1	0	4	1	25%	7%	10%
	floodplain	3	2	10	3	1	0	0	0	14	5	36%	23%	26%
	floodplain waterholes	0	0	2	0	0	0	1	0	3	0	0%	1%	0%
	in-stream pool	0	0	6	1	0	0	0	0	6	1	17%	9%	7%
	in-stream reservoirs	0	0	0	0	0	0	0	0	0	0	NA	0%	0%
	in-stream riffles	0	0	0	0	0	0	0	0	0	0	NA	1%	2%
	in-stream stock ponds	0	0	0	0	0	0	0	0	0	0	NA	0%	1%
	in-stream waterholes	0	0	4	0	0	0	1	0	5	0	0%	2%	0%
	stream	10	2	15	4	5	1	2	0	32	7	22%	55%	55%
	Streamflow Type Subtotals	13	4	39	9	9	1	5	0	**66**	**14**	**21%**		
Ephemeral	basin scale	0	0	0	0	5	0	0	0	5	0	0%		
	catchment scale	2	2	3	2	6	3	10	6	21	13	62%		
	floodplain	9	4	29	11	3	0	14	3	55	18	33%		
	floodplain waterholes	0	0	0	0	1	0	0	0	1	0	0%		
	in-stream pool	1	0	16	6	3	0	1	0	21	6	29%		
	in-stream reservoirs	0	0	0	0	0	0	0	0	0	0	NA		
	in-stream riffles	0	0	2	2	0	0	0	0	2	2	100%		
	in-stream stock ponds	0	0	0	0	0	0	1	1	1	1	100%		
	in-stream waterholes	0	0	1	0	3	0	0	0	4	0	0%		
	stream	35	18	52	23	26	5	47	13	160	59	37%		
	Streamflow Type Subtotals	47	24	103	44	47	8	73	23	**270**	**99**	**37%**		
Intermittent	basin scale	0	0	0	0	1	0	0	0	1	0	0%		
	catchment scale	0	0	3	3	1	0	0	0	4	3	75%		
	floodplain	6	1	21	17	3	2	0	0	30	20	67%		
	floodplain waterholes	0	0	1	0	0	0	0	0	1	0	0%		
	in-stream pool	2	0	9	5	0	0	0	0	11	5	45%		
	in-stream reservoirs	0	0	1	0	0	0	0	0	1	0	0%		
	in-stream riffles	0	0	2	1	0	0	0	0	2	1	50%		
	in-stream stock ponds	0	0	0	0	0	0	0	0	0	0	NA		
	in-stream waterholes	0	0	1	0	0	0	0	0	1	0	0%		
	stream	11	3	32	20	3	2	2	1	48	26	54%		
	Streamflow Type Subtotals	19	4	70	46	8	4	2	1	**99**	**55**	**56%**		
Totals		79	32	212	99	64	13	80	24	**435**	**168**	**39%**		

Table 33. Overall occurrence trends of the primary function categories among sampling location types within global and U.S. arid non-perennial stream literature. The relative representation between the function categories is noted as slight (>), moderate (>>), or significant (>>>). Data layer trends that mirror overall study trends are denoted as "*".

Global							
Overall	**Habitat**	**>>**	**Biogeochemical**	**>**	**Sediment**	**>**	**Hydrology**
Sampling location	**Habitat**	**>>>**	**Sediment**	**>**	**Biogeochemical**	**>**	**Hydrology**
Stream	Habitat	>>	Sediment	>	Biogeochemical	>>	Hydrology
Floodplain	Habitat	=	Hydrology		NA		NA
In-Stream pool	Habitat	>>>	Hydrology	>>	Biogeochemical	>	Sediment
Catchment scale	Sediment	>	Hydrology	>	Habitat	>>>	Biogeochemical
Basin scale	Hydrology		NA		NA		NA
In-Stream riffle	*		NA		NA		NA
Floodplain waterhole	Habitat	=	Hydrology		NA		NA
In-Stream reservoir	*		NA		NA		NA

U.S.							
Overall	**Habitat**	**>>**	**Biogeochemical**	**>>**	**Sediment**	**>**	**Hydrology**
Sampling location	*	**>>>**	*	**>**	*	**>>**	*
Stream	*	>>	*	>	*	>>	*
Floodplain	*	>>>	*	>>	*	>	*
Catchment scale	Sediment	>	Habitat	>	Hydrology	>	Biogeochemical
In-Stream pool	Habitat	>>>	Sediment		NA		NA
In-Stream riffle	Habitat		NA		NA		NA
Basin scale	NA		NA		NA		NA
Floodplain waterhole	NA		NA		NA		NA
In-Stream reservoir	NA		NA		NA		NA

Table 34. Overall occurrence trends of the primary function categories among sampling location types, Koppen-Geiger subclimes, and streamflow regimes within global arid non-perennial stream literature. The relative representation between the function categories is noted as slight (>), moderate (>>), or significant (>>>). Data layer trends that mirror overall study trends are denoted as "*".

Global								
Overall		**Cold Steppe**	**>**	**Hot Desert**	**>**	**Hot Steppe**	**>>**	**Cold Desert**
By Function	Biogeochemical	*	>	*	>	*	>>	*
	Habitat	*	>>	*	>	*	>>	*
	Hydrology	Hot Desert	>	Hot Steppe	>	Cold Steppe	>>	Cold Desert
	Sediment	*	>	*	>	*	>>>	*
By Ephemeral flow	Biogeochemical	Hot Desert	>	Cold Steppe	>	Hot Steppe	>	Cold Desert
	Habitat	Hot Desert	>	Cold Steppe	>	Hot Steppe	>>>	Cold Desert
	Hydrology	Hot Desert	>	Hot Steppe	>	Cold Steppe	>>	Cold Desert
	Sediment	Hot Desert	>	Cold Steppe	>>	Hot Steppe	>>>	Cold Desert
By Intermittent flow	Biogeochemical	Cold Steppe	>	Hot Steppe	>	Hot Desert	>>>	Cold Desert
	Habitat	Cold Steppe	>>	Hot Steppe	>>	Hot Desert	>>	Cold Desert
	Hydrology	Hot Desert	>>	Hot Steppe	>>>	Cold Steppe		NA
	Sediment	*	>	*		NA		NA
Sampling location		*	>	*	>	*	>>>	*
By Function	Biogeochemical	Hot Steppe	>	Hot Desert	>	Cold Steppe	>>	Cold Desert
	Habitat	*	>	*	>	*	>>>	*
	Hydrology	Hot Desert	>	Hot Steppe	>	Cold Steppe	>>	Cold Desert
	Sediment	Hot Desert	>	Cold Steppe	>>>	Hot Steppe	>>>	Cold Desert
By Ephemeral flow	Biogeochemical	Hot Desert	>	Hot Steppe	>	Cold Steppe	>>	Cold Desert
	Habitat	Hot Desert	>	Cold Steppe	>>	Hot Steppe	>>>	Cold Desert
	Hydrology	Hot Desert	>	Cold Steppe	>	Hot Steppe	>>	Cold Desert
	Sediment	Hot Desert	>	Cold Steppe	>>	Hot Steppe	>>>	Cold Desert
By Intermittent flow	Biogeochemical	Hot Steppe	>>	Cold Steppe	=	Hot Desert	>>	Cold Desert
	Habitat	Cold Steppe	>>	Hot Steppe	>>	Hot Desert	>>	Cold Desert
	Hydrology	Hot Steppe	>	Hot Desert	>>>	Cold Steppe		NA
	Sediment	Cold Steppe	=	Hot Desert		NA		NA

Table 35. Overall occurrence trends of the primary function categories among sampling location types, hot and cold temperatures, and streamflow regimes within global arid non-perennial stream literature. The relative representation between the function categories is noted as slight (>), moderate (>>), or significant (>>>). Data layer trends that mirror overall study trends are denoted as "*".

Global				
Overall		**Hot arid**	**>**	**Cold arid**
By Function	Biogeochemical	*	>	*
	Habitat	*	>	*
	Hydrology	*	>>	*
	Sediment	*	>	*
By Ephemeral flow	Biogeochemical	*	>	*
	Habitat	*	>>	*
	Hydrology	*	>>	*
	Sediment	*	>>	*
By Intermittent flow	Biogeochemical	*	>	*
	Habitat	Cold arid	>	Hot arid
	Hydrology	*	>>>	*
	Sediment	Cold arid	>>	Hot arid
Sampling location		*	>	*
By Function	Biogeochemical	*	>>	*
	Habitat	*	>	*
	Hydrology	*	>>	*
	Sediment	*	>	*
By Ephemeral flow	Biogeochemical	*	>>	*
	Habitat	*	>	*
	Hydrology	*	>	*
	Sediment	*	>	*
By Intermittent flow	Biogeochemical	*	>>	*
	Habitat	Cold arid	>	Hot arid
	Hydrology	*	>>>	*
	Sediment	*	=	*

Table 36. Overall occurrence trends of the primary function categories among sampling location types and Koppen-Geiger subclimes within global arid non-perennial stream literature. The relative representation between the function categories is noted as slight (>), moderate (>>), or significant (>>>). Data layer trends that mirror overall study trends are denoted as "*".

Global							
Overall	**Cold Steppe**	**>**	**Hot Desert**	**>**	**Hot Steppe**	**>>**	**Cold Desert**
Biogeochemical	*	>	*	>	*	>>	*
Habitat	*	>>	*	>	*	>>	*
Hydrology	Hot Desert	>	Hot Steppe	>	Cold Steppe	>>	Cold Desert
Sediment	*	>	*	>	*	>>>	*
Sampling location	*	>	*	>	*	>>>	*
Biogeochemical	Hot Steppe	>	Hot Desert	>	Cold Steppe	>>	Cold Desert
Habitat	*	>	*	>	*	>>>	*
Hydrology	Hot Desert	>	Hot Steppe	>	Cold Steppe	>>	Cold Desert
Sediment	Hot Desert	>	Cold Steppe	>>>	Hot Steppe	>>>	Cold Desert

Table 37. Overall occurrence trends of the primary function categories among sampling location types and hot and cold temperatures within global arid non-perennial stream literature. The relative representation between the function categories is noted as slight (>), moderate (>>), or significant (>>>). Data layer trends that mirror overall study trends are denoted as "*".

Global			
Overall	**Hot arid**	**>**	**Cold arid**
Biogeochemical	*	>	*
Habitat	*	>	*
Hydrology	*	>>	*
Sediment	*	>	*
Sampling location	*	>	*
Biogeochemical	*	>>	*
Habitat	*	>	*
Hydrology	*	>>	*
Sediment	*	>	*

Table 38. Overall occurrence trends of the primary function categories among sampling location types and arid precipitation types within global arid non-perennial stream literature. The relative representation between the function categories is noted as slight (>), moderate (>>), or significant (>>>). Data layer trends that mirror overall study trends are denoted as "*".

Global			
Overall	**Steppe**	**>**	**Desert**
Biogeochemical	*	>	*
Habitat	*	>>	*
Hydrology	*	>	*
Sediment	*	>	*
Sampling location	*	>	*
Biogeochemical	*	>	*
Habitat	*	>>	*
Hydrology	*	>	*
Sediment	*	>	*

Table 39. Overall occurrence trends of the primary function categories among sampling location types and streamflow regimes within global arid non-perennial stream literature. The relative representation between the function categories is noted as slight (>), moderate (>>), or significant (>>>). Data layer trends that mirror overall study trends are denoted as "*".

Global			
Overall	**Ephemeral**	**>>**	**Intermittent**
Biogeochemical	*	>>	*
Habitat	Intermittent	>	Ephemeral
Hydrology	*	>>>	*
Sediment	*	>>>	*
Sampling location	*	>>	*
Biogeochemical	*	>>	*
Habitat	*	>	*
Hydrology	*	>>>	*
Sediment	*	>>>	*

Table 40. Overall occurrence trends of the primary function categories among sampling location types, arid precipitation types, and streamflow regimes within global arid non-perennial stream literature. The relative representation between the function categories is noted as slight (>), moderate (>>), or significant (>>>). Data layer trends that mirror overall study trends are denoted as "*".

Global				
Overall		**Steppe**	**>**	**Desert**
By Function	Biogeochemical	*	>	*
	Habitat	*	>>	*
	Hydrology	*	>	*
	Sediment	*	>	*
By Ephemeral flow	Biogeochemical	*	>	*
	Habitat	*	>	*
	Hydrology	*	>	*
	Sediment	*	>	*
By Intermittent flow	Biogeochemical	*	>>	*
	Habitat	*	>>>	*
	Hydrology	**Desert**	>	**Steppe**
	Sediment	*	>	*
Sampling location		*	>	*
By Function	Biogeochemical	*	>	*
	Habitat	*	>>	*
	Hydrology	*	>	*
	Sediment	*	>	*
By Ephemeral flow	Biogeochemical	*	>	*
	Habitat	*	>	*
	Hydrology	*	>	*
	Sediment	*	>	*
By Intermittent flow	Biogeochemical	*	>>	*
	Habitat	*	>>>	*
	Hydrology	*	>>	*
	Sediment	*	=	*

Figures

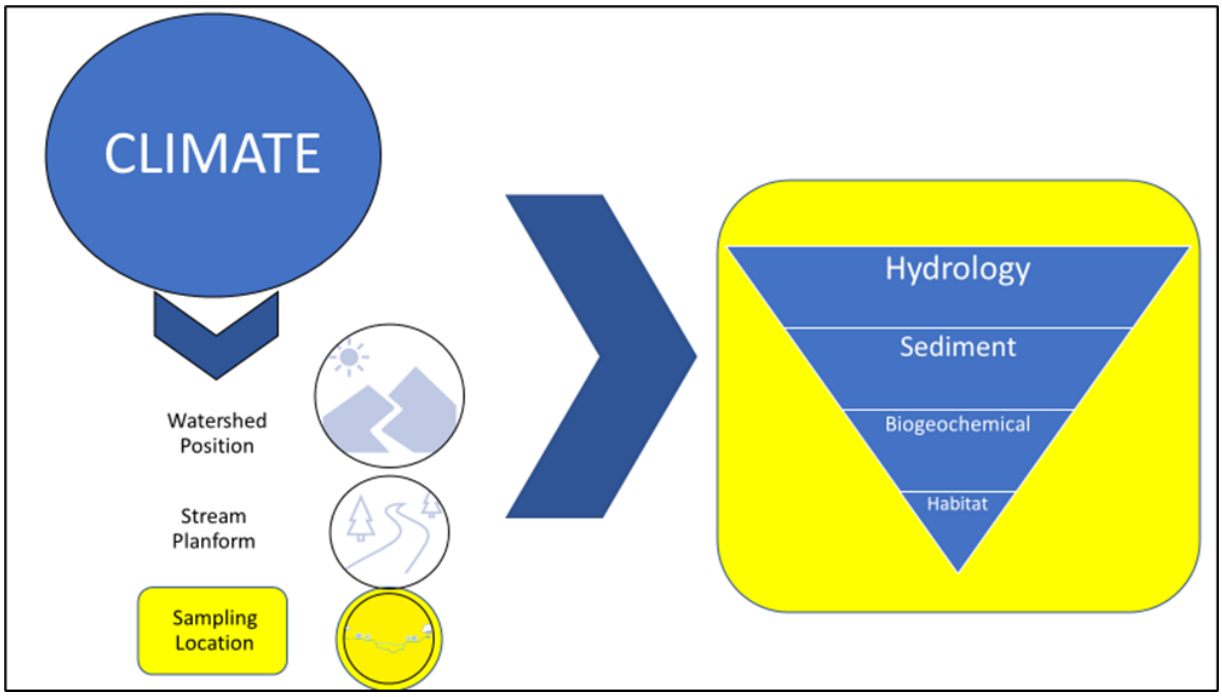


Figure 171. The conceptual relation of sampling location type (environmental parameter) to the hierarchy of broad stream function categories.

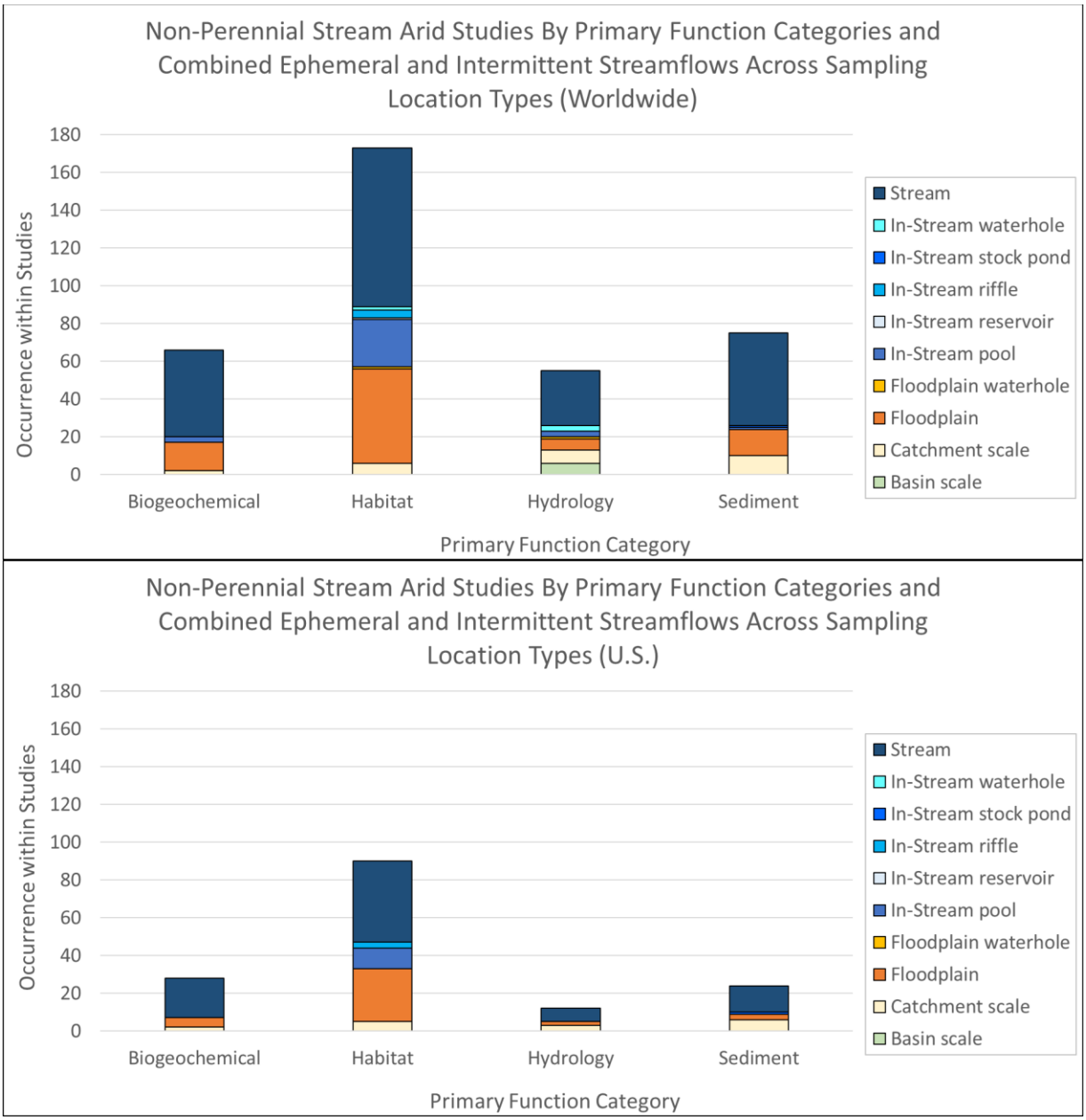


Figure 172. Sampling of primary broad function categories across sampling location and known streamflow types, within global and U.S. arid non-perennial stream literature.

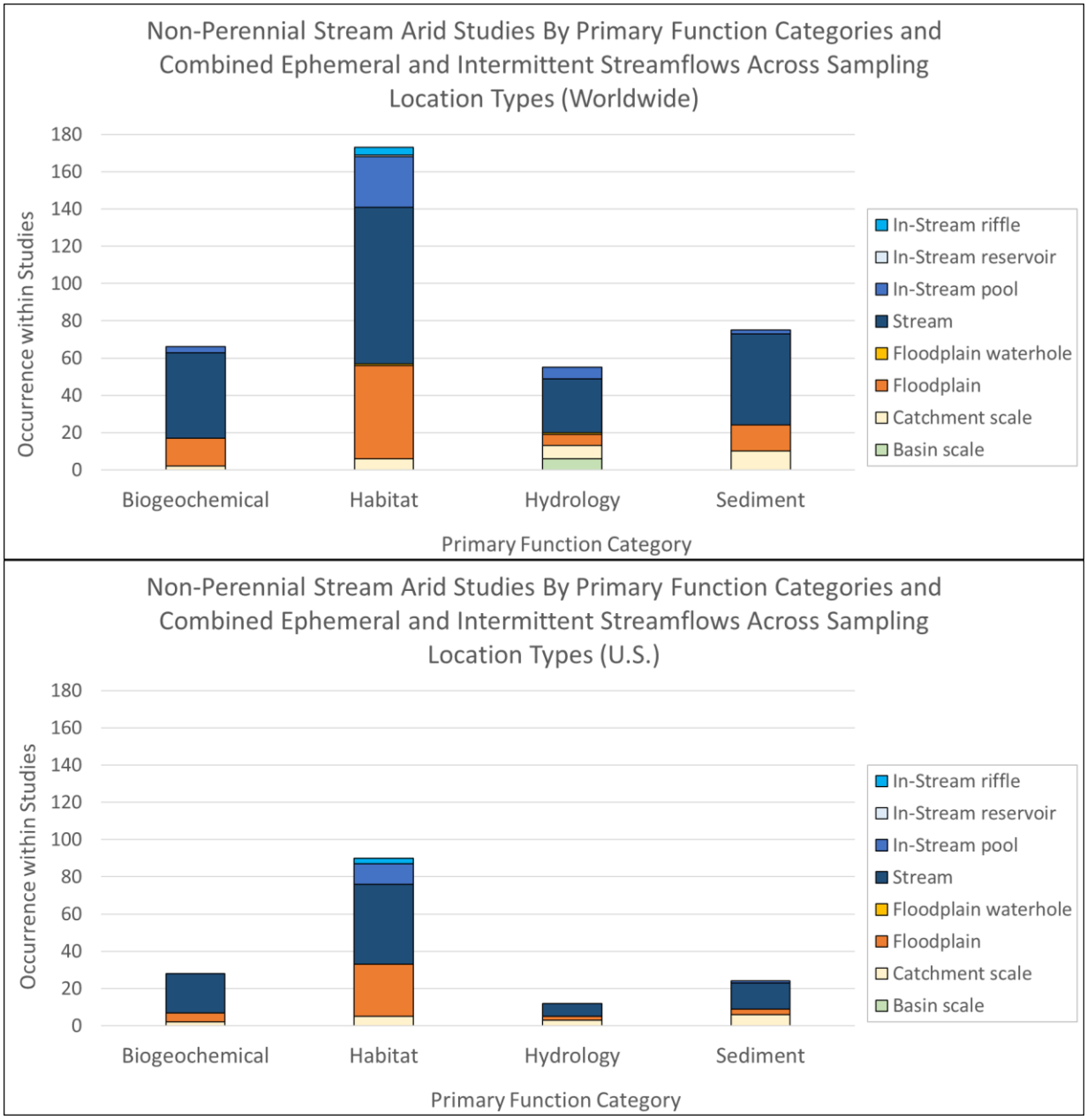


Figure 173. Sampling of primary broad function categories across condensed sampling location types and known streamflow types, within global and U.S. arid non-perennial stream literature.

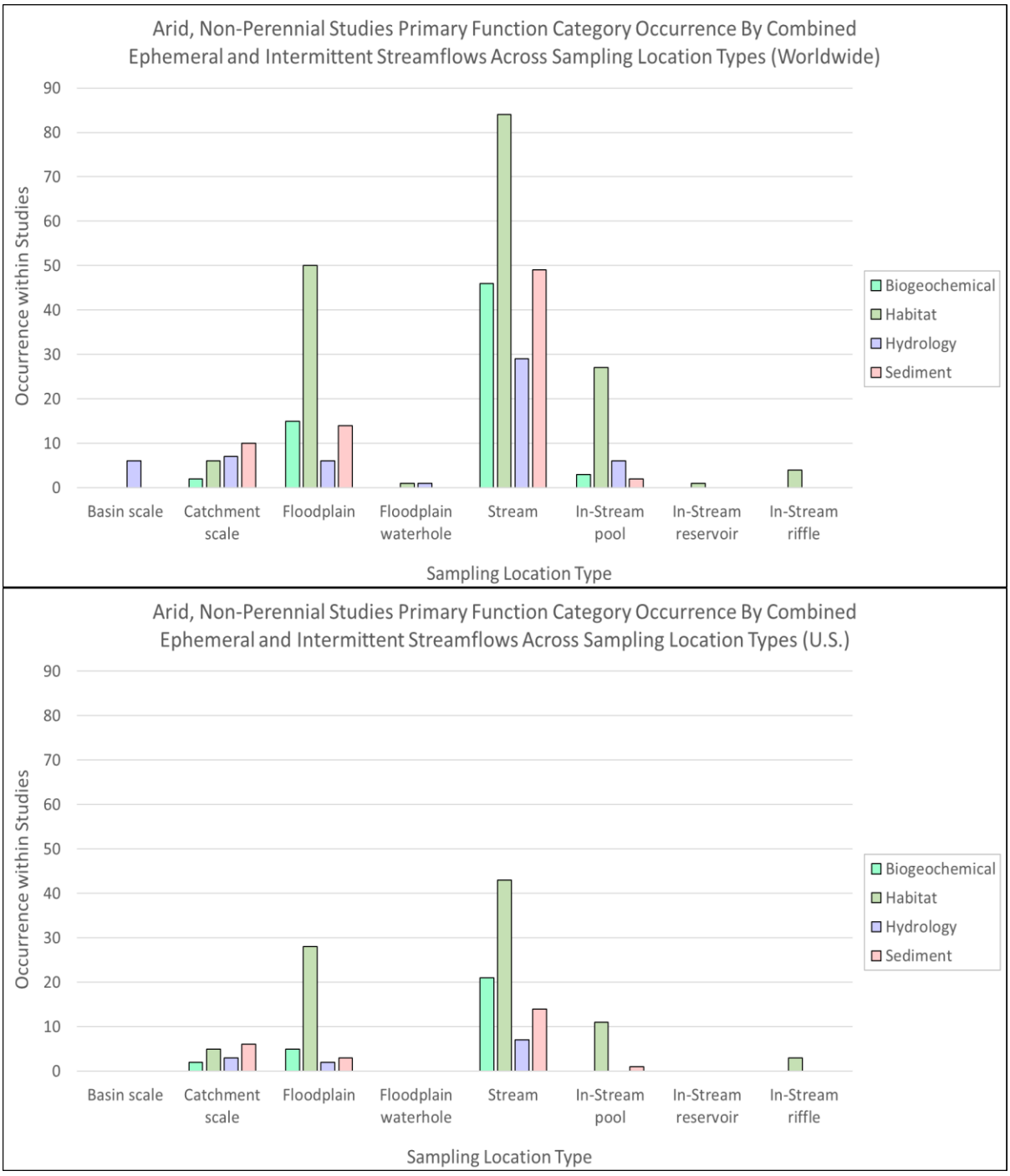


Figure 174. Condensed sampling location types across primary broad function categories and known streamflow types, within global and U.S. arid non-perennial stream literature.

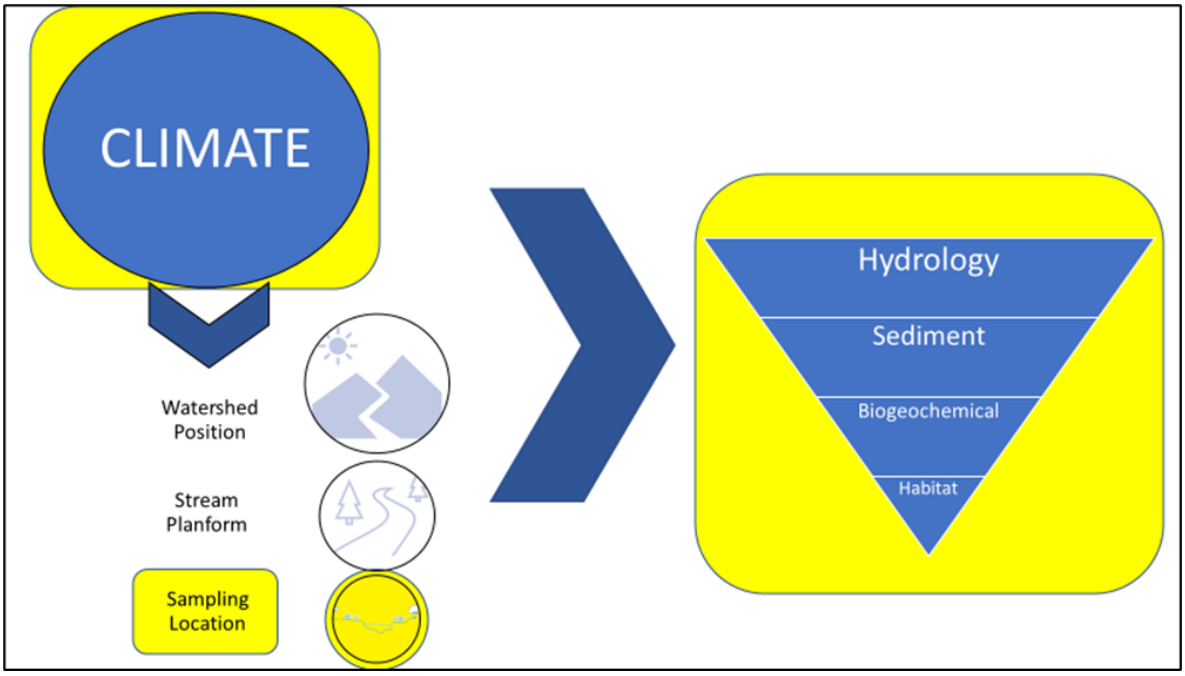


Figure 175. The conceptual relations of climate and sampling location type (environmental parameter) to the hierarchy of broad stream function categories.

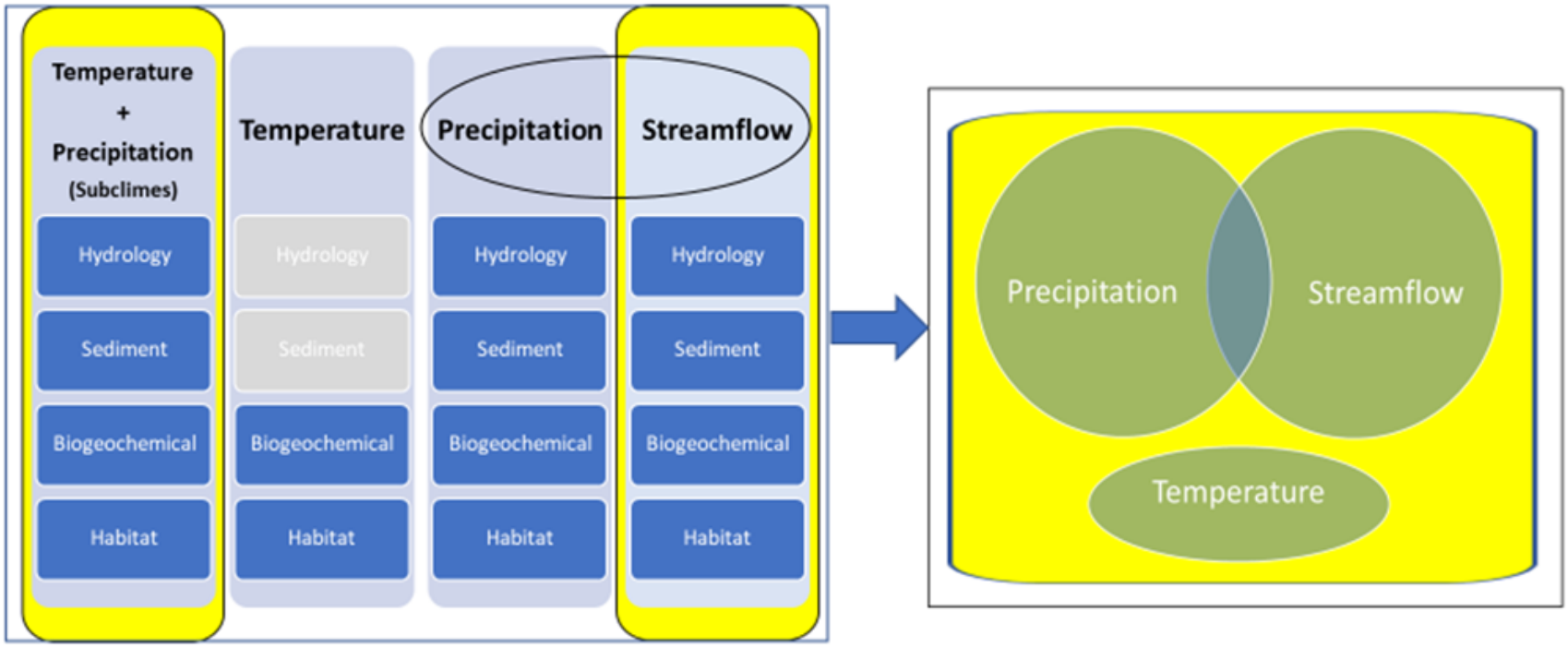


Figure 176. The conceptual relations and hierarchies of subclimes (combined temperature and precipitation types) and hydrology (inherent precipitation and streamflow types) factors and their influence on broad stream function categories.

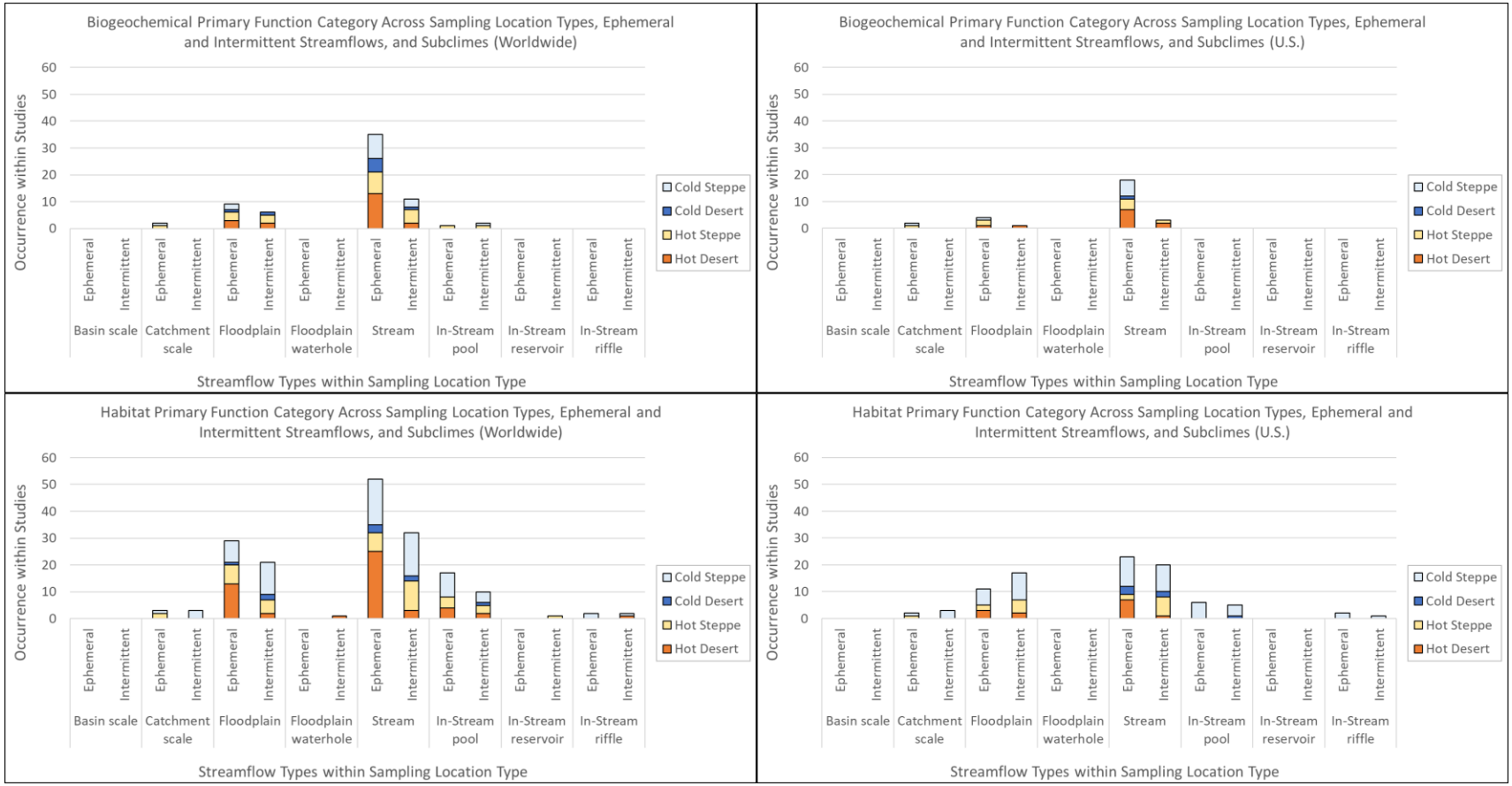


Figure 177. Sampling of Biogeochemical and Habitat function categories across condensed sampling location types and subclime types by known streamflow types, within global arid non-perennial stream literature.

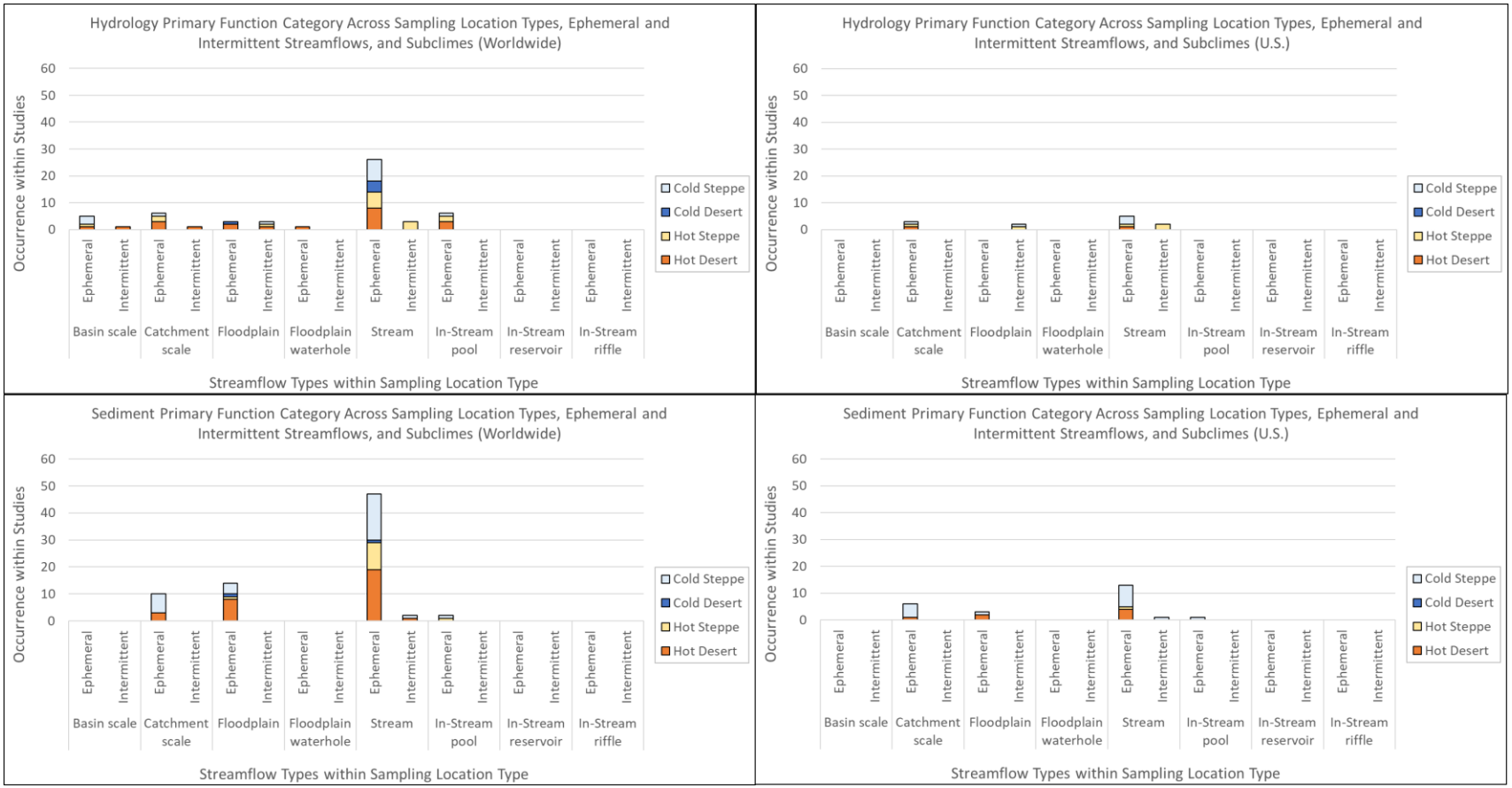


Figure 178. Sampling of Hydrology and Sediment function categories across condensed sampling location types and subclime types by known streamflow types, within global arid non-perennial stream literature.

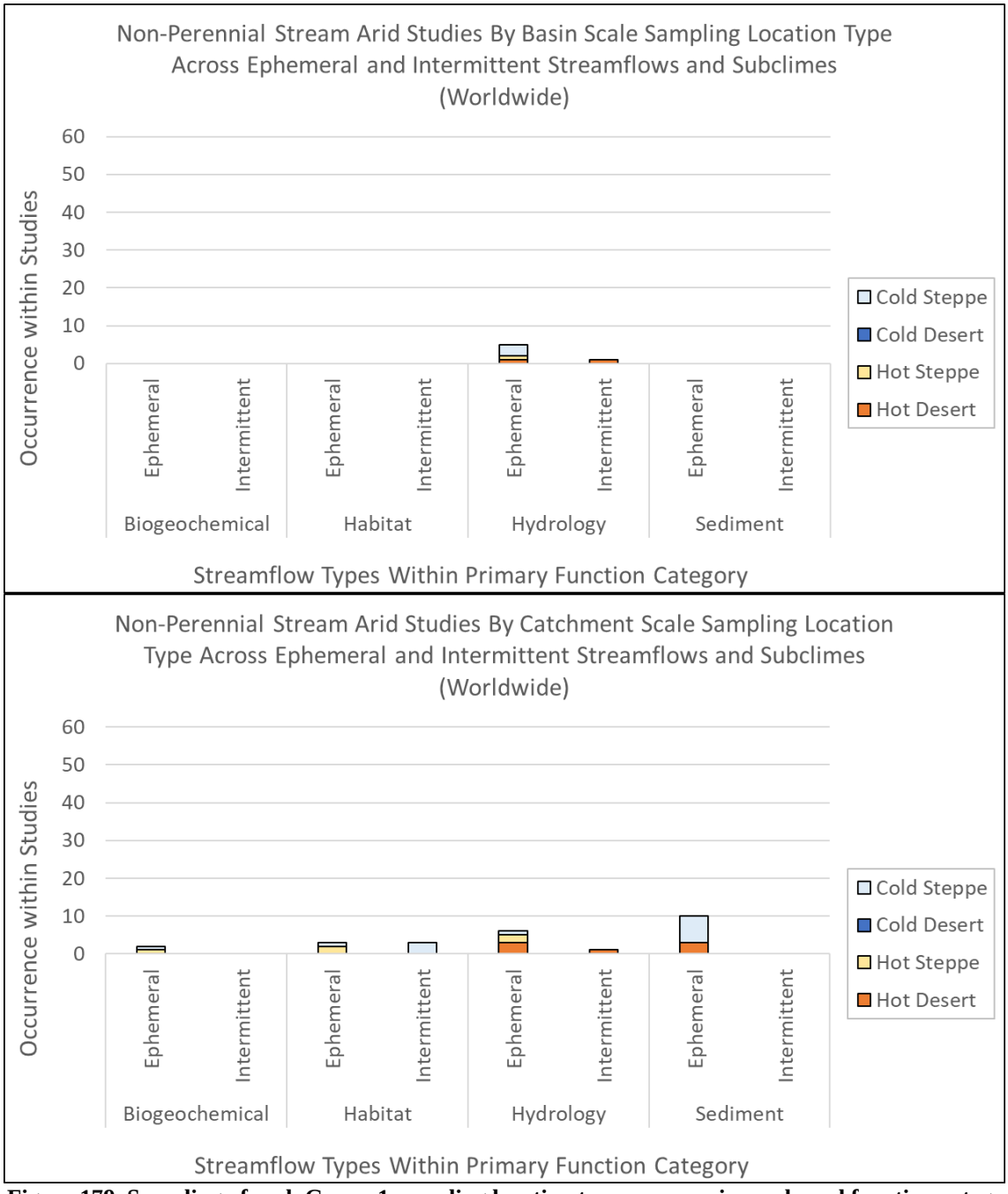


Figure 179. Sampling of each Group 1 sampling location type across primary broad function categories and subclimes, by ephemeral and intermittent streamflow, within global arid non-perennial stream literature.

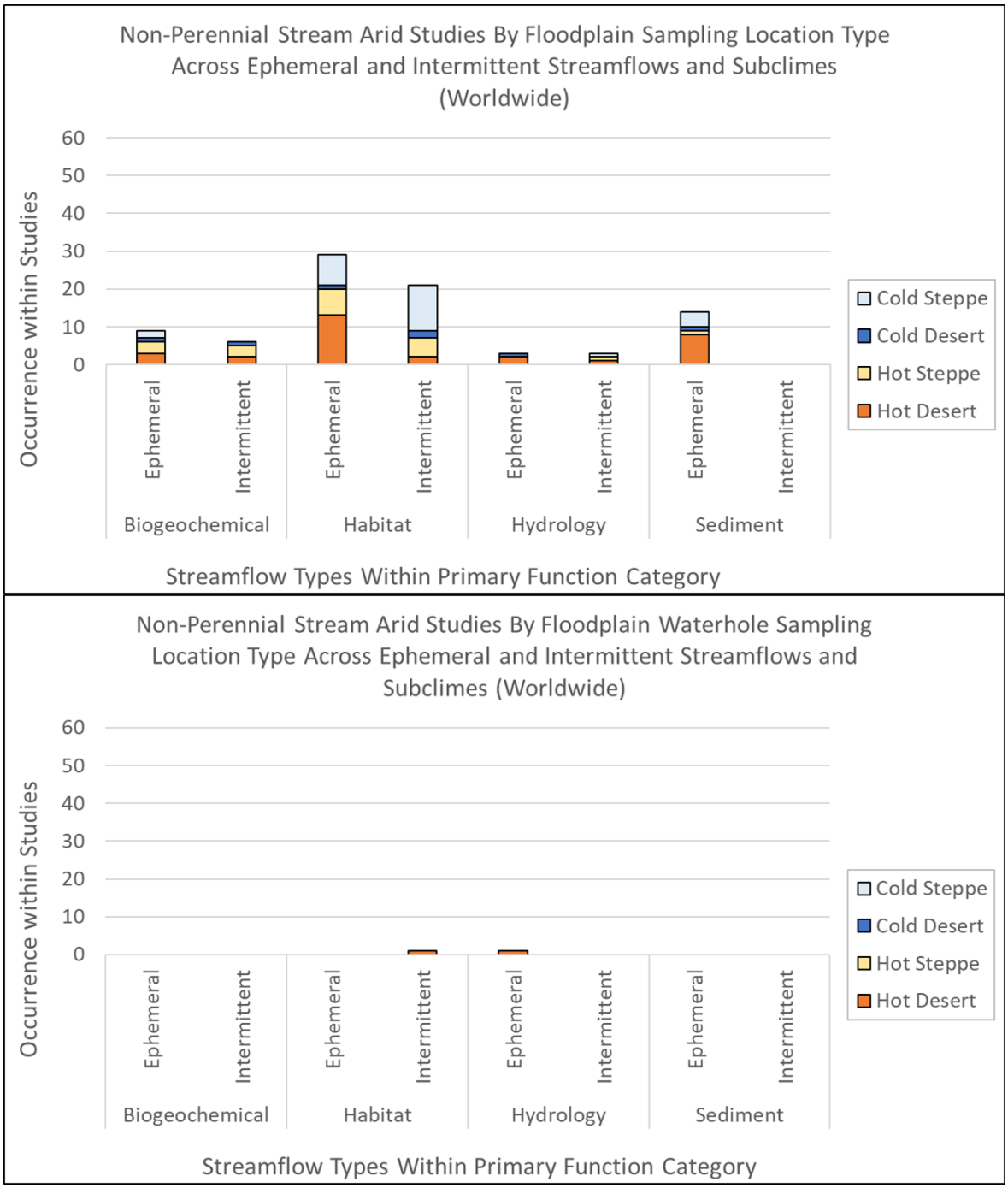


Figure 180. Sampling of each Group 2 sampling location type across primary broad function categories and subclimes, by ephemeral and intermittent streamflow, within global arid non-perennial stream literature.

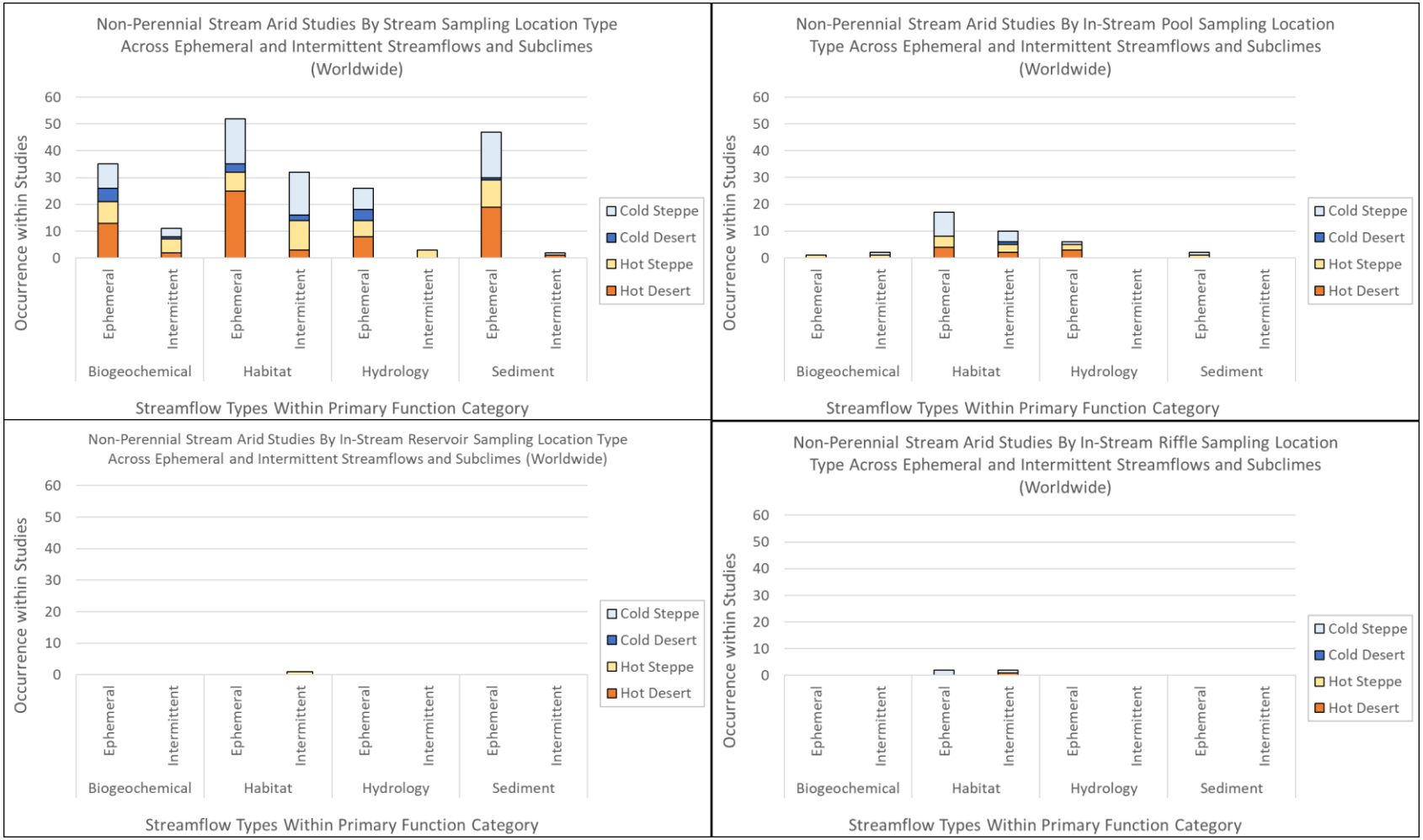


Figure 181. Sampling of each Group 3 sampling location type across primary broad function categories and subclimes, by ephemeral and intermittent streamflow, within global arid non-perennial stream literature.

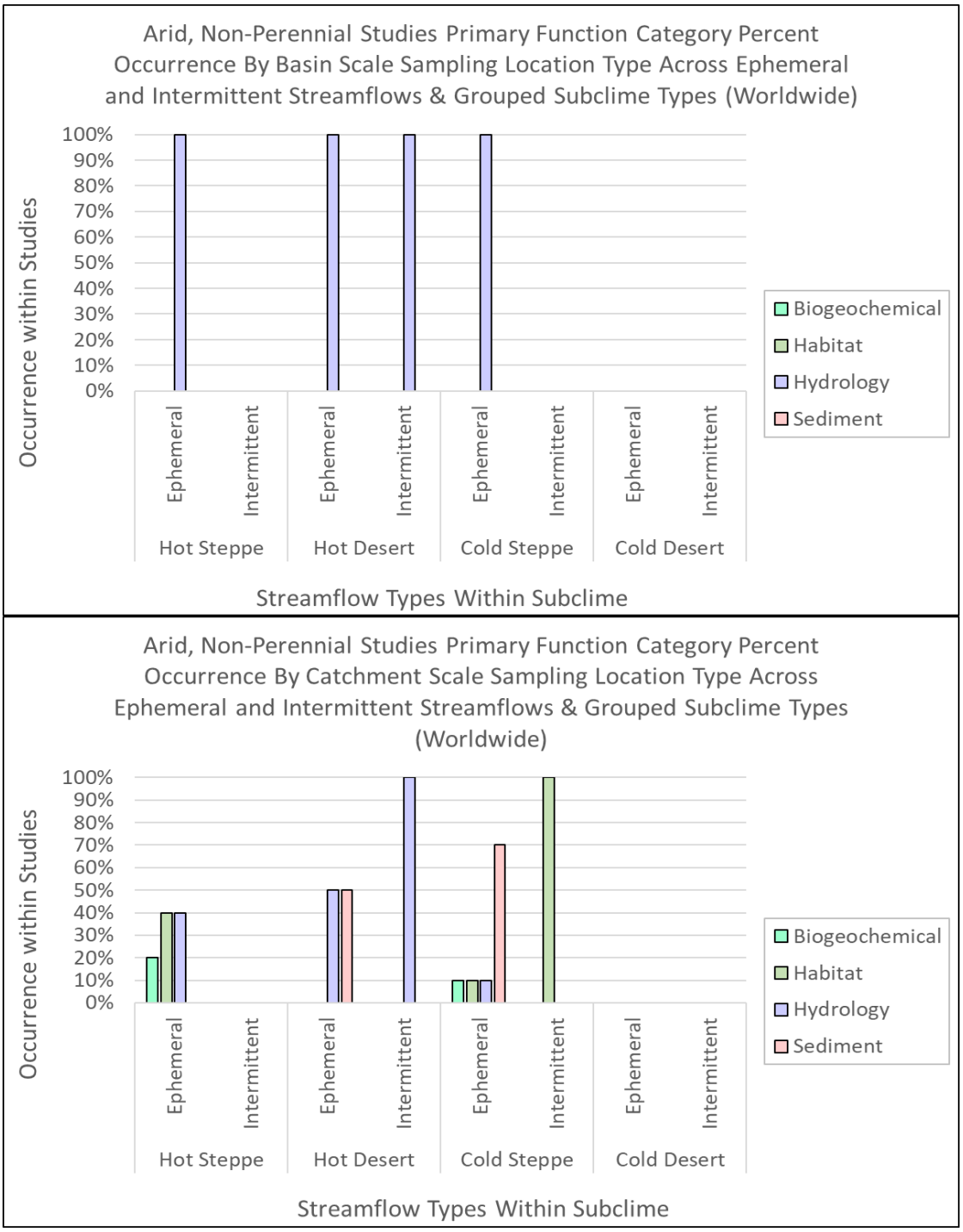


Figure 182. Sampling of each Group 1 condensed sampling location type across primary broad function categories and subclimes by known streamflow types, within global arid non-perennial stream literature.

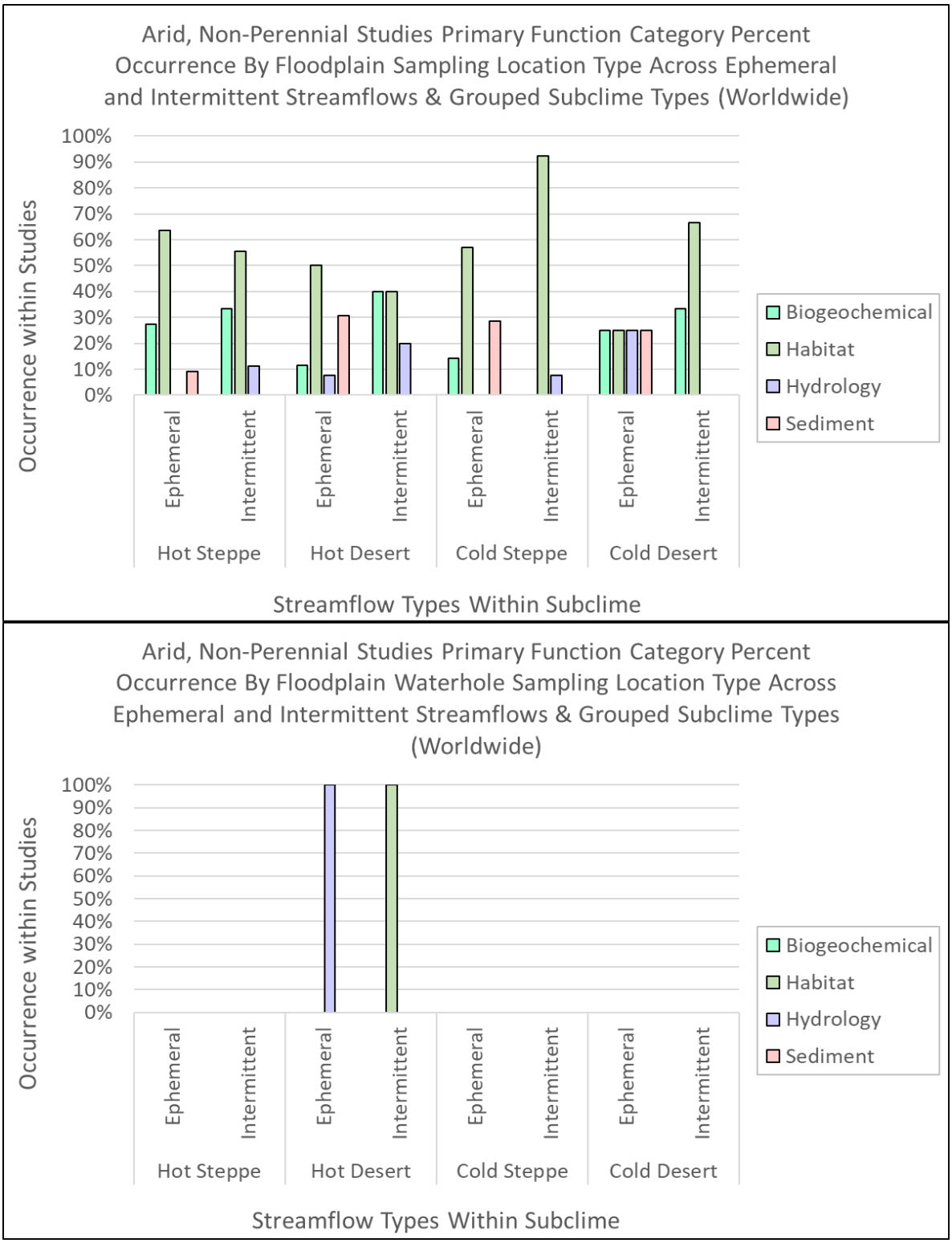


Figure 183. Sampling of each Group 2 condensed sampling location type across primary broad function categories and subclimes by known streamflow types, within global arid non-perennial stream literature.

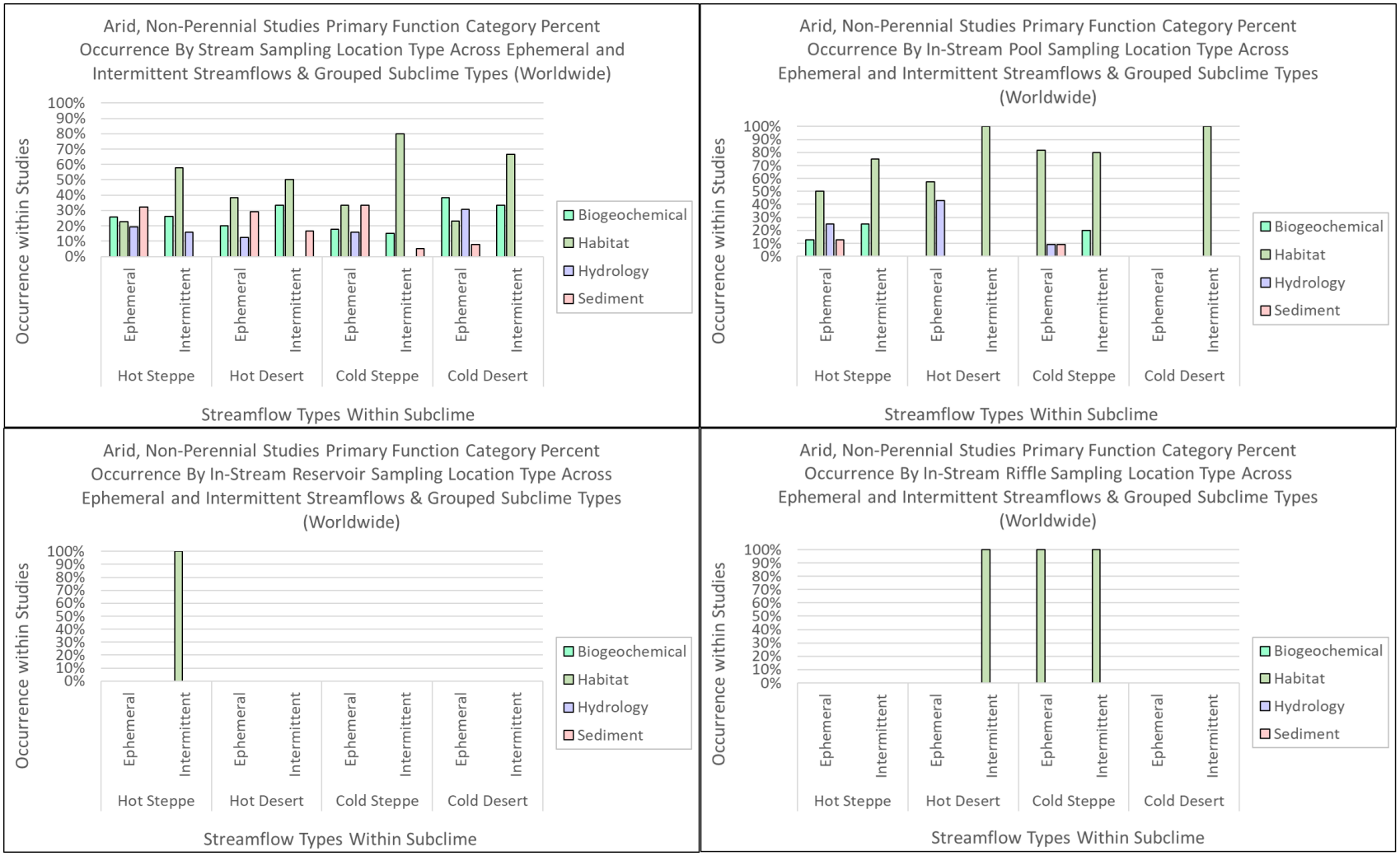


Figure 184. Sampling of each Group 3 condensed sampling location type across primary broad function categories and subclimes by known streamflow types, within global arid non-perennial stream literature.

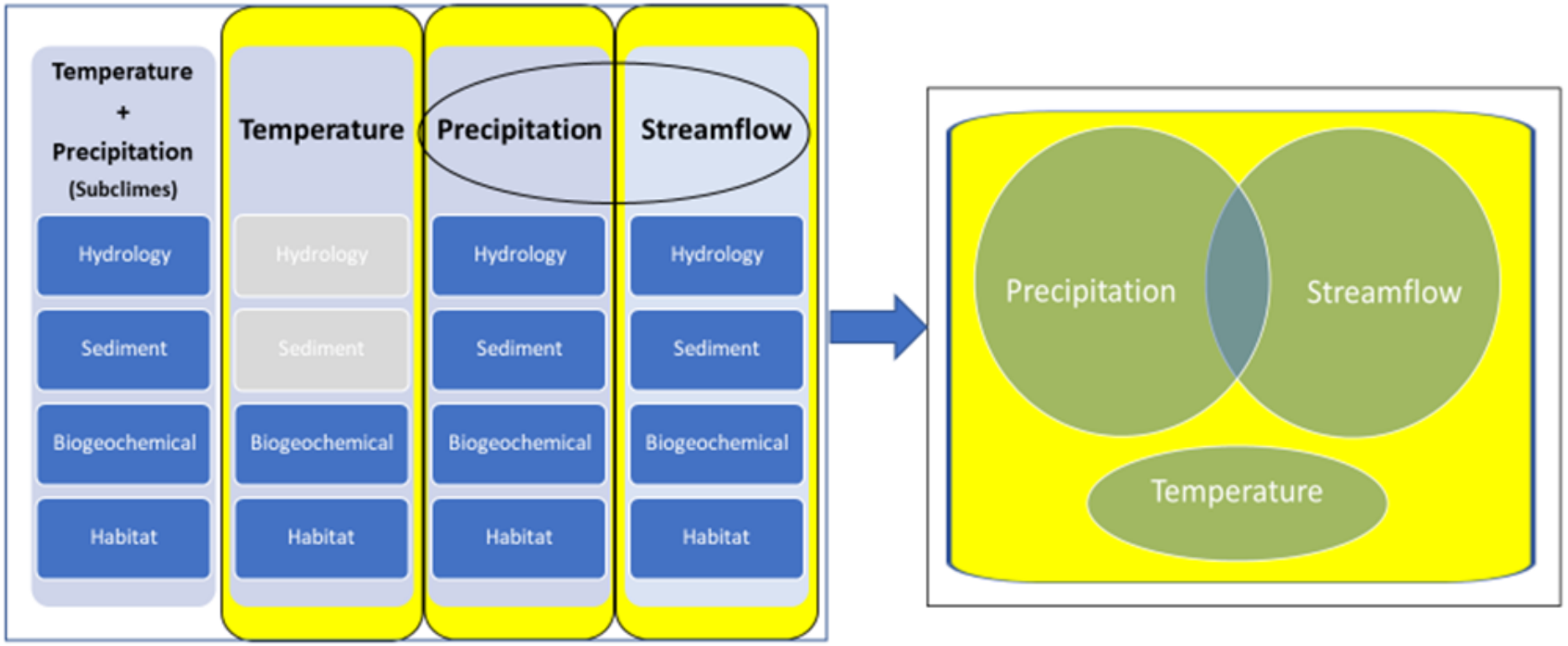


Figure 185. The conceptual relations and hierarchies of subclime components (temperature and precipitation types) and hydrology (inherent precipitation and streamflow types) factors and their influence on broad stream function categories.

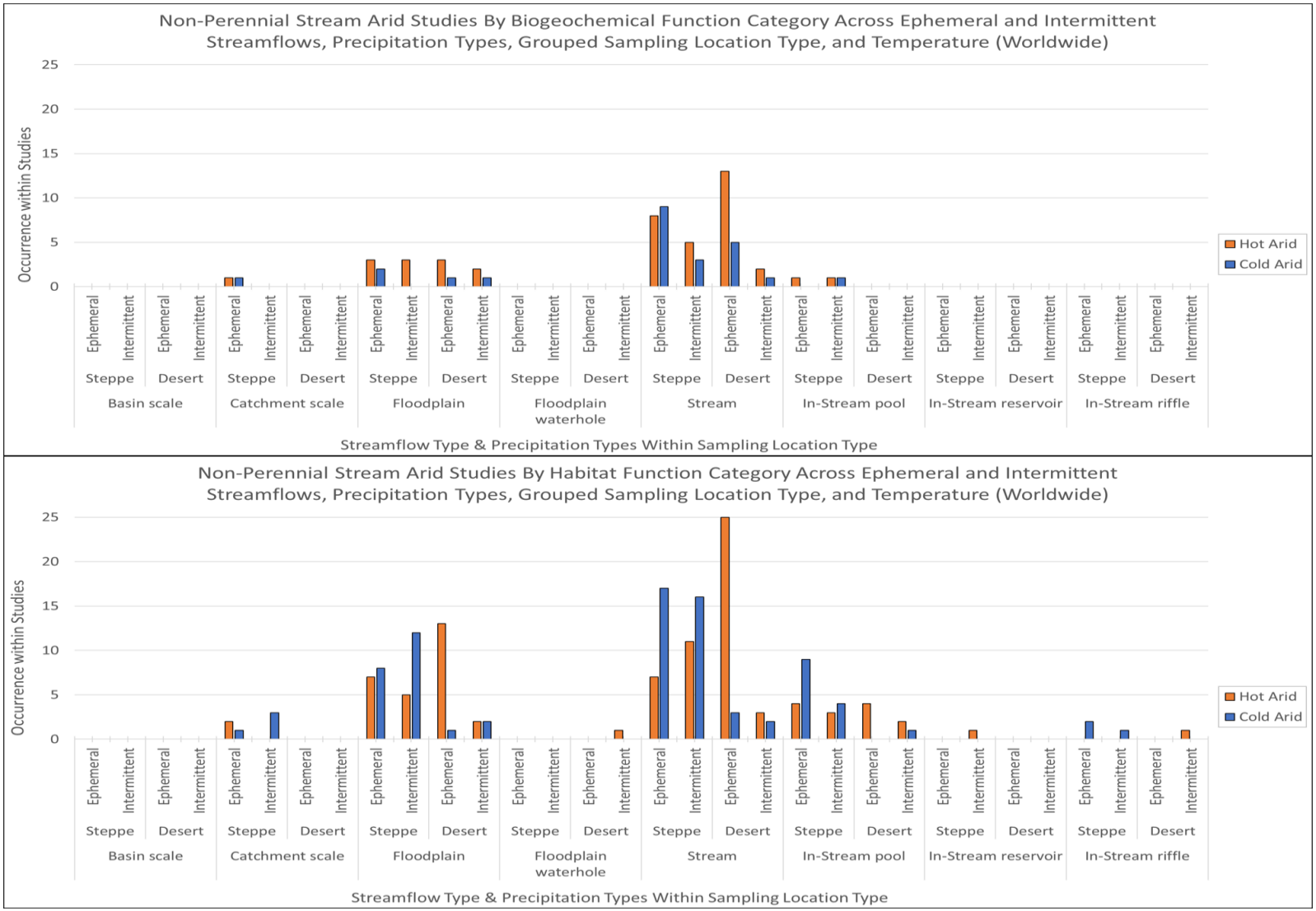


Figure 186. Sampling of Biogeochemical and Habitat function categories across condensed sampling location types and temperatures, by precipitation and known streamflow types, within global arid non-perennial stream literature.

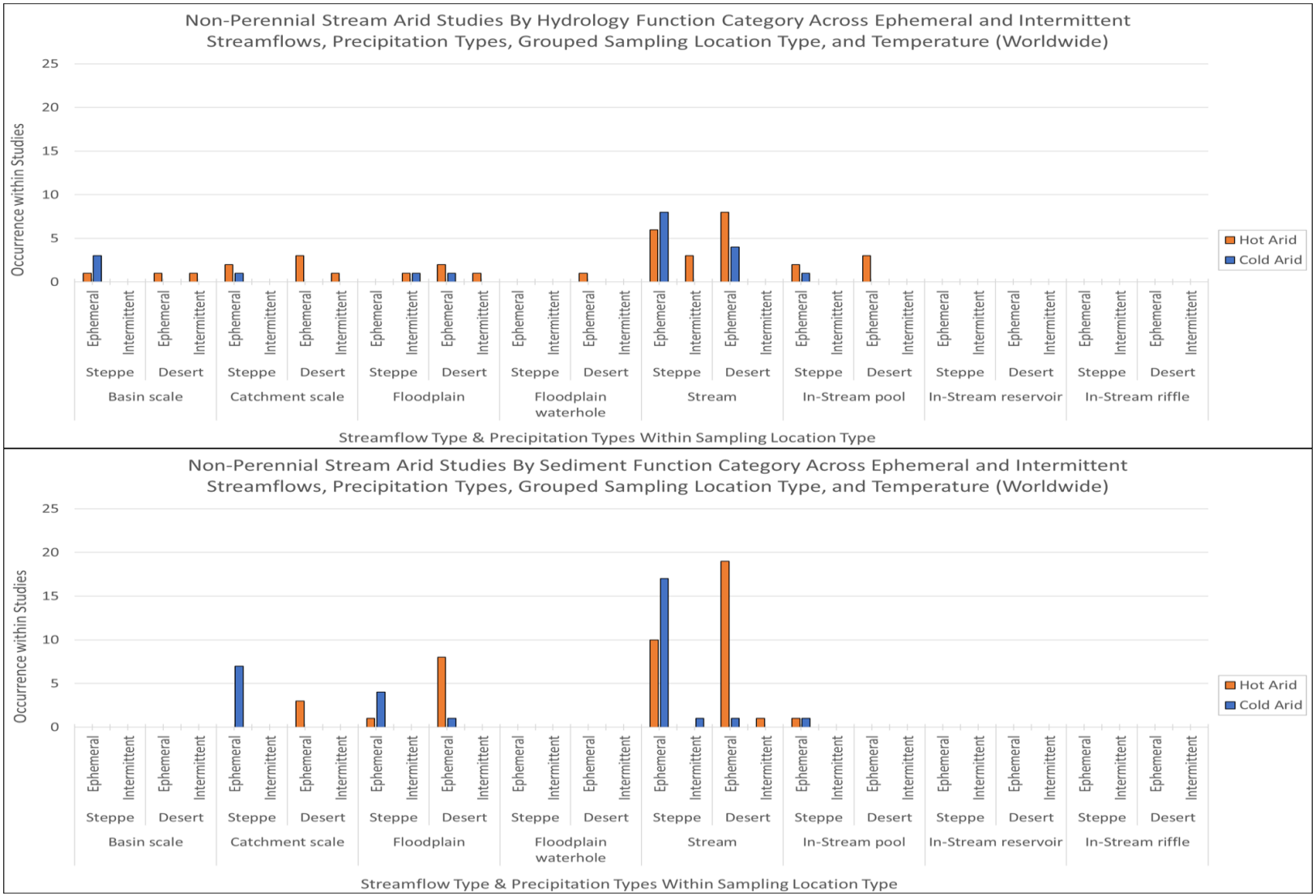


Figure 187. Sampling of Hydrology and Sediment function categories across condensed sampling location types and temperatures, by precipitation and known streamflow types, within global arid non-perennial stream literature.

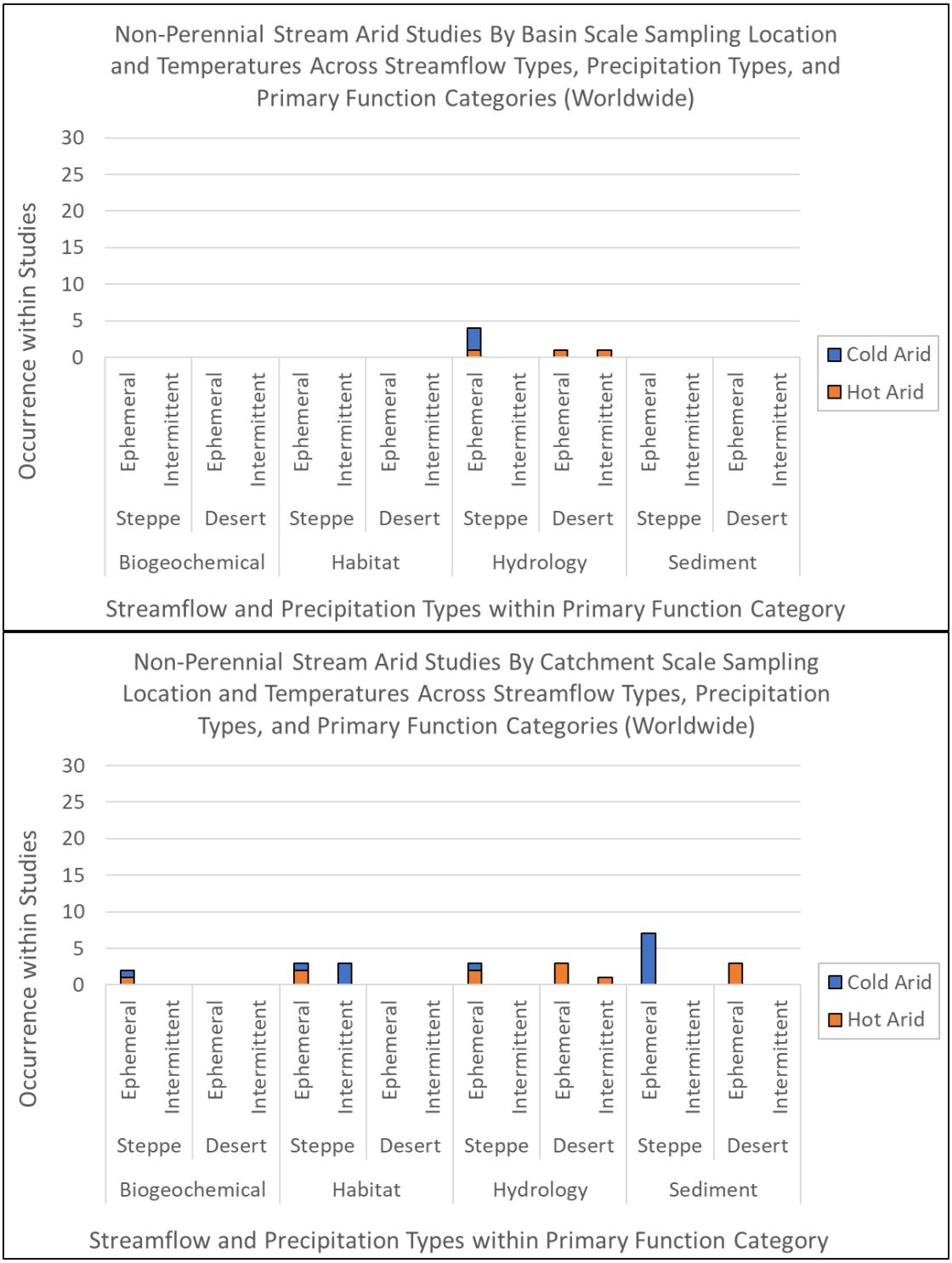


Figure 188. Sampling of each Group 1 sampling location type across primary broad function categories and temperatures, by precipitation and known streamflow types, within global arid non-perennial stream literature.

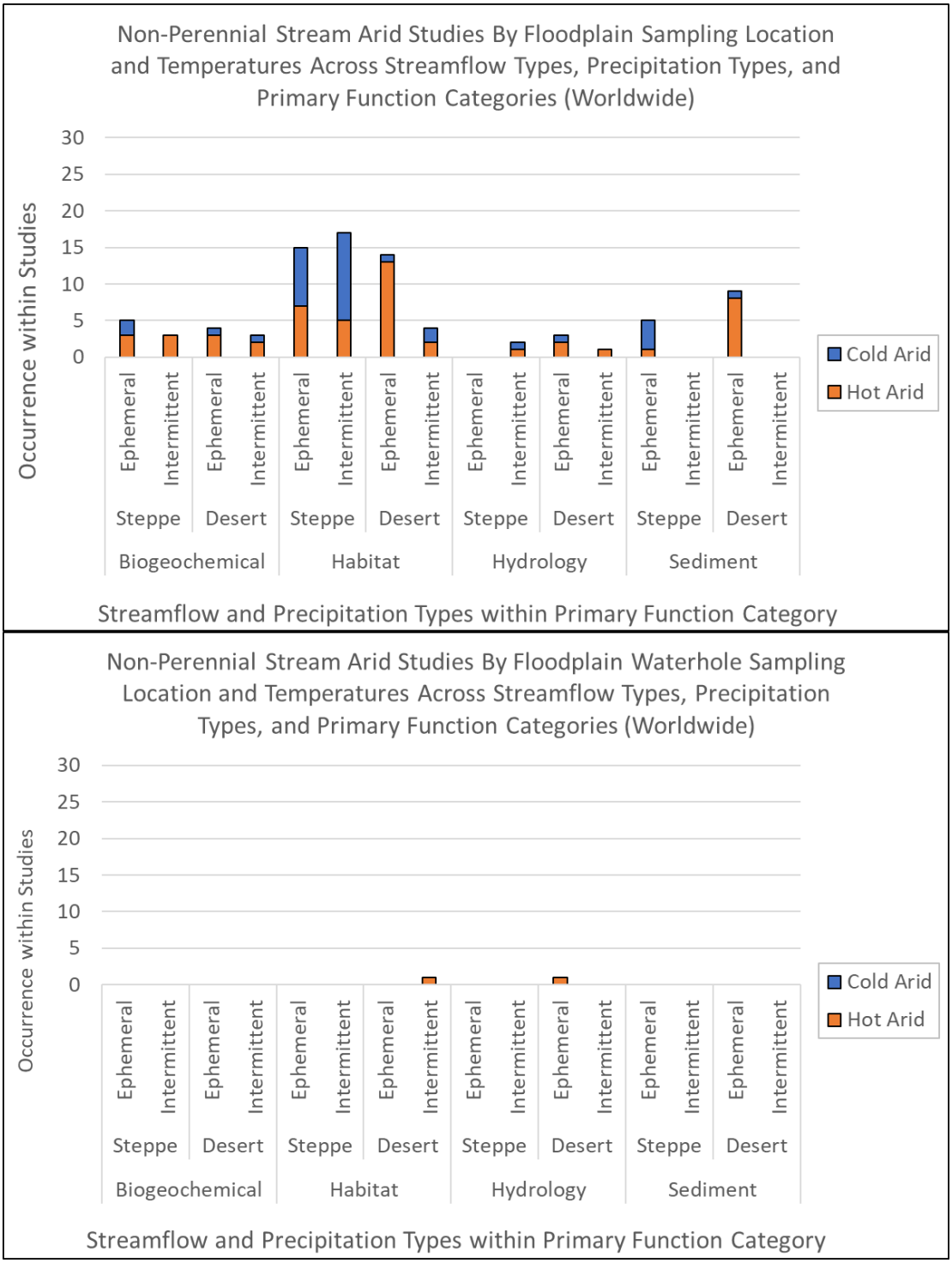


Figure 189. Sampling of each Group 2 sampling location type across primary broad function categories and temperatures, by precipitation and known streamflow types, within global arid non-perennial stream literature.

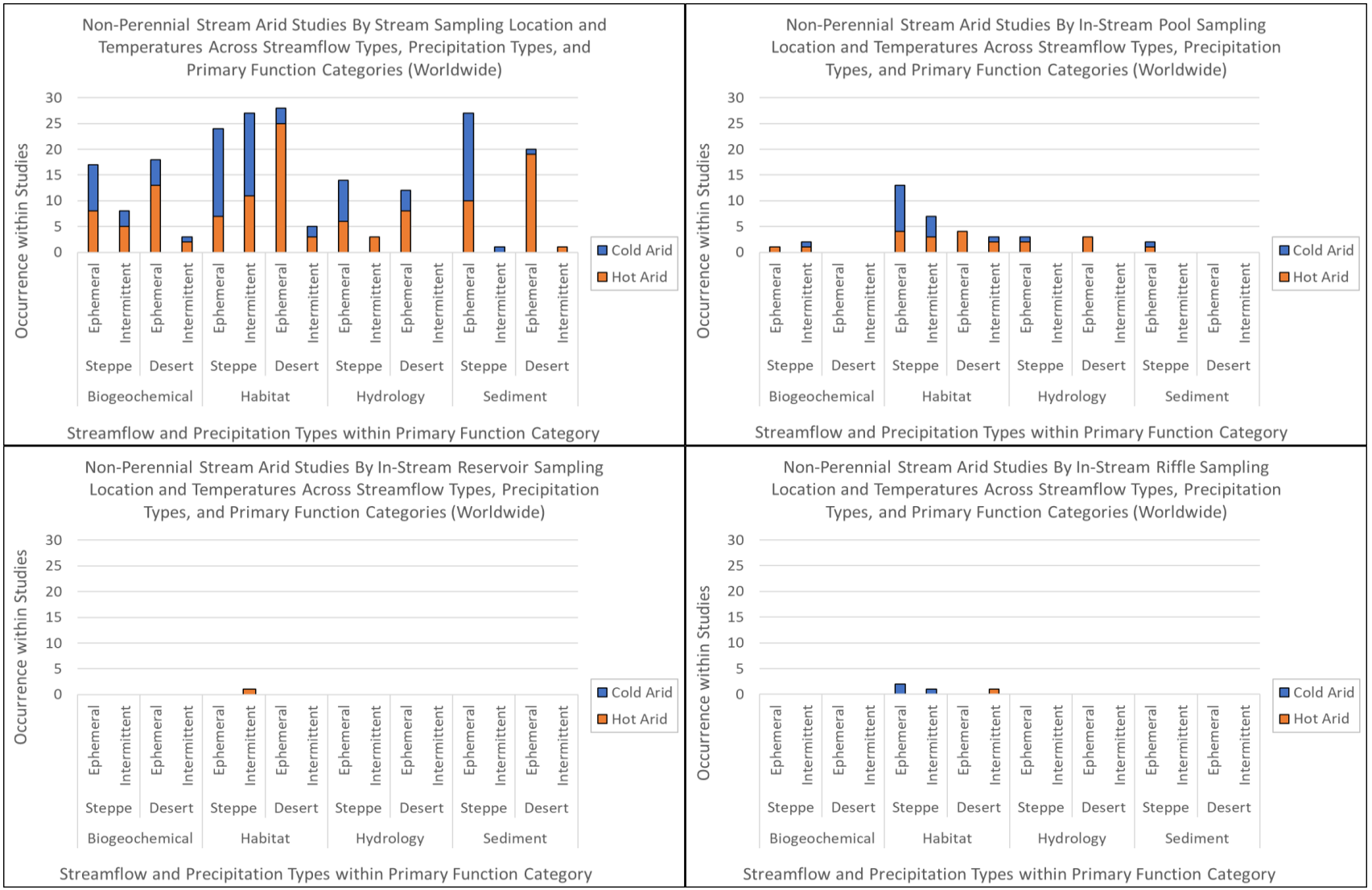


Figure 190. Sampling of each Group 3 sampling location type across primary broad function categories and temperatures, by precipitation and known streamflow types, within global arid non-perennial stream literature.

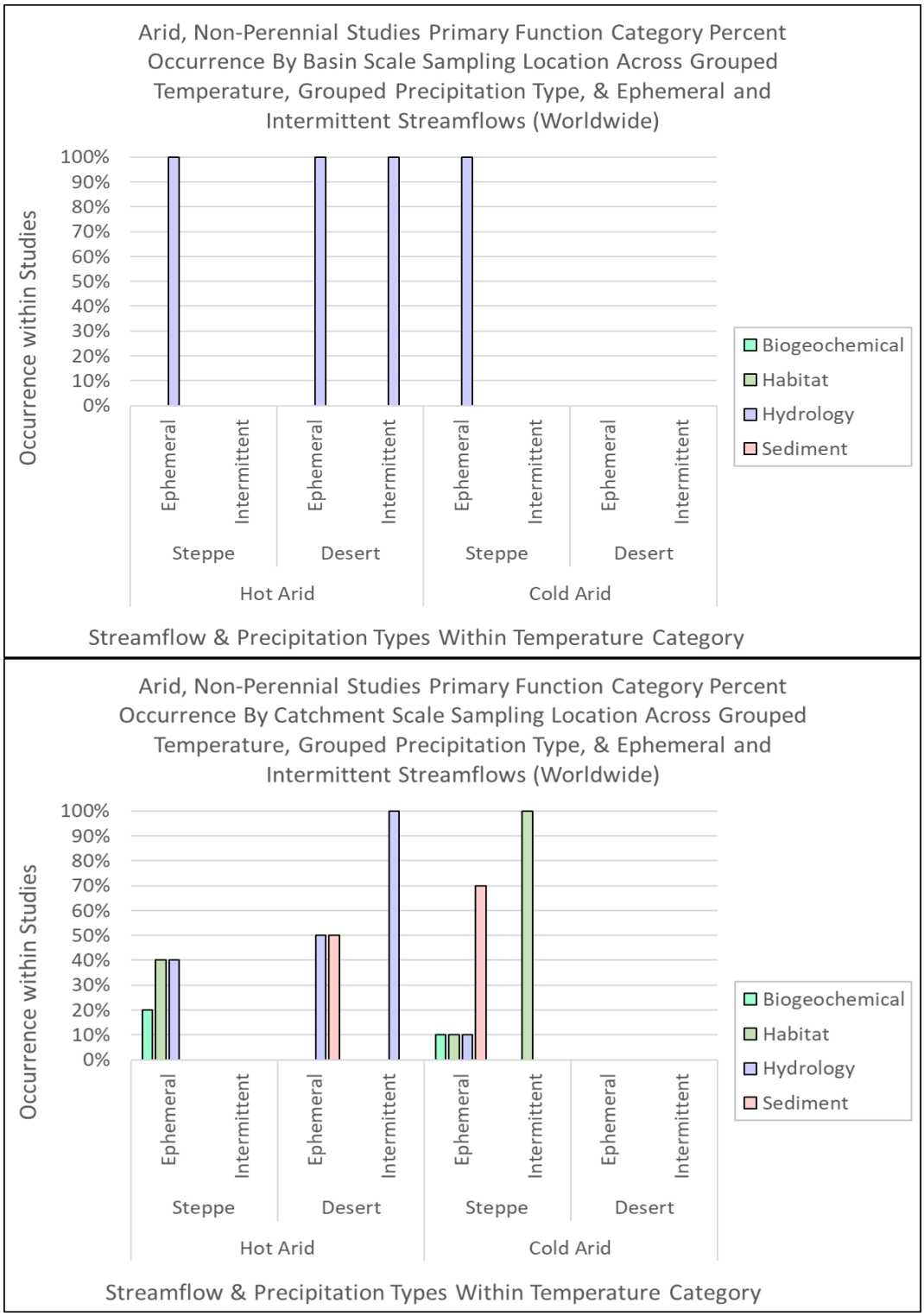


Figure 191. Sampling of each Group 1 sampling location type across primary broad function categories by temperatures, and by precipitation and known streamflow types, within global arid non-perennial stream literature.

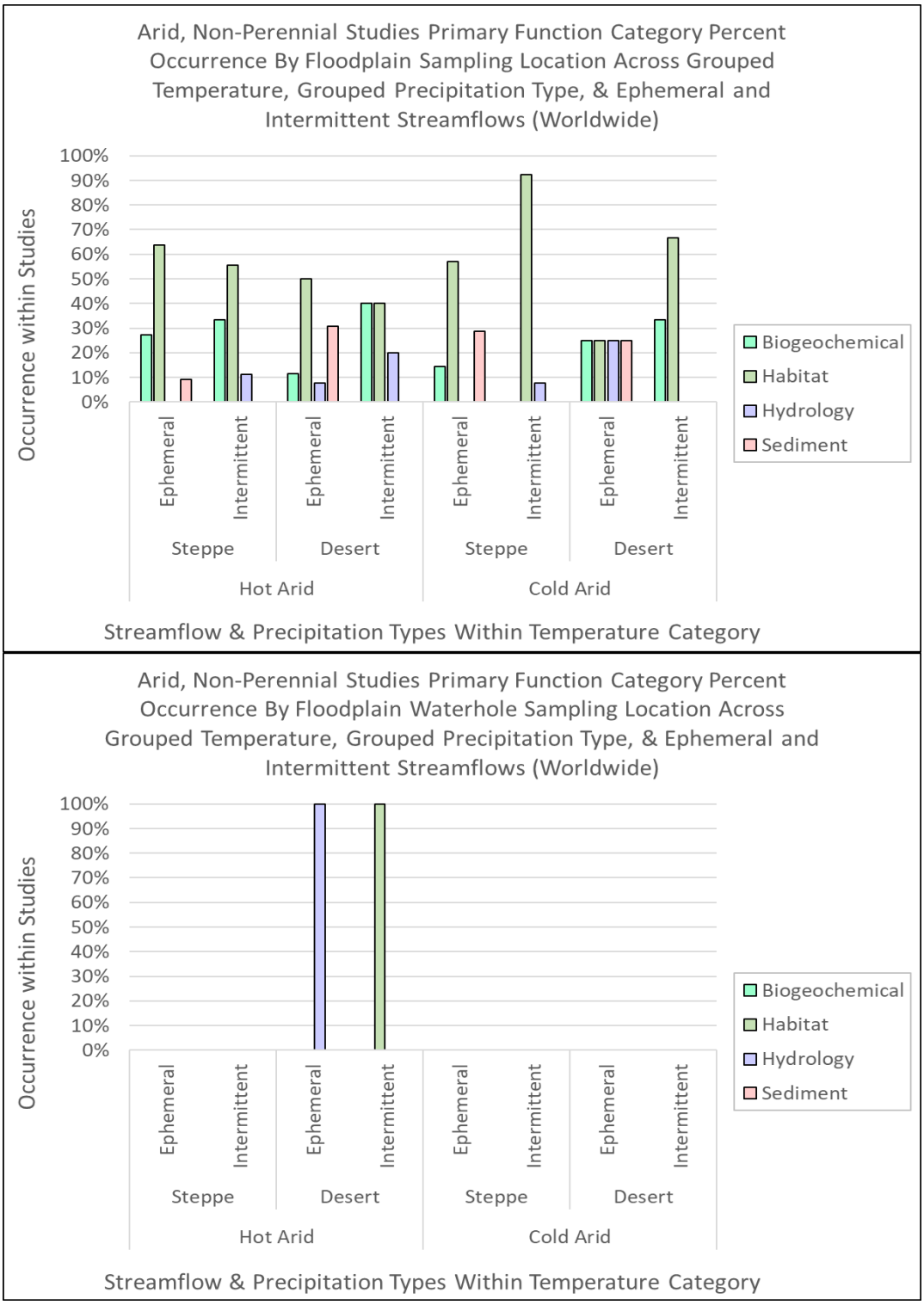


Figure 192. Sampling of each Group 2 sampling location type across primary broad function categories by temperatures, and by precipitation and known streamflow types, within global arid non-perennial stream literature.

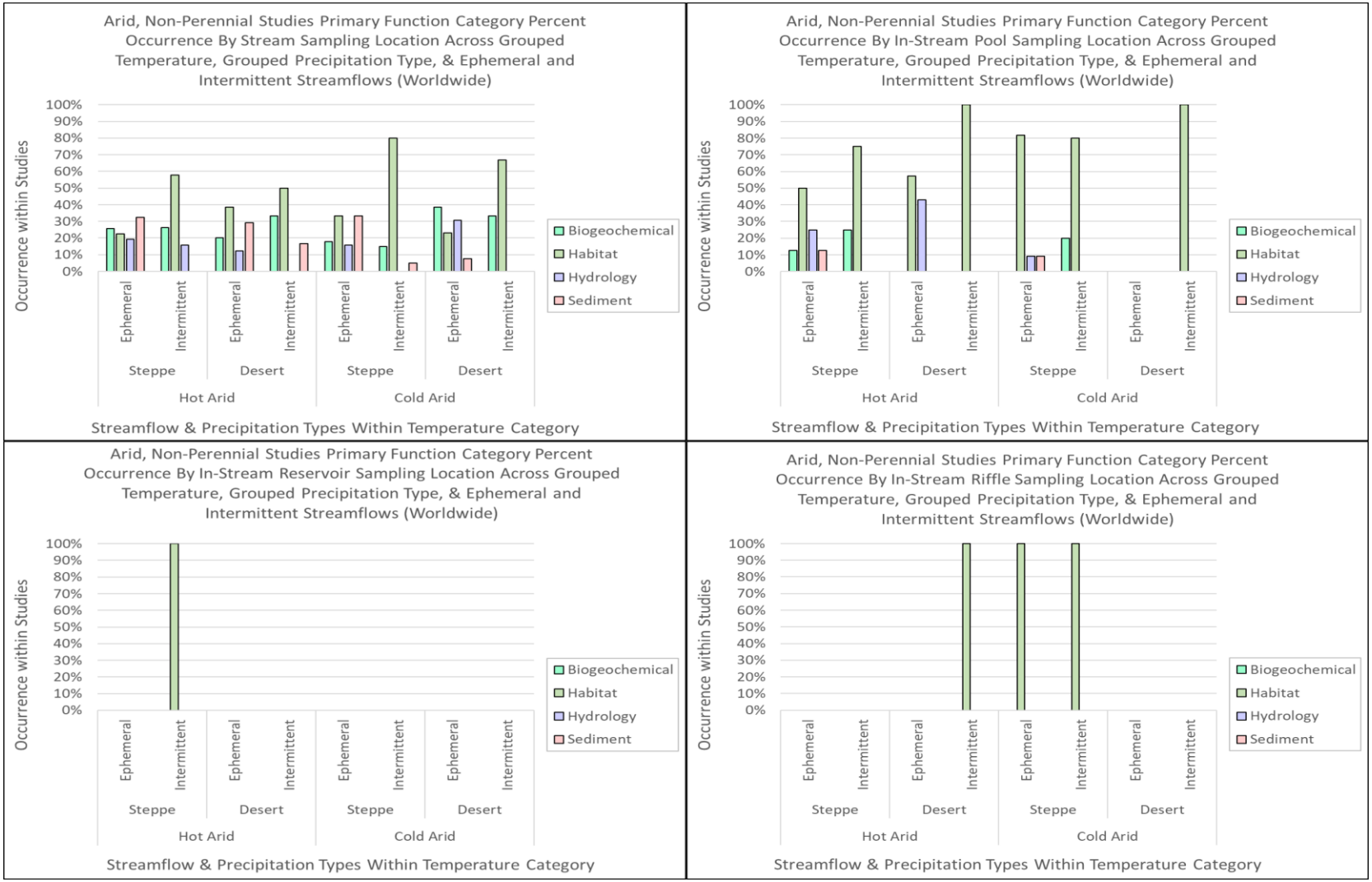


Figure 193. Sampling of each Group 3 sampling location type across primary broad function categories by temperatures, and by precipitation and known streamflow types, within global arid non-perennial stream literature.

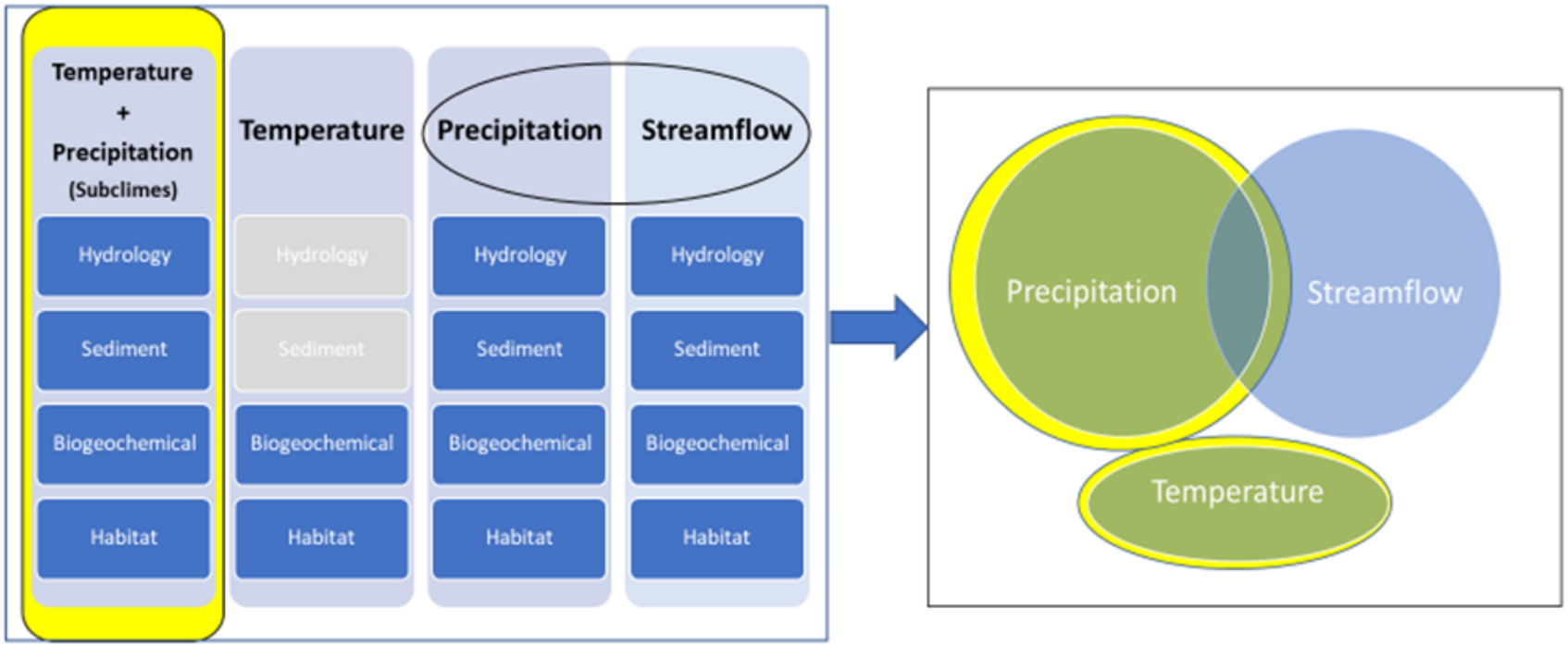


Figure 194. The conceptual relations and hierarchies of subclime (combined temperature and precipitation types) factors and an inherent hydrology component (precipitation types) factor and their influence on broad stream function categories.

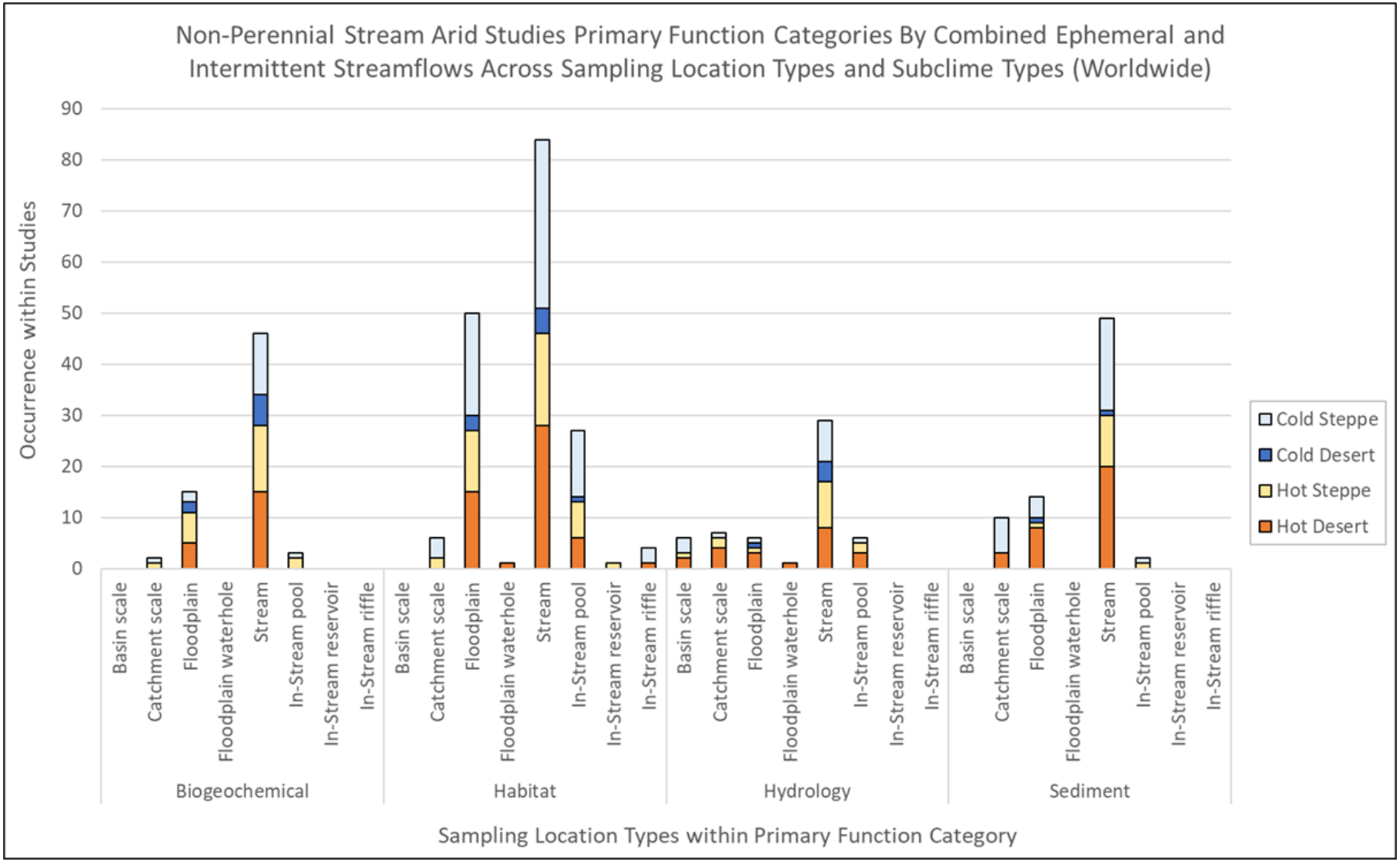


Figure 195. Sampling of primary broad function categories across condensed sampling location types by subclimes, within global arid non-perennial stream literature.

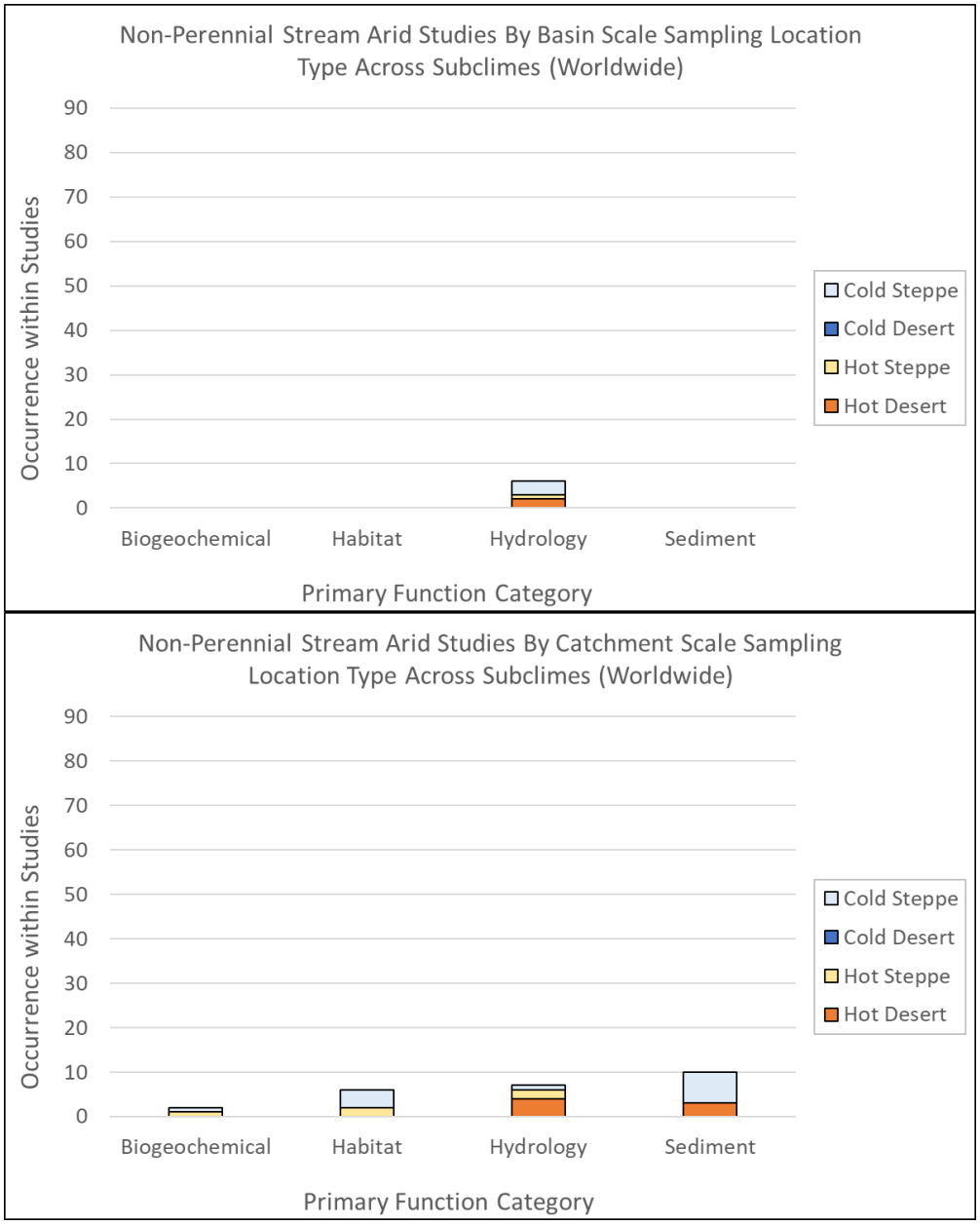


Figure 196. Sampling of each Group 1 sampling location type across primary broad function categories and subclimes, within global arid non-perennial stream literature.

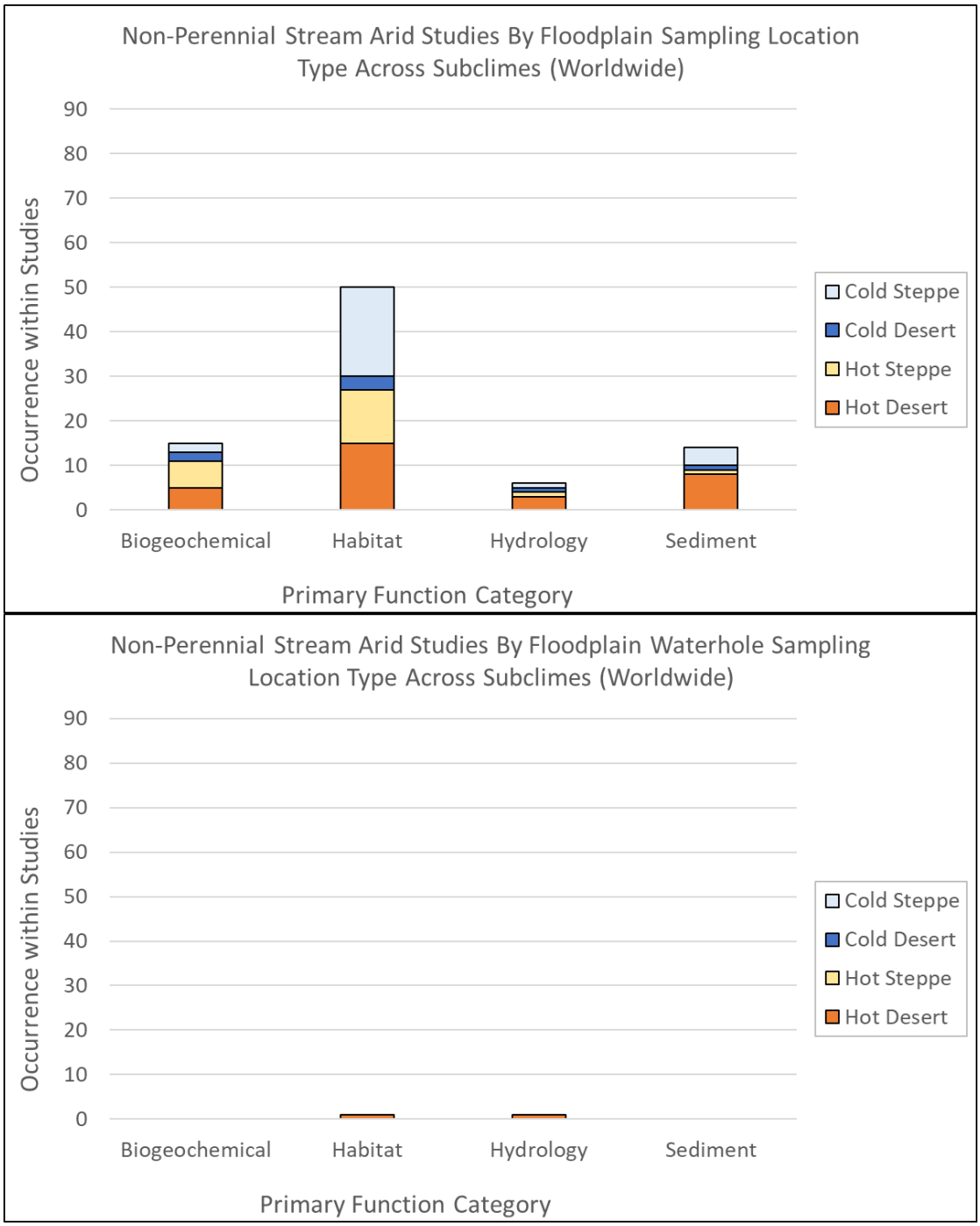


Figure 197. Sampling of each Group 2 sampling location type across primary broad function categories and subclimes, within global arid non-perennial stream literature.

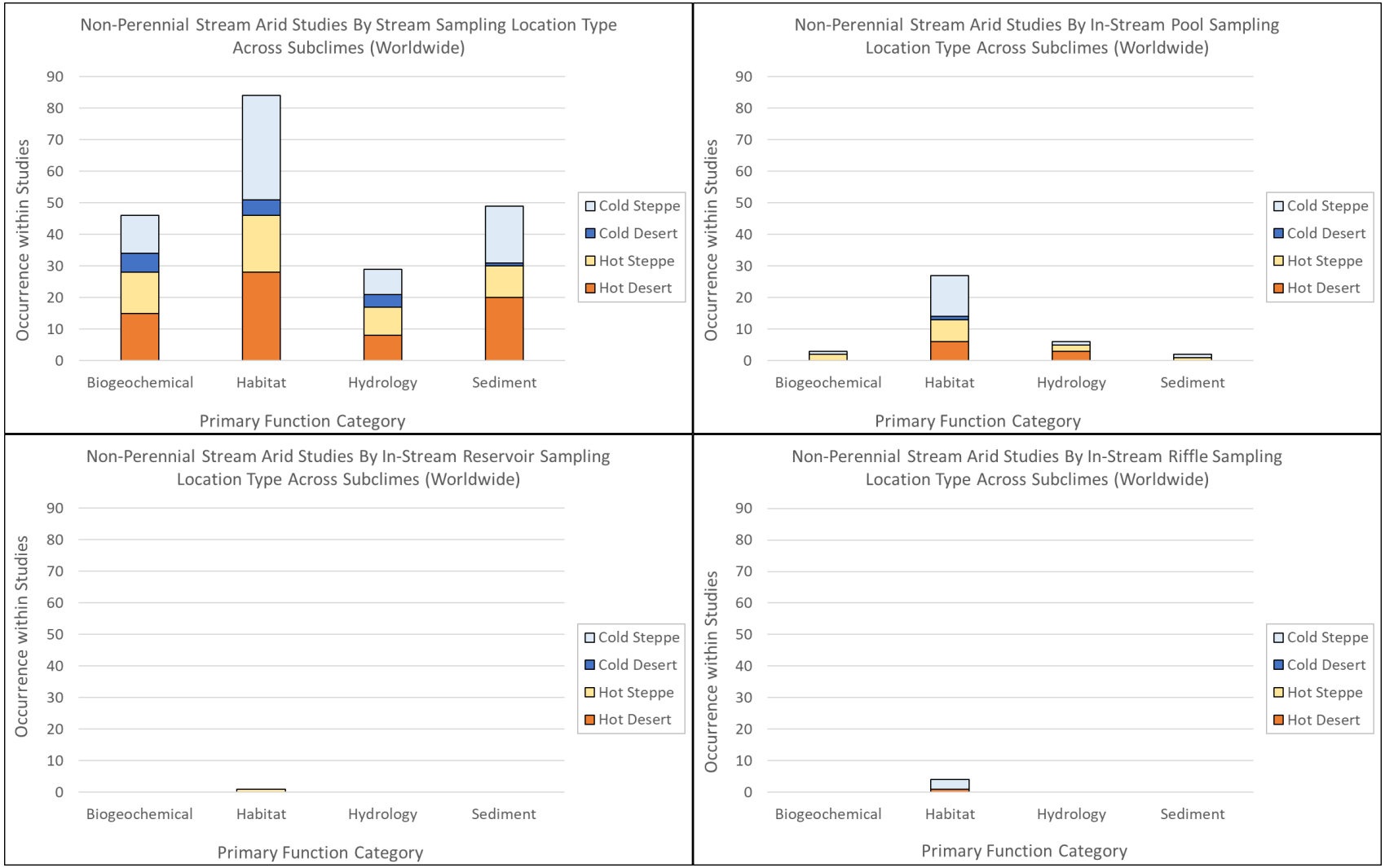


Figure 198. Sampling of each Group 3 sampling location type across primary broad function categories and subclimes, within global arid non-perennial stream literature.

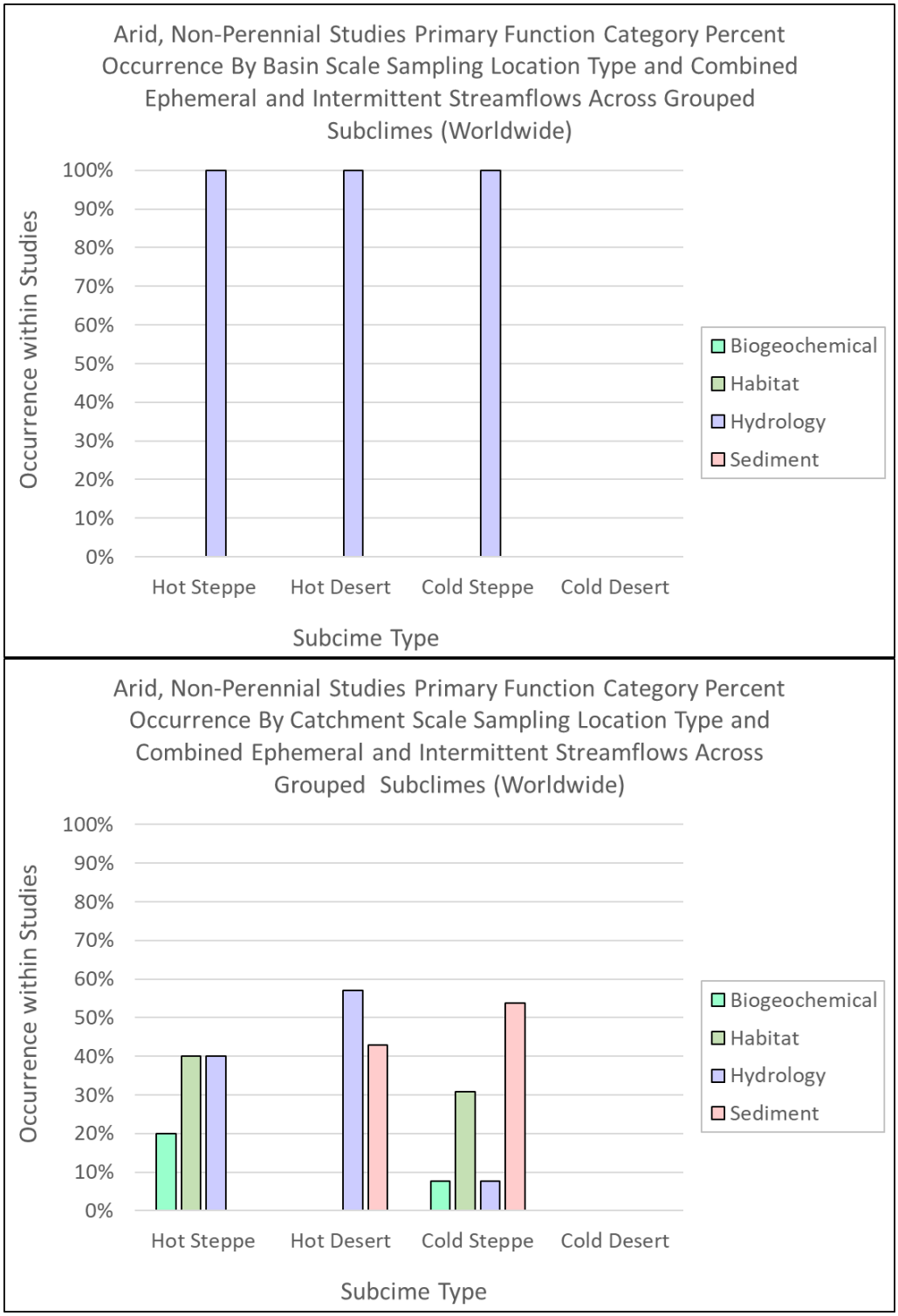
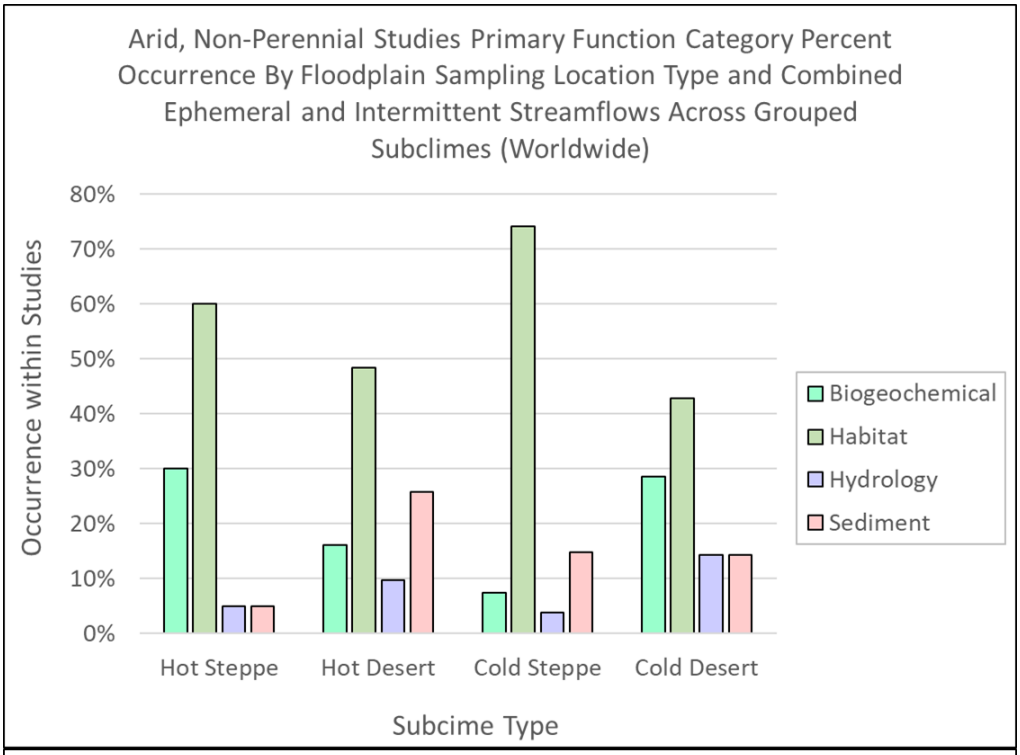


Figure 199. Sampling of each Group 1 sampling location type across primary broad function categories by subclimes, within global arid non-perennial stream literature.



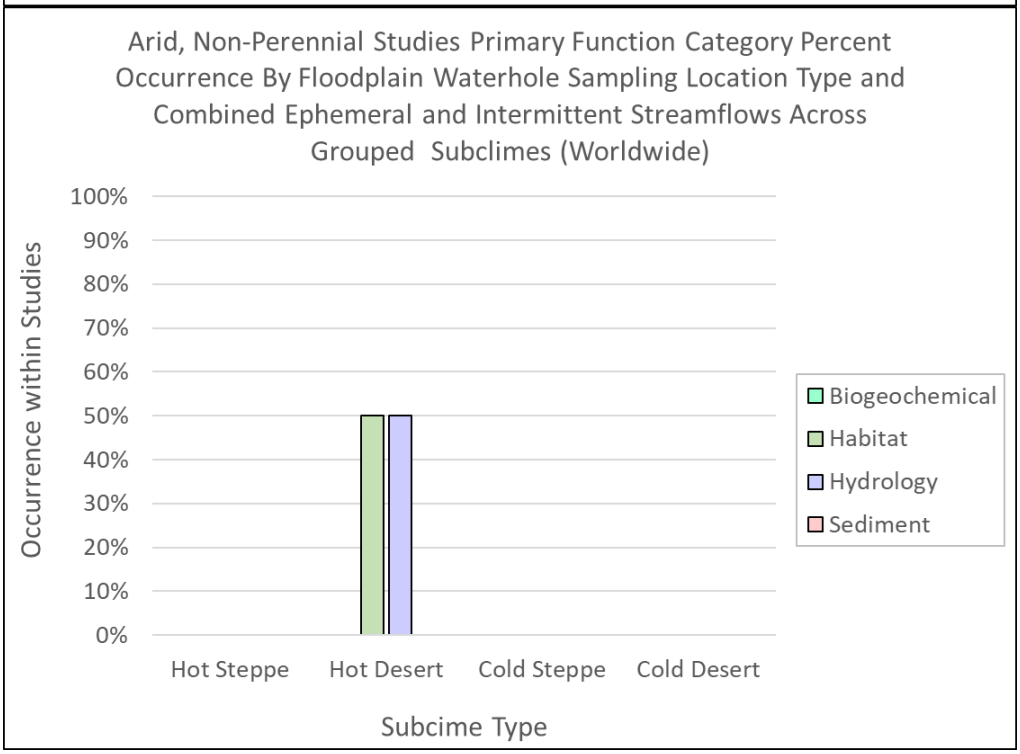


Figure 200. Sampling of each Group 2 sampling location type across primary broad function categories by subclimes, within global arid non-perennial stream literature.

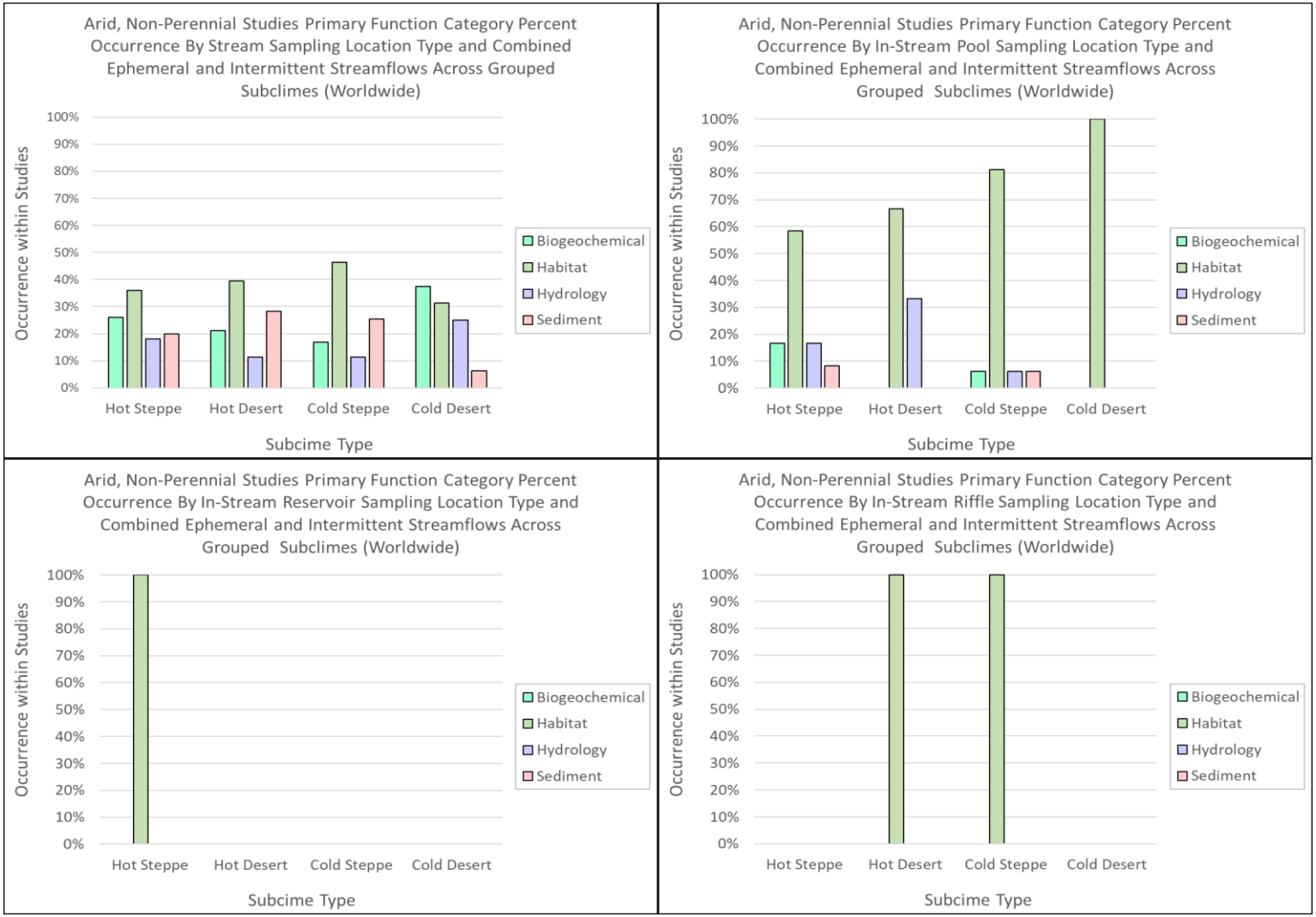


Figure 201. Sampling of each Group 3 sampling location type across primary broad function categories by subclimes, within global arid non-perennial stream literature.

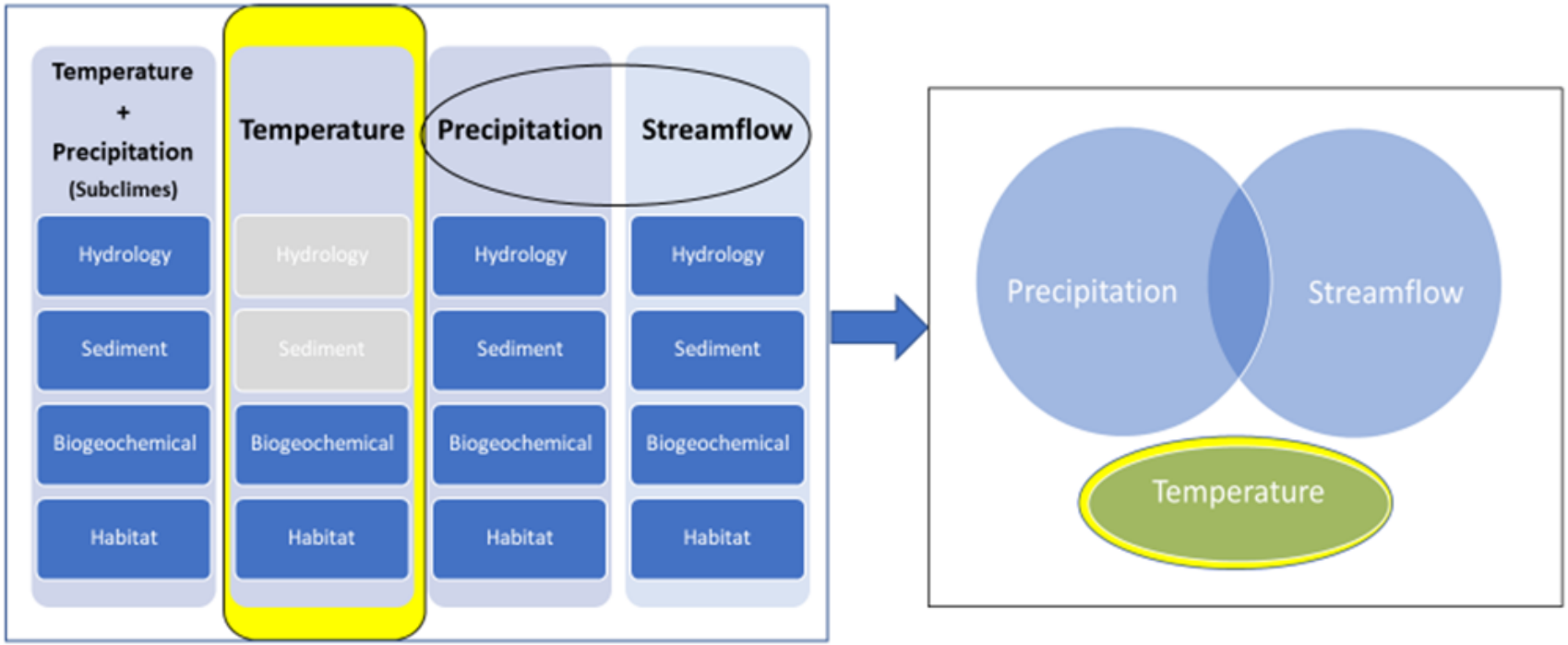


Figure 202. The conceptual relations and hierarchies of a subclime component (temperature) factor and its influence on broad stream function categories.

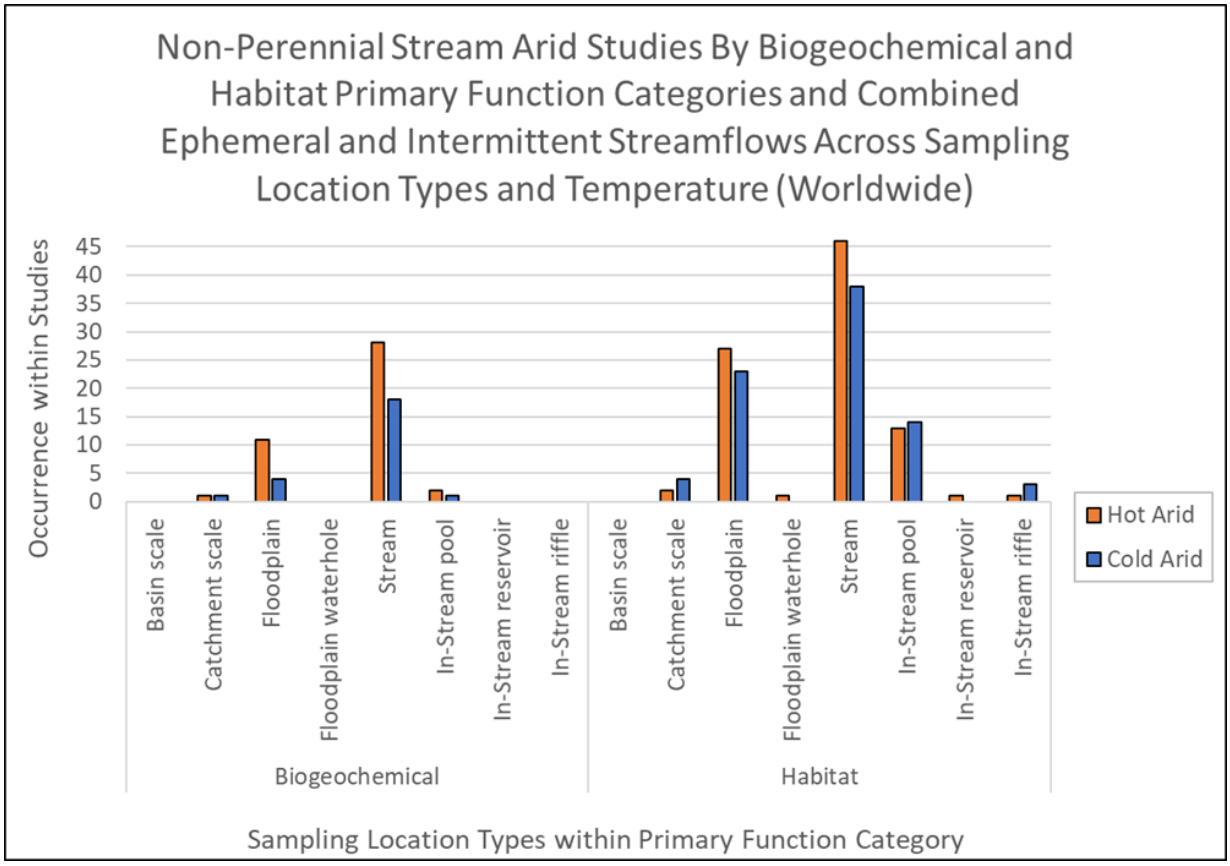


Figure 203. Sampling of Biogeochemical and Habitat primary broad function categories across condensed sampling location types and temperatures, within global arid non-perennial stream literature.

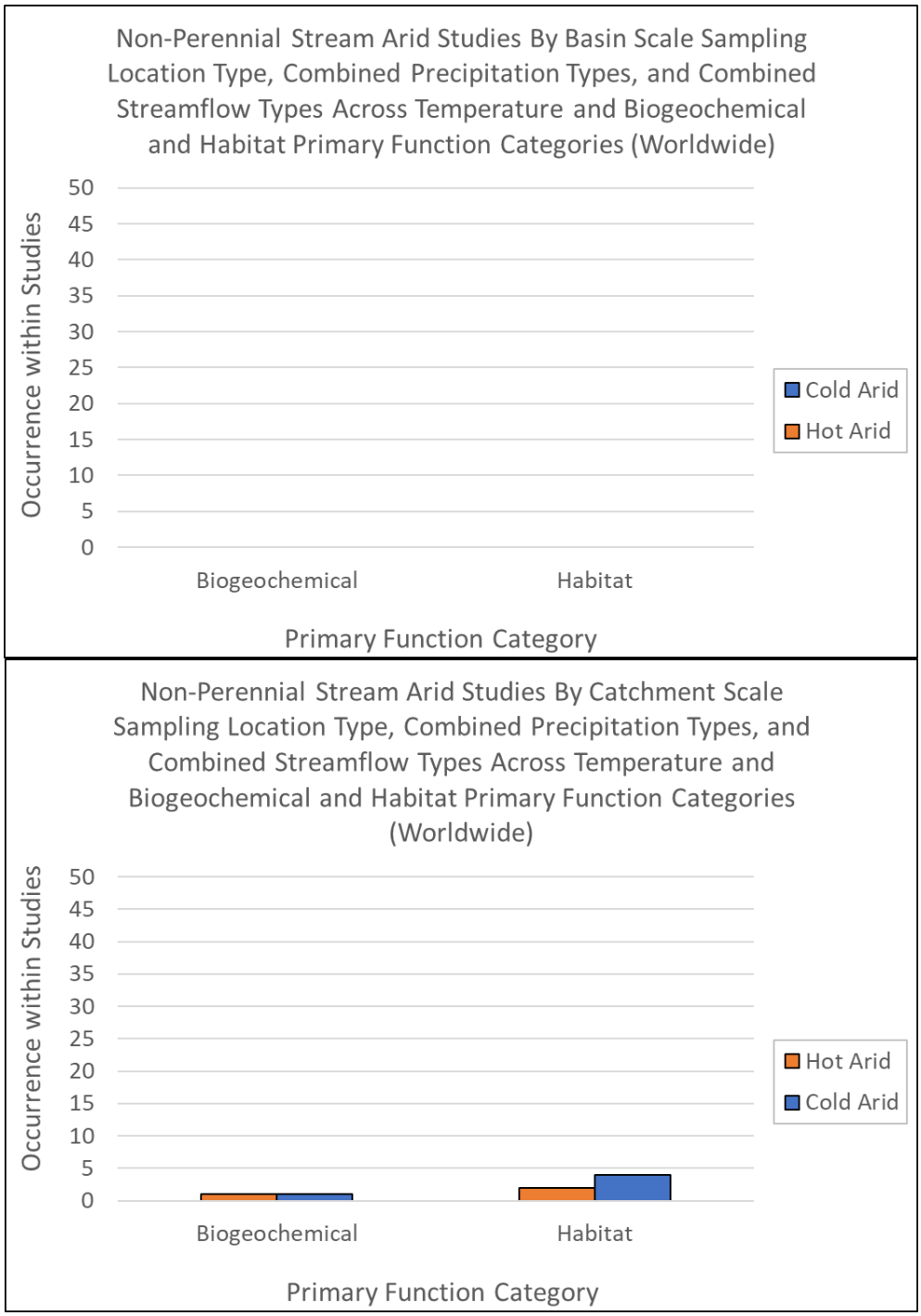


Figure 204. Sampling of each Group 1 sampling location type across Biogeochemical and Habitat primary broad function categories and temperatures, within global arid non-perennial stream literature.

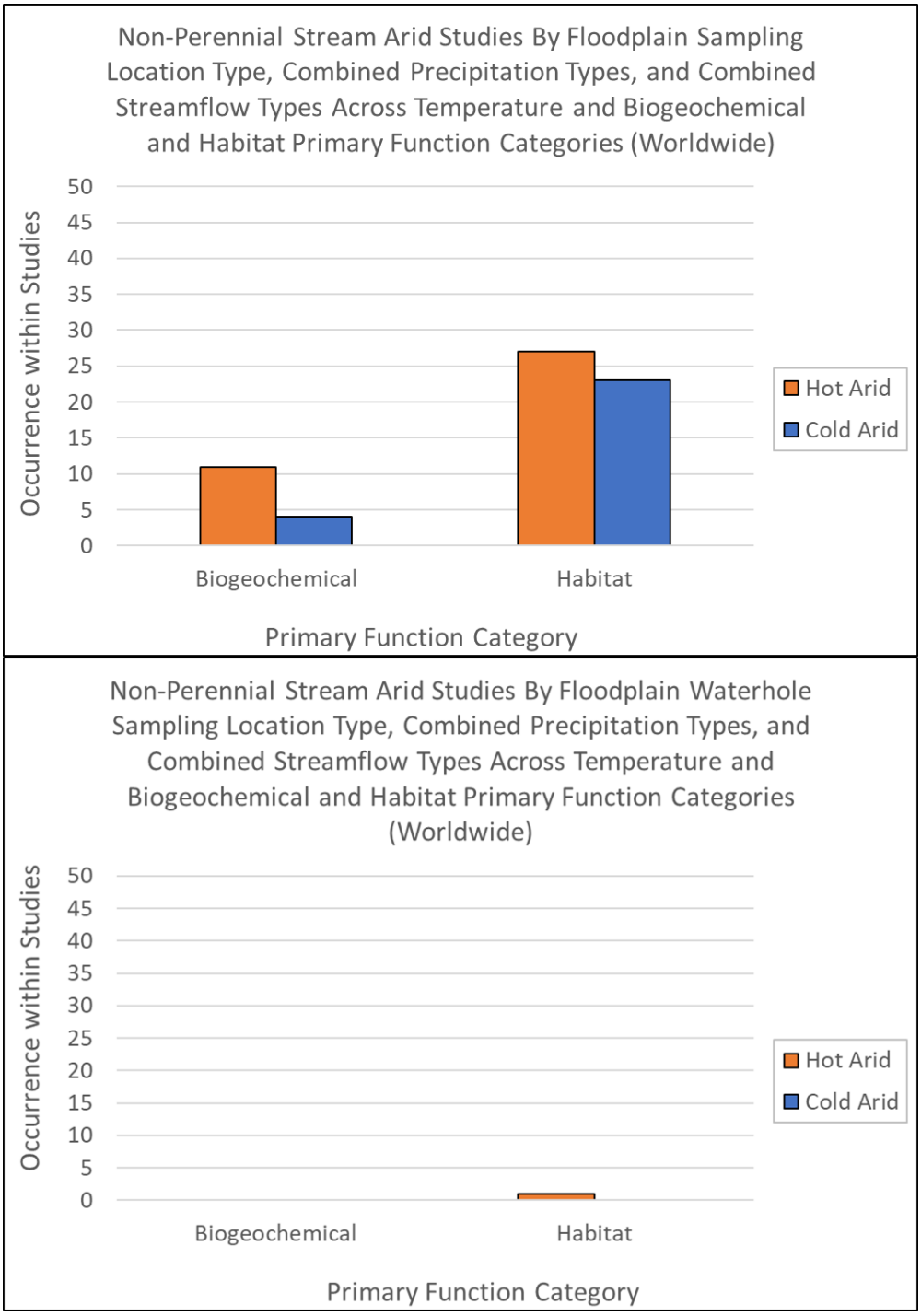


Figure 205. Sampling of each Group 2 sampling location type across Biogeochemical and Habitat primary broad function categories and temperatures, within global arid non-perennial stream literature.

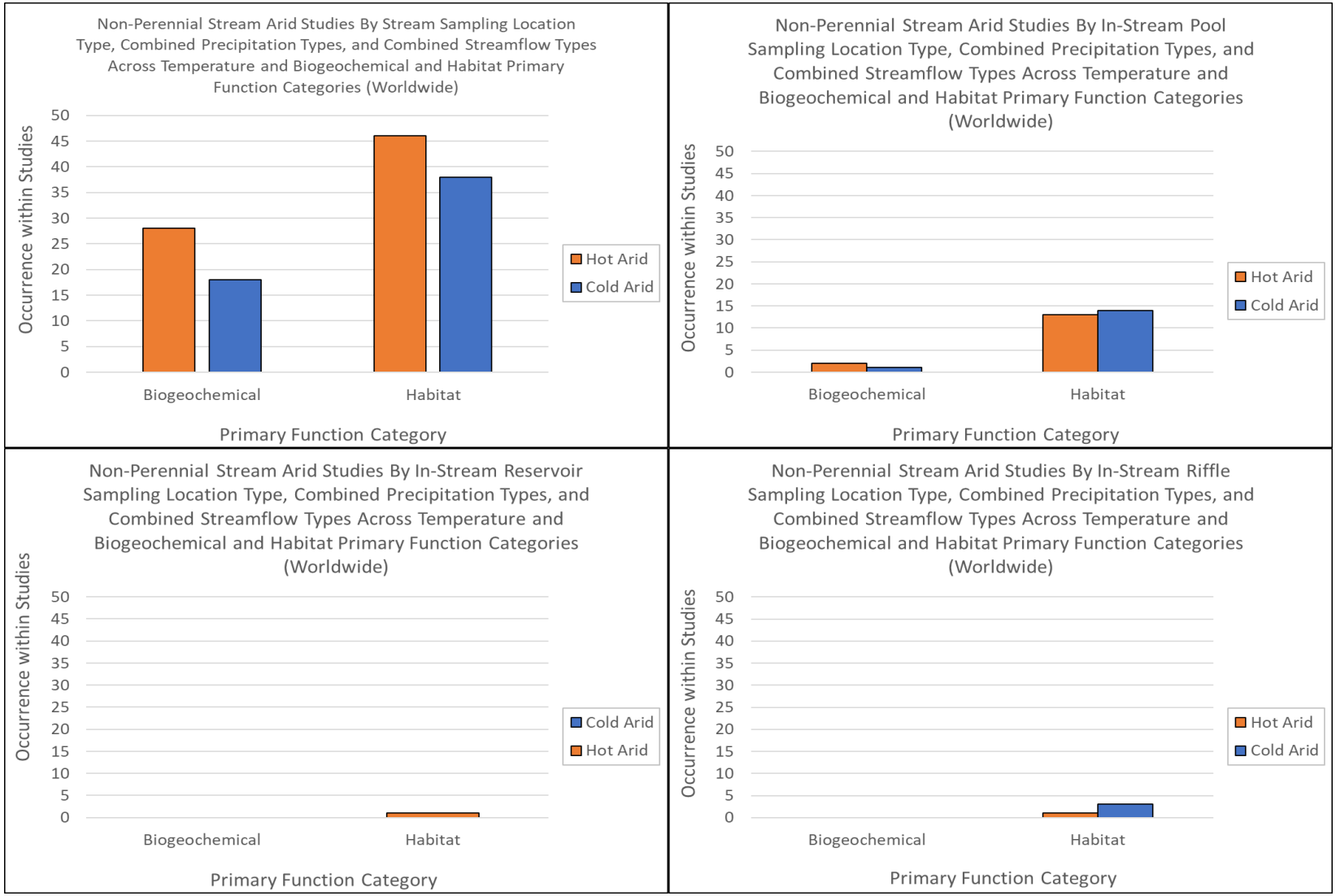


Figure 206. Sampling of each Group 3 sampling location type across Biogeochemical and Habitat primary broad function categories and temperatures, within global arid non-perennial stream literature.

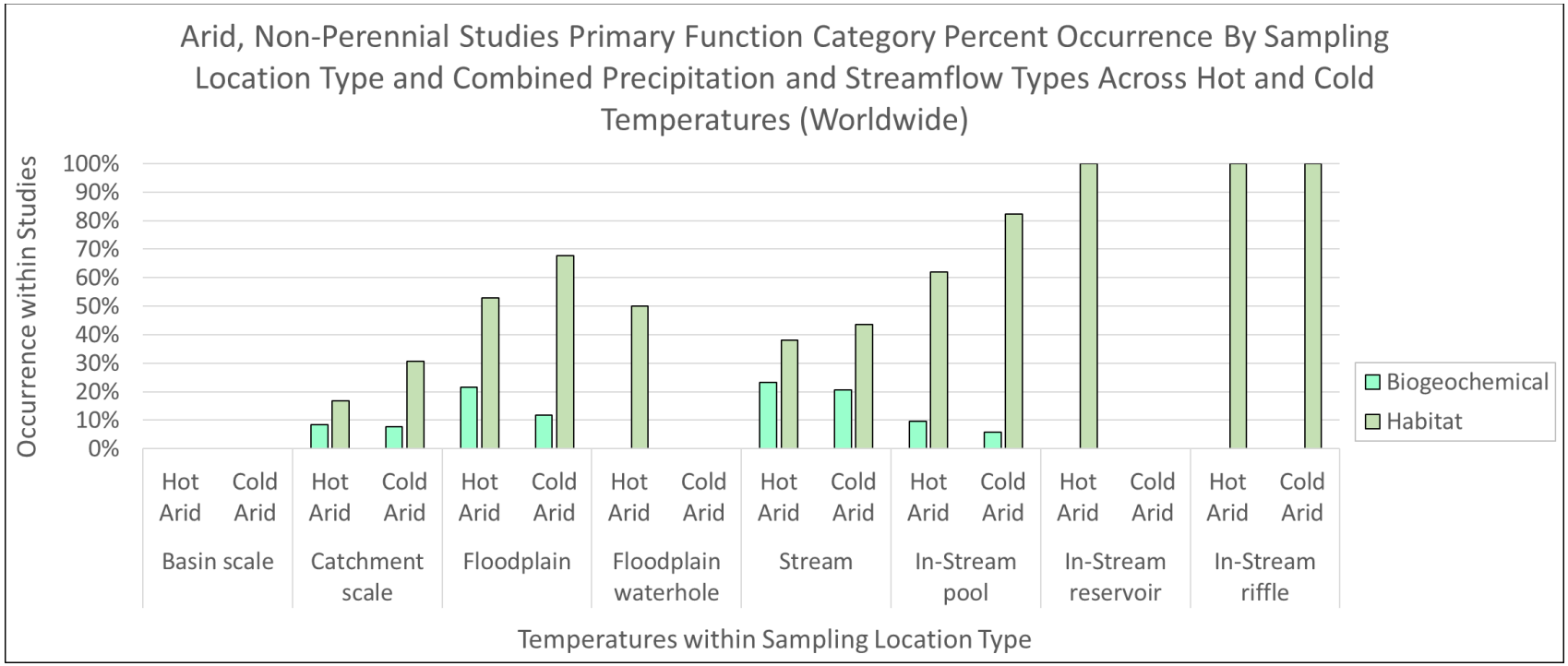


Figure 207. Sampling of sampling location types across Biogeochemical and Habitat primary broad function categories by temperatures, within global arid non-perennial stream literature.

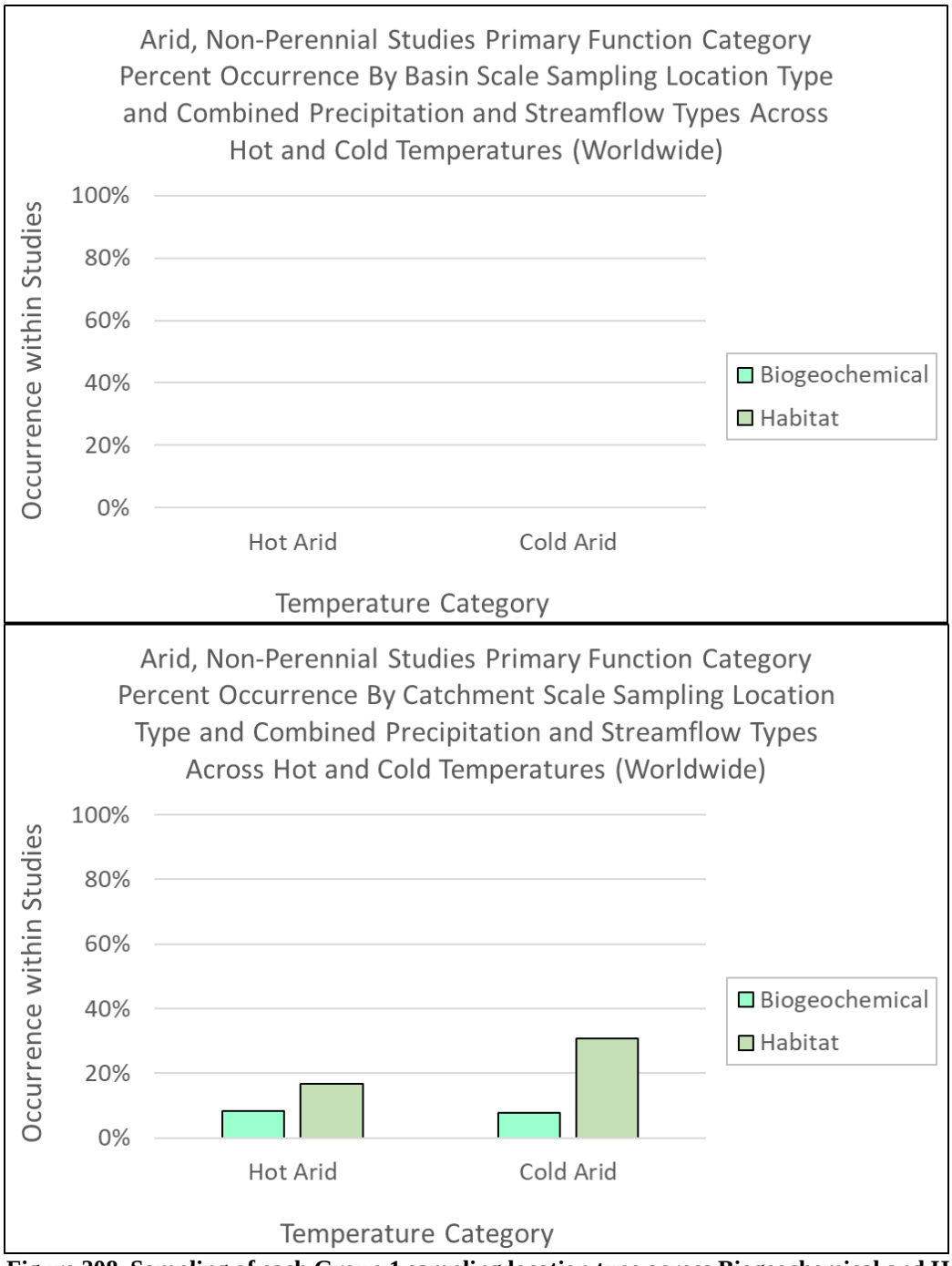


Figure 208. Sampling of each Group 1 sampling location type across Biogeochemical and Habitat primary broad function categories by temperatures, within global arid non-perennial stream literature.

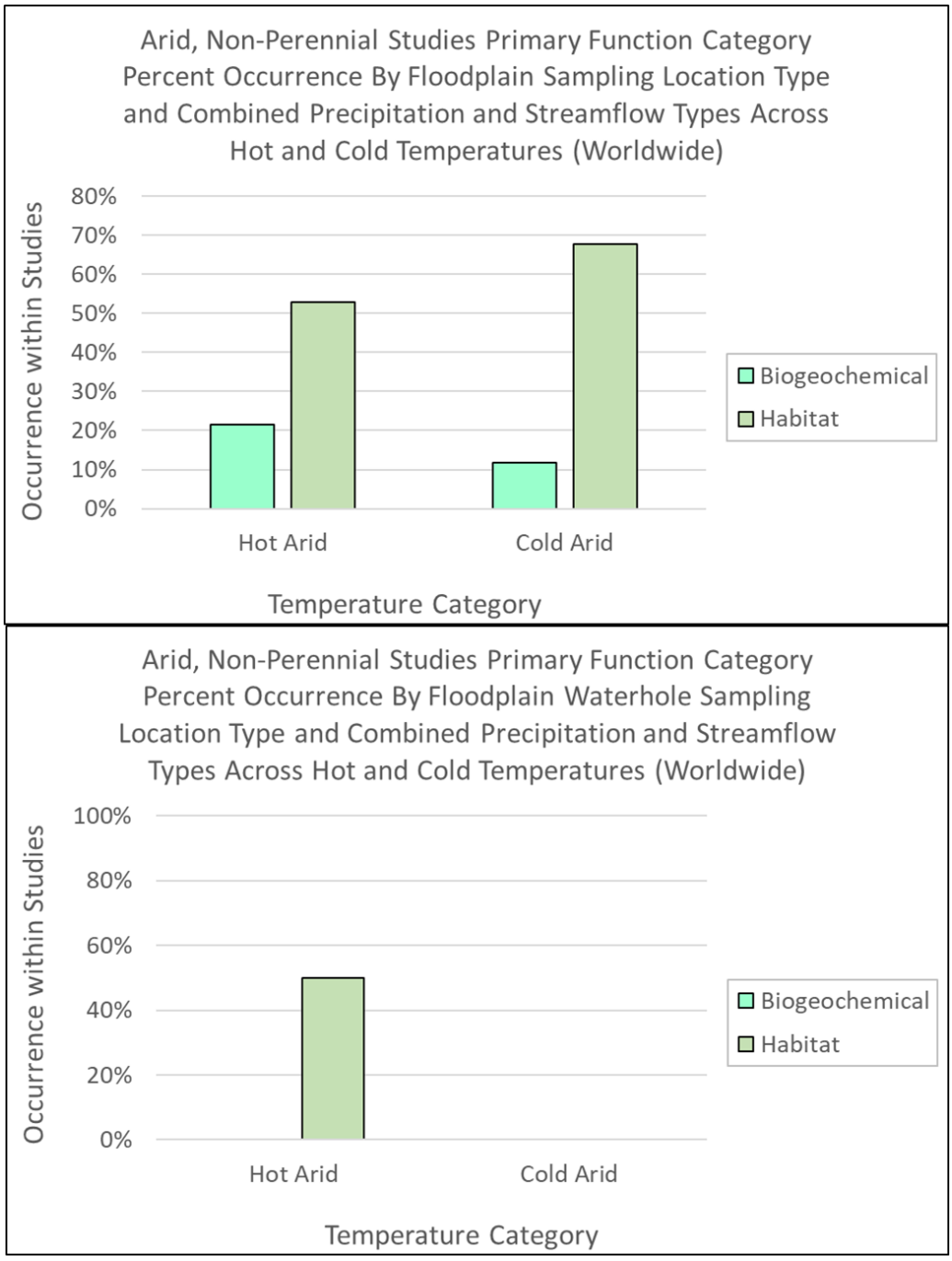


Figure 209. Sampling of each Group 2 sampling location type across Biogeochemical and Habitat primary broad function categories by temperatures, within global arid non- perennial stream literature.

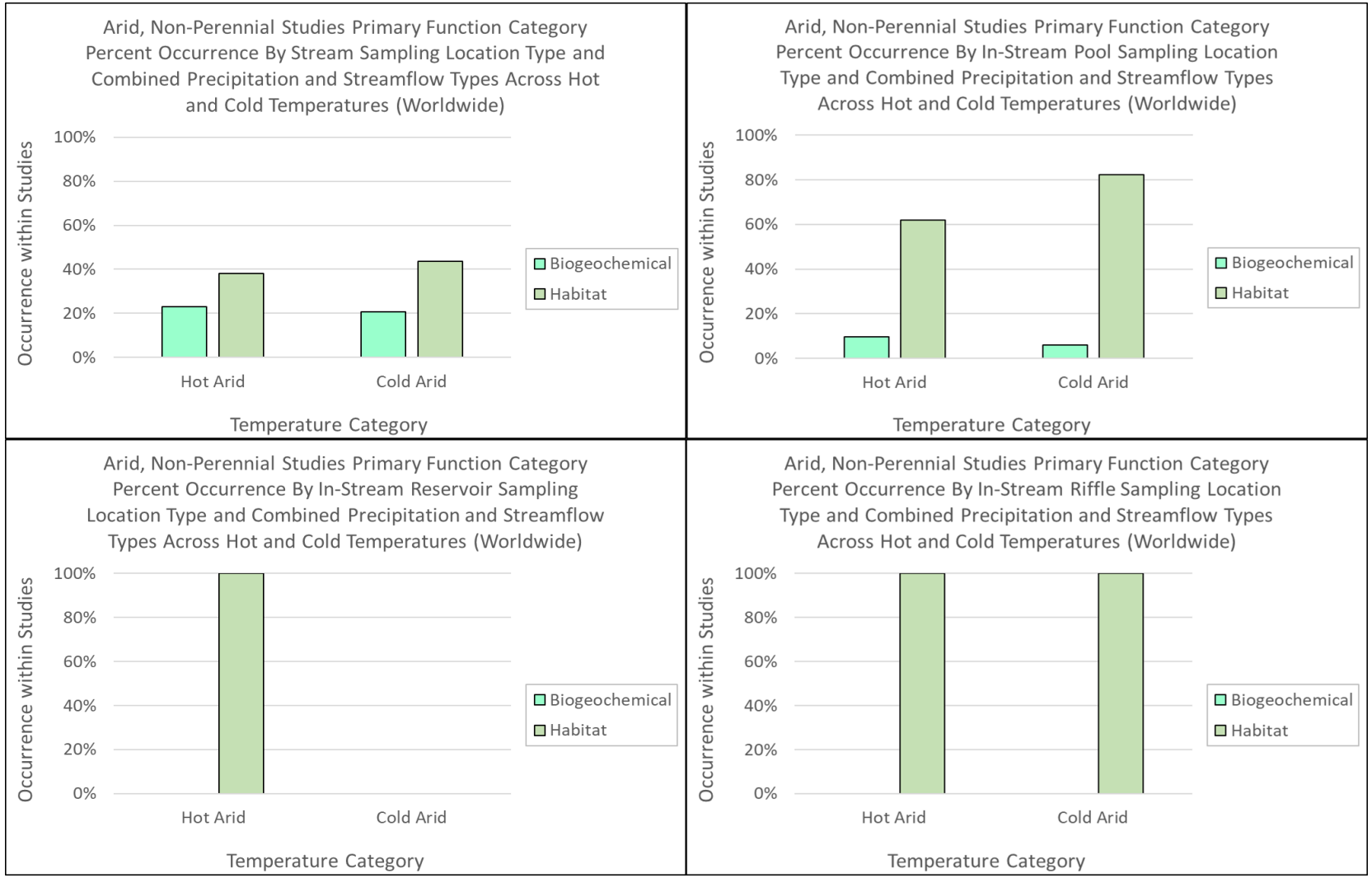


Figure 210. Sampling of each Group 3 sampling location type across Biogeochemical and Habitat primary broad function categories by temperatures, within global arid non- perennial stream literature.

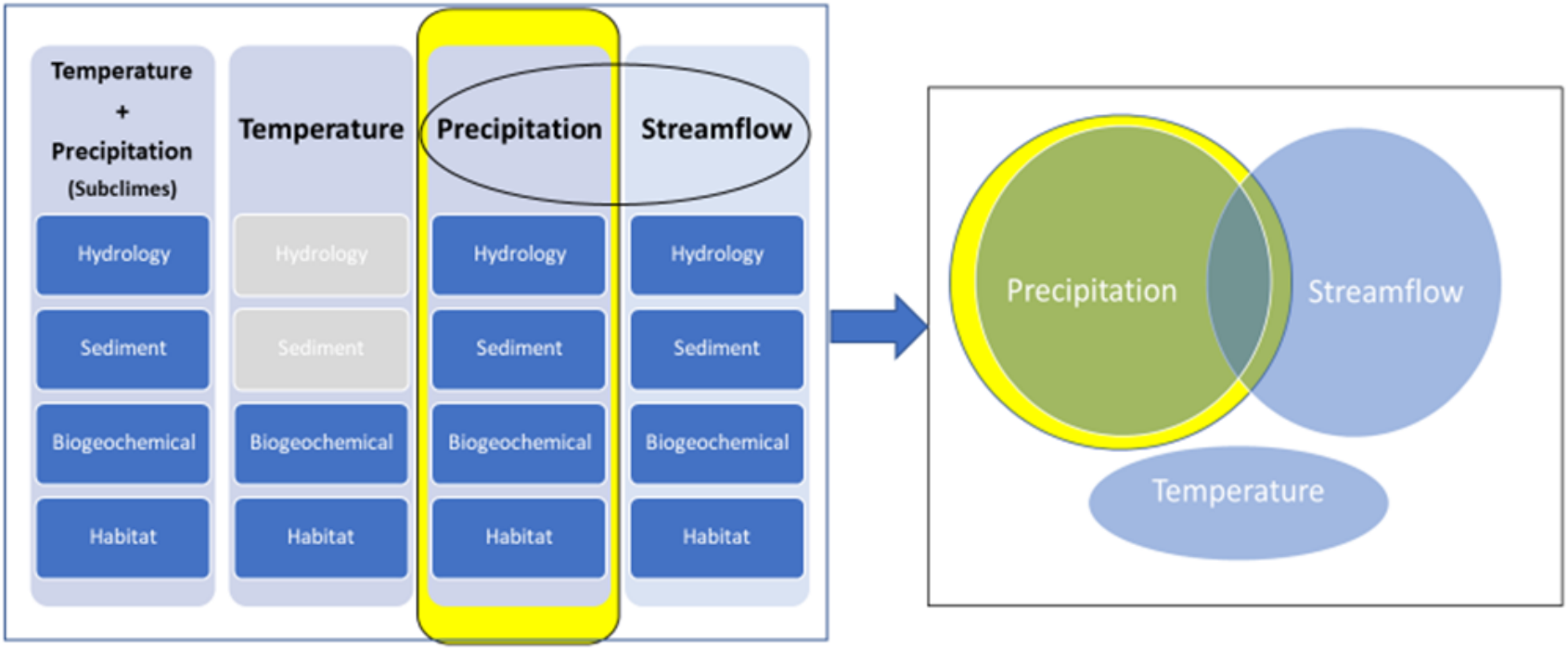


Figure 211. The conceptual relations and hierarchies of a subclime component (precipitation types) and an inherent hydrology component (precipitation types) factor and its influence on broad stream function categories.

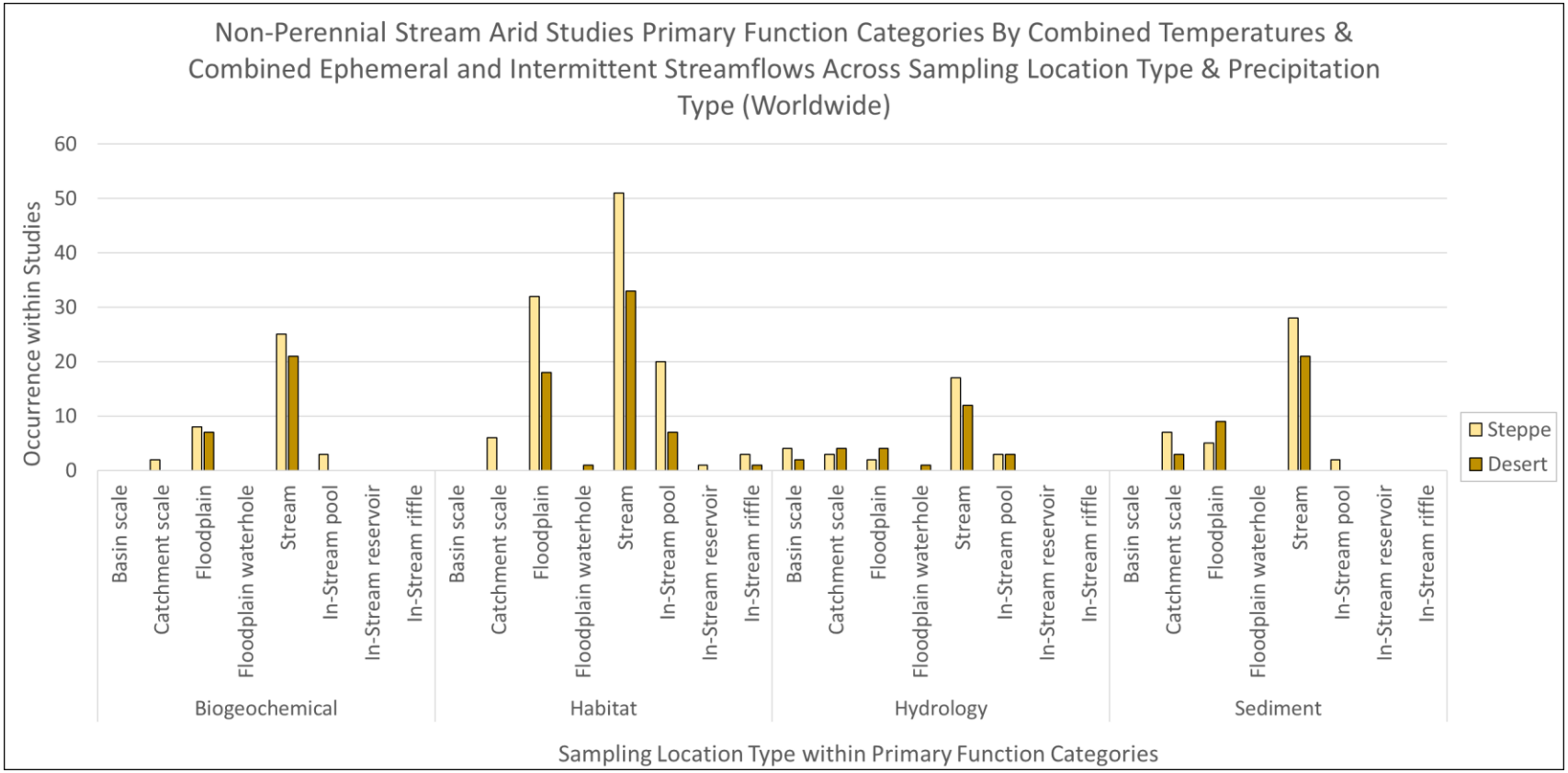


Figure 212. Sampling of primary broad function categories across condensed sampling location types and precipitation types, within global arid non-perennial stream literature.

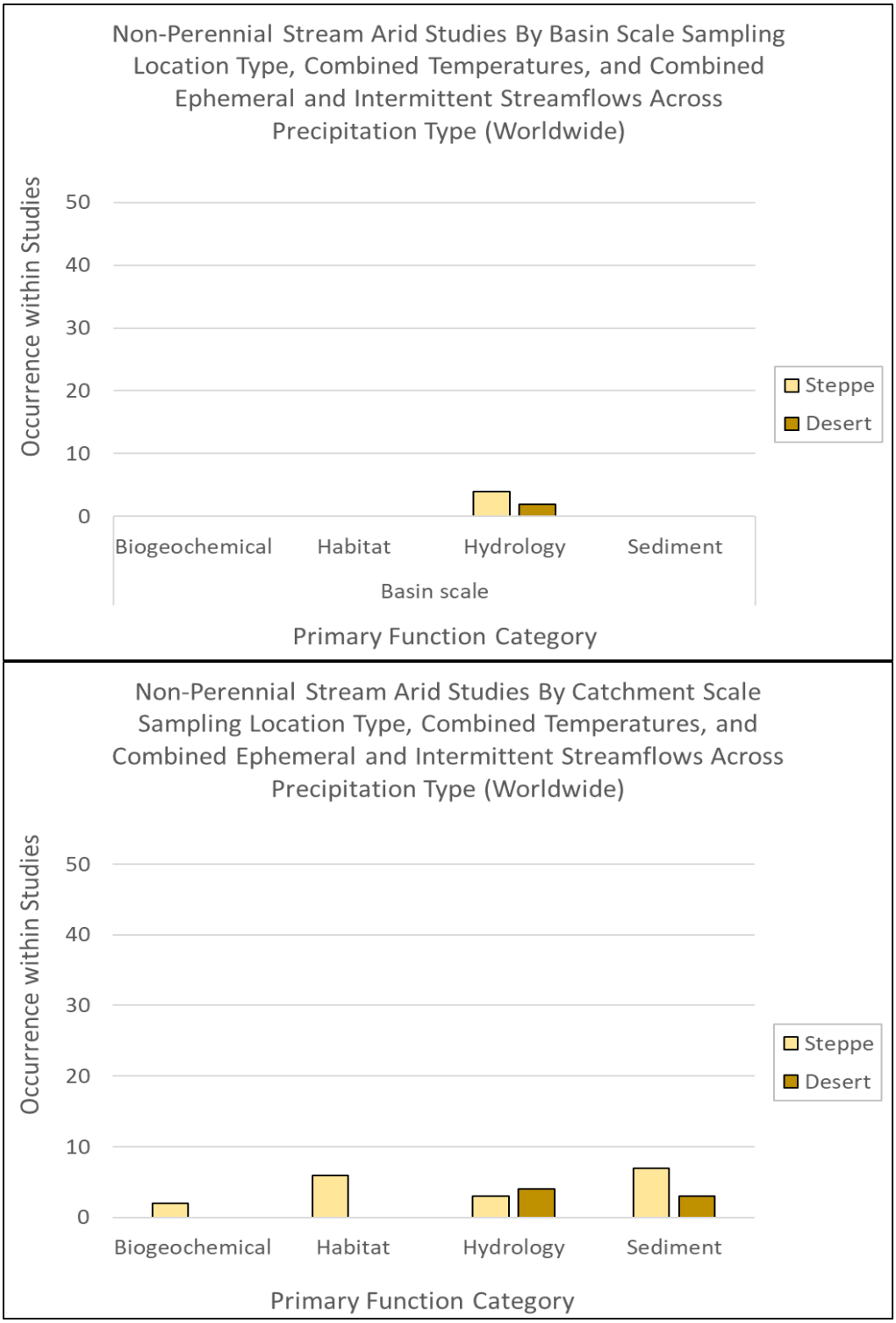


Figure 213. Sampling of each Group 1 condensed sampling location type across primary broad function categories and precipitation types, within global arid non-perennial stream literature.

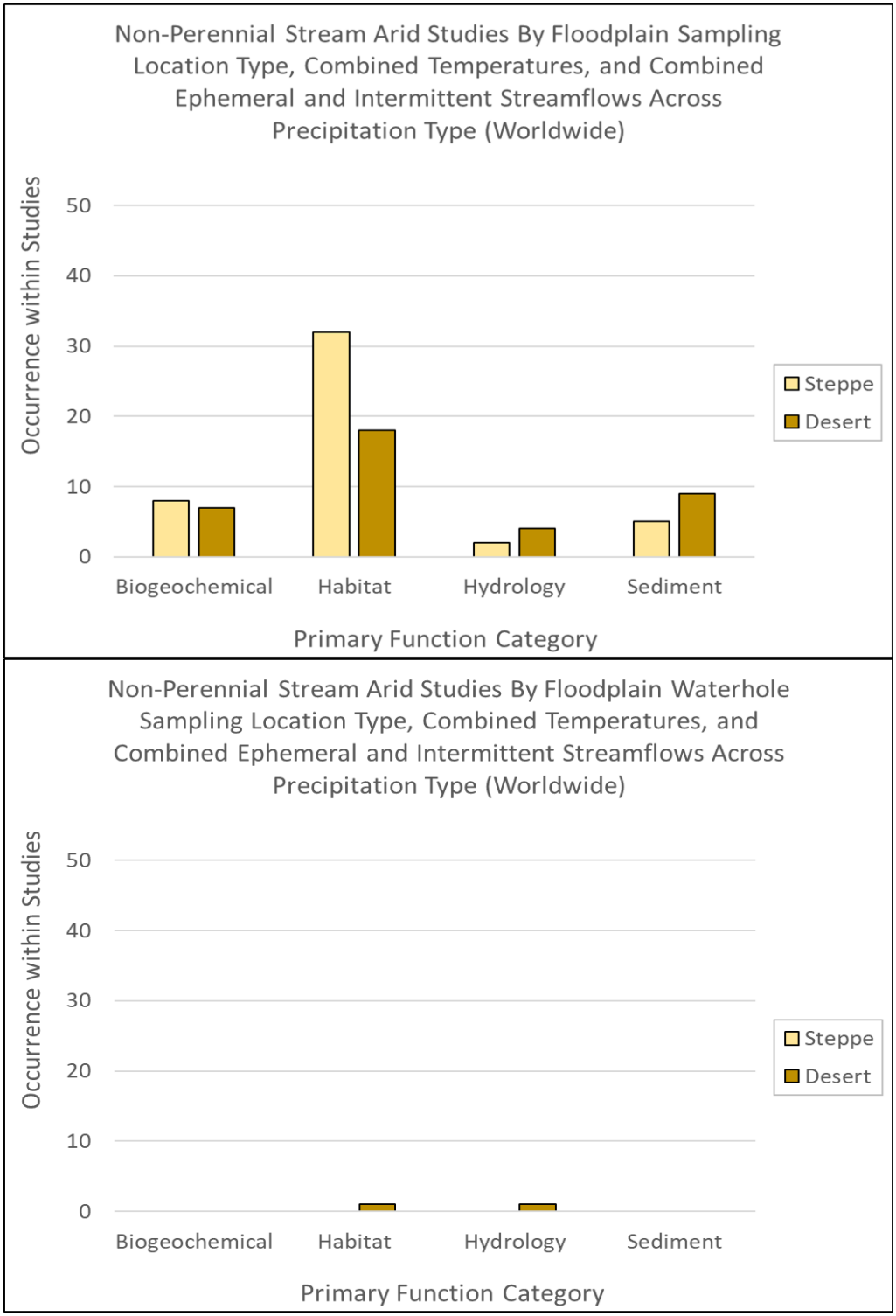


Figure 214. Sampling of each Group 2 condensed sampling location type across primary broad function categories and precipitation types, within global arid non-perennial stream literature.

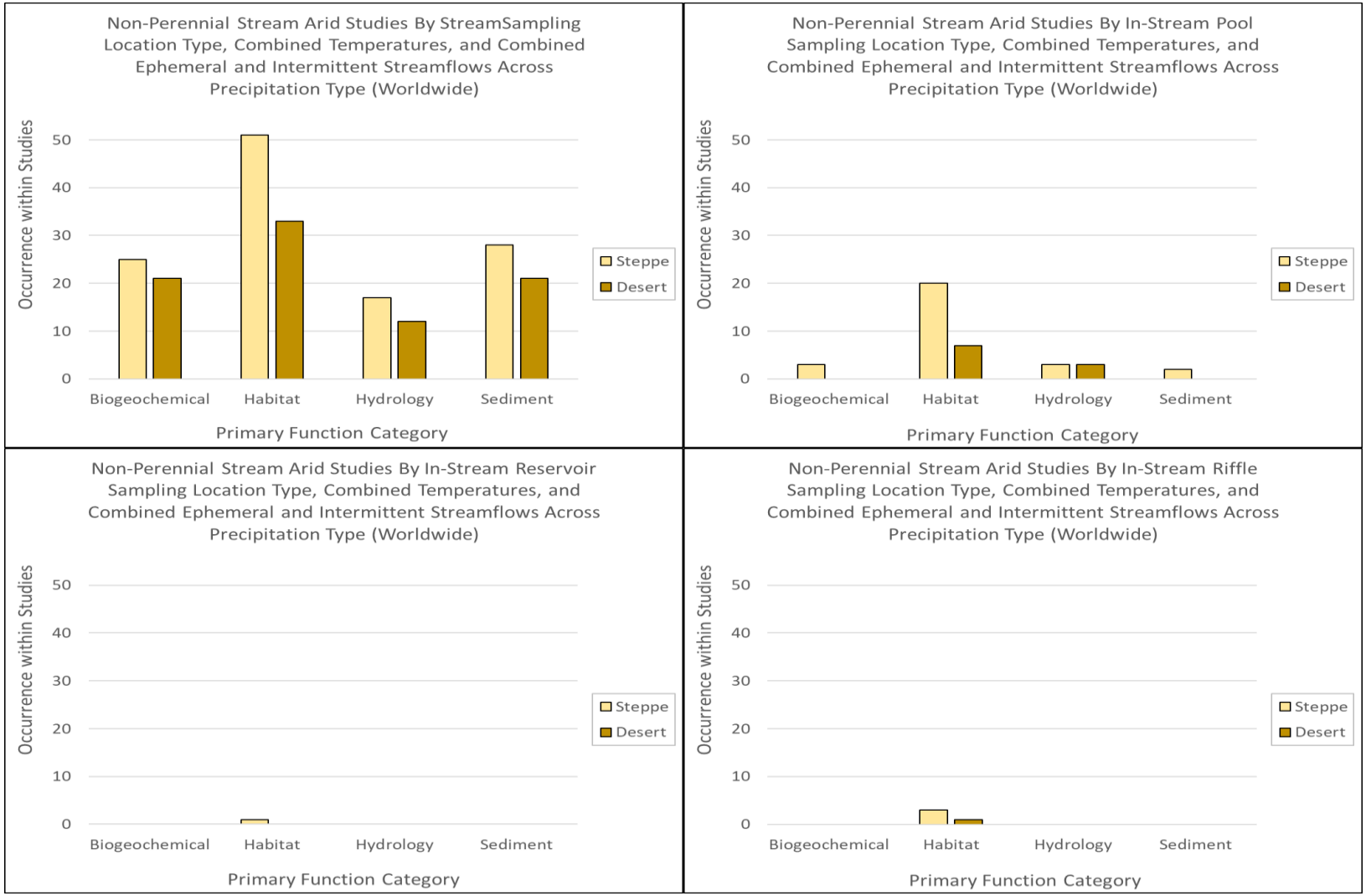


Figure 215. Sampling of each Group 3 condensed sampling location type across primary broad function categories and precipitation types, within global arid non-perennial stream literature.

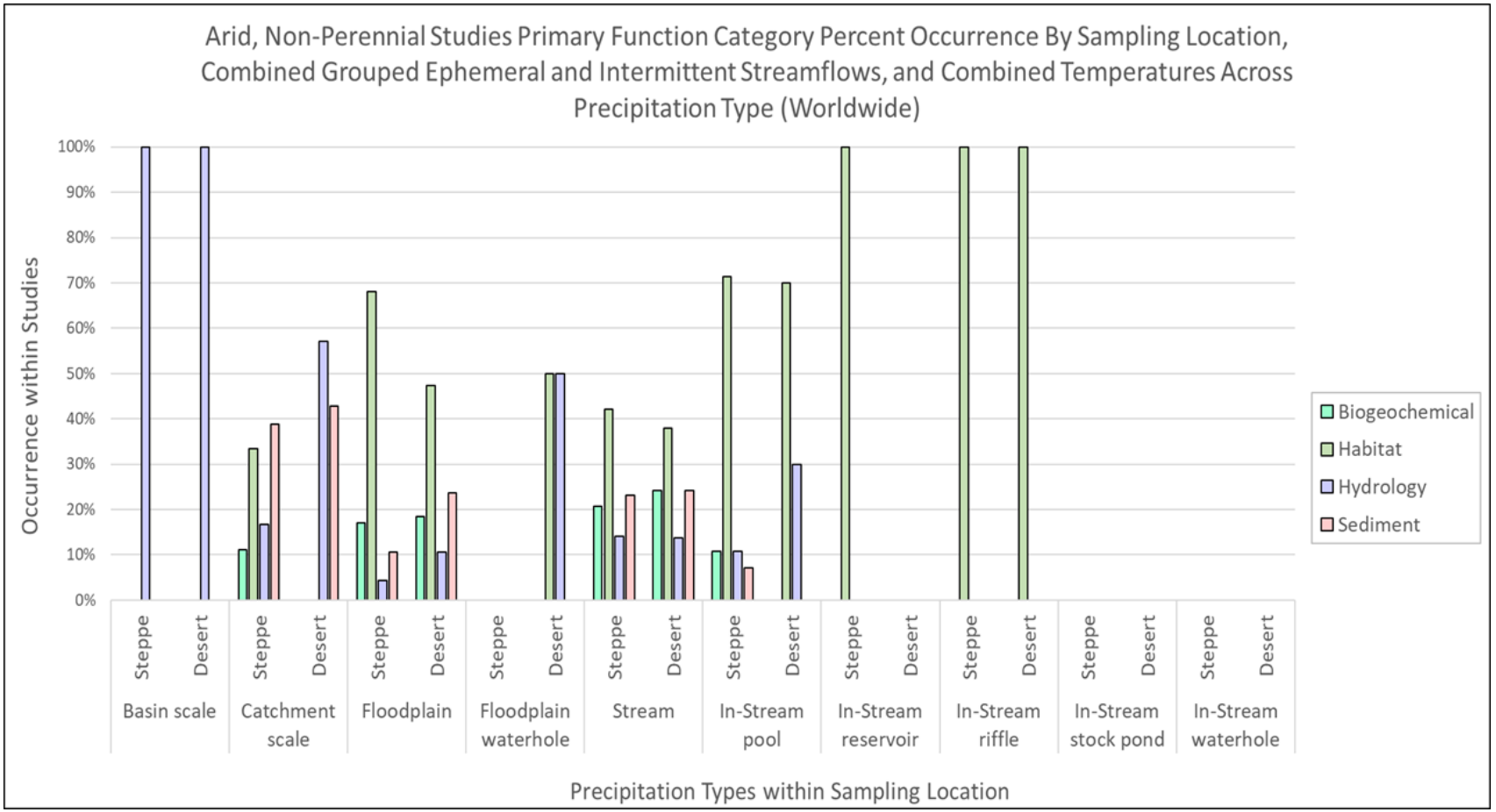


Figure 216. Sampling of condensed sampling location types across primary broad function categories by precipitation types, within global arid non-perennial stream literature.

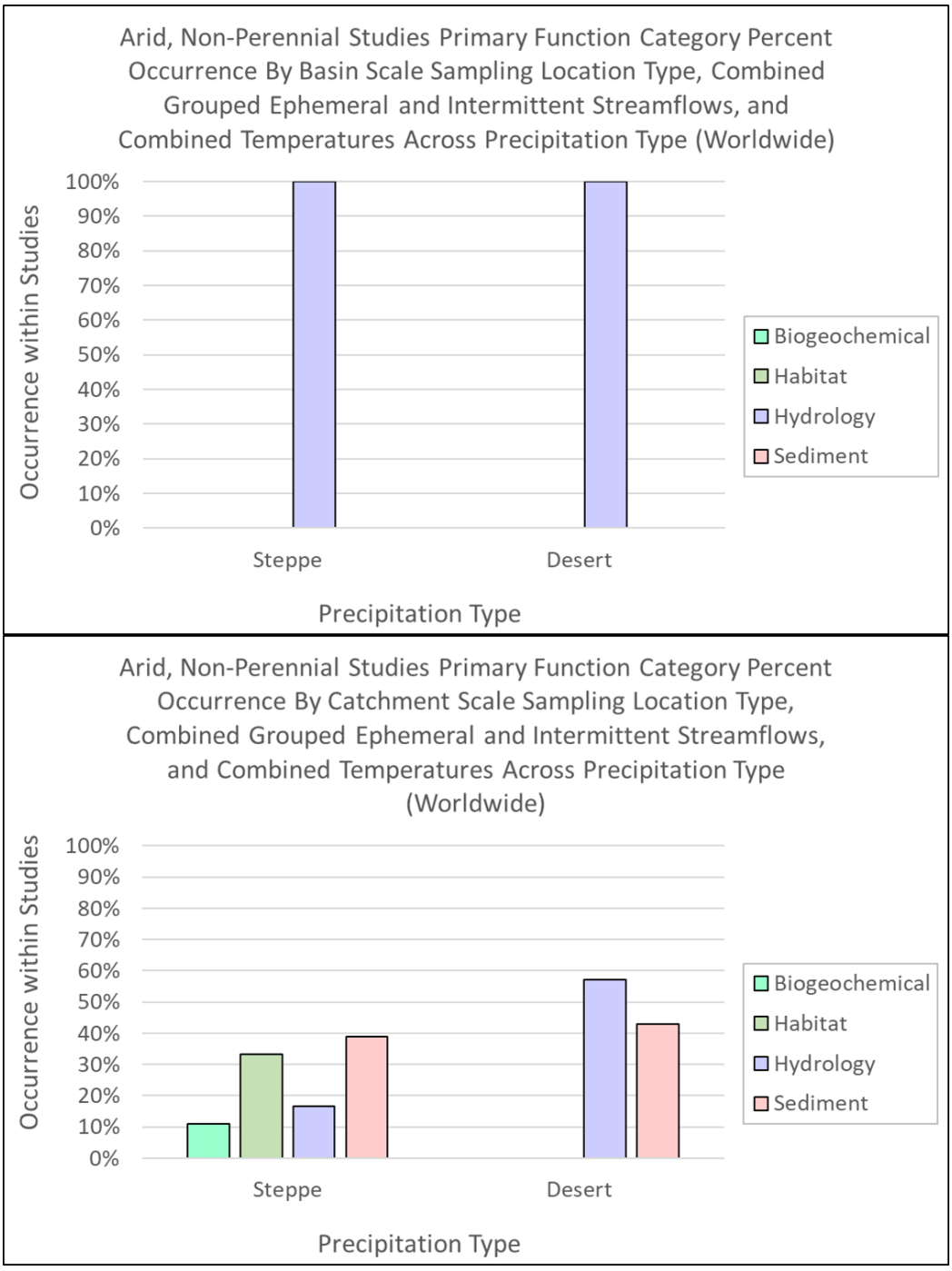


Figure 217. Sampling of each Group 1 condensed sampling location type across primary broad function categories by precipitation types, within global arid non-perennial stream literature.

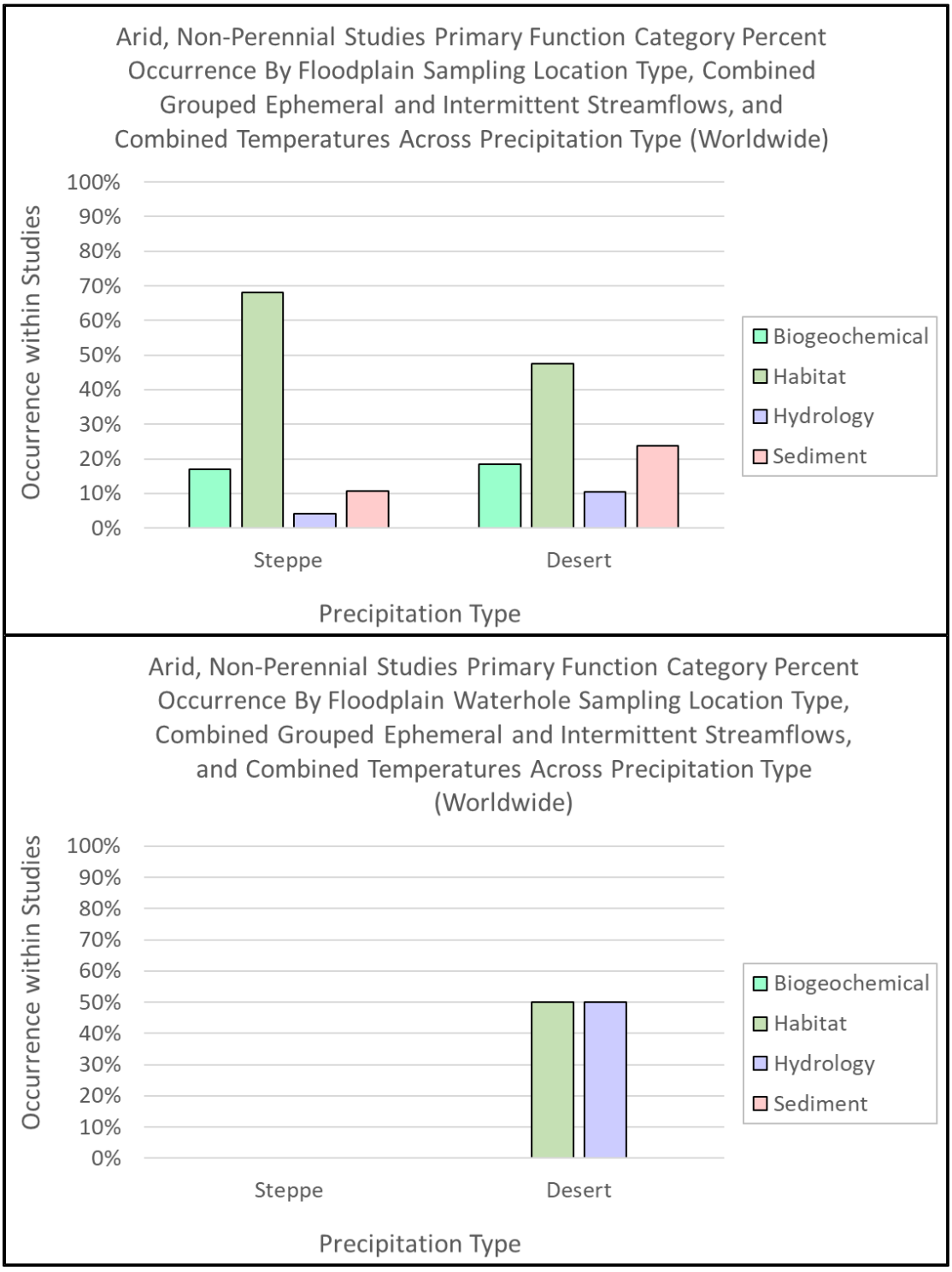


Figure 218. Sampling of each Group 2 condensed sampling location type across primary broad function categories by precipitation types, within global arid non-perennial stream literature.

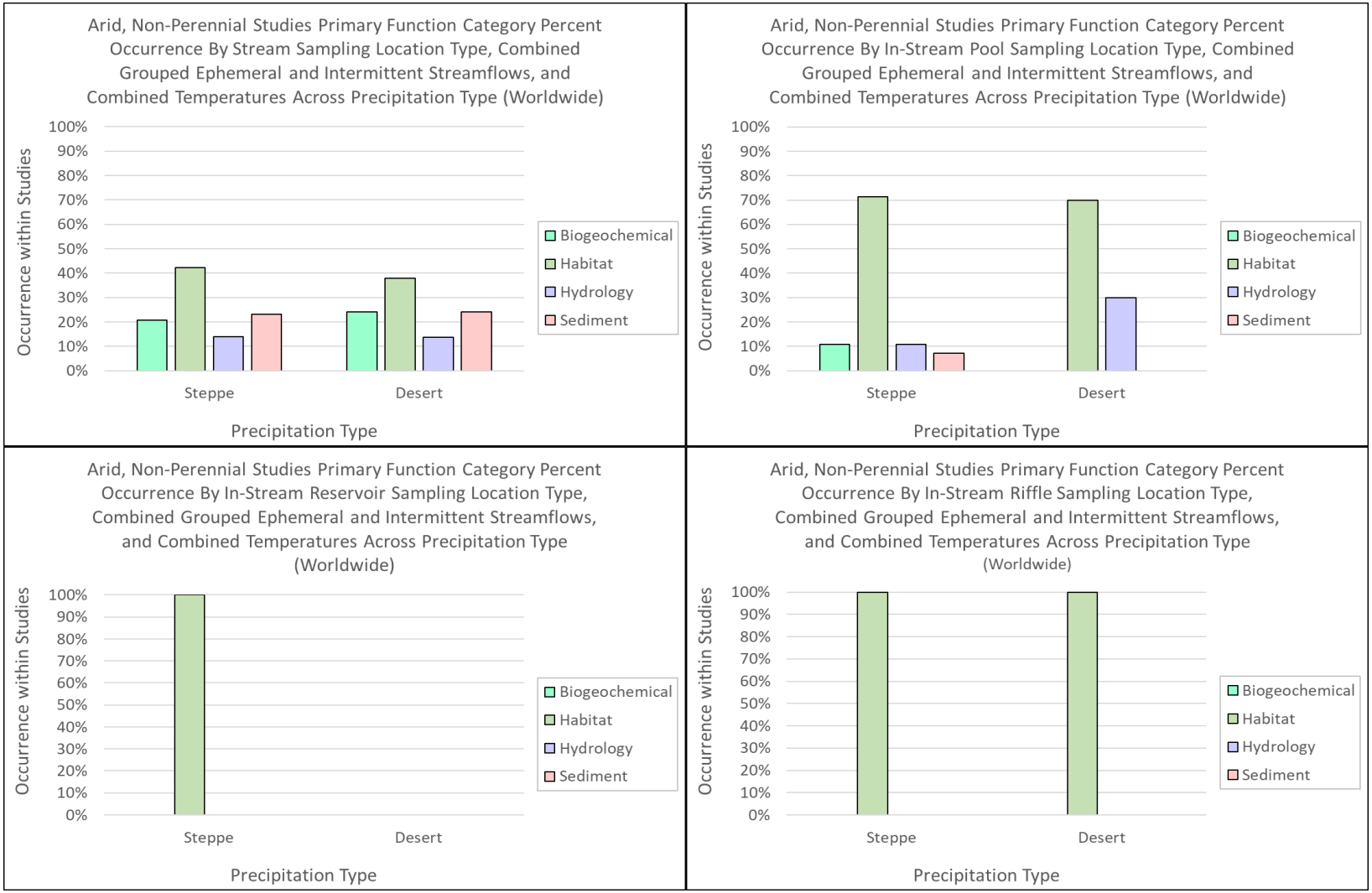


Figure 219. Sampling of each Group 3 condensed sampling location type across primary broad function categories by precipitation types, within global arid non-perennial stream literature.

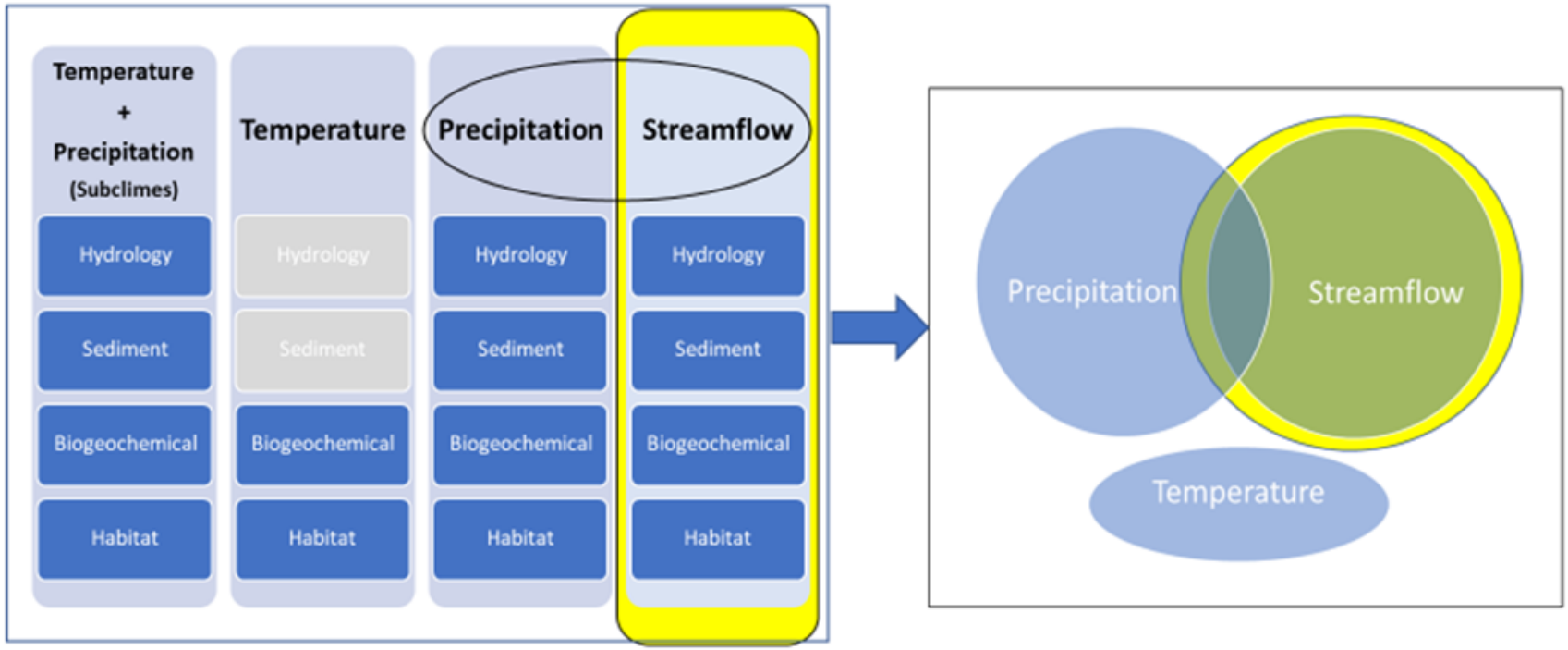


Figure 220. The conceptual relations and hierarchies of a hydrology component (streamflow types) factor and its influence on broad stream function categories.

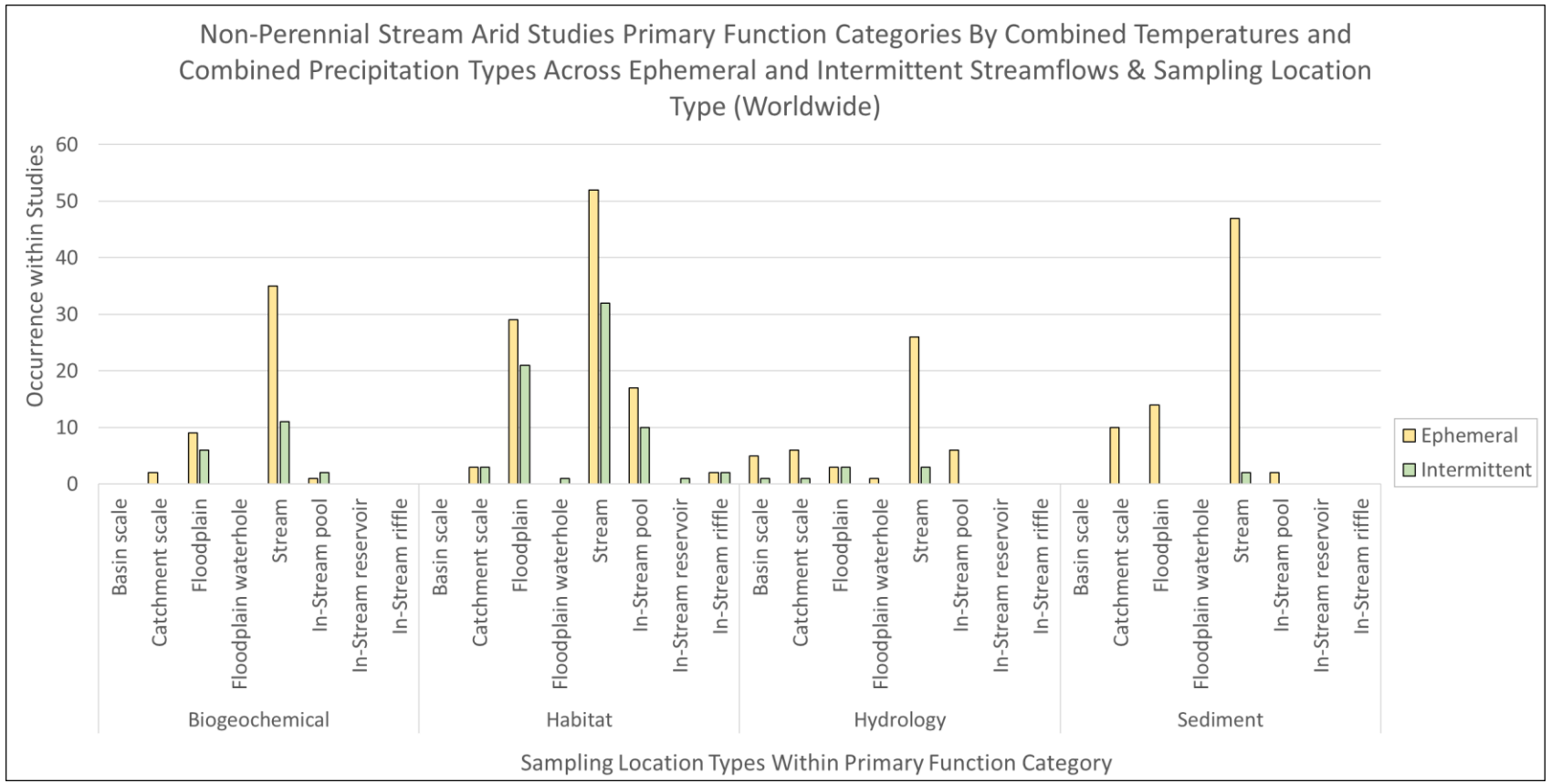


Figure 221. Sampling of primary broad function categories across condensed sampling location types by known streamflow types, within global arid non-perennial stream literature.

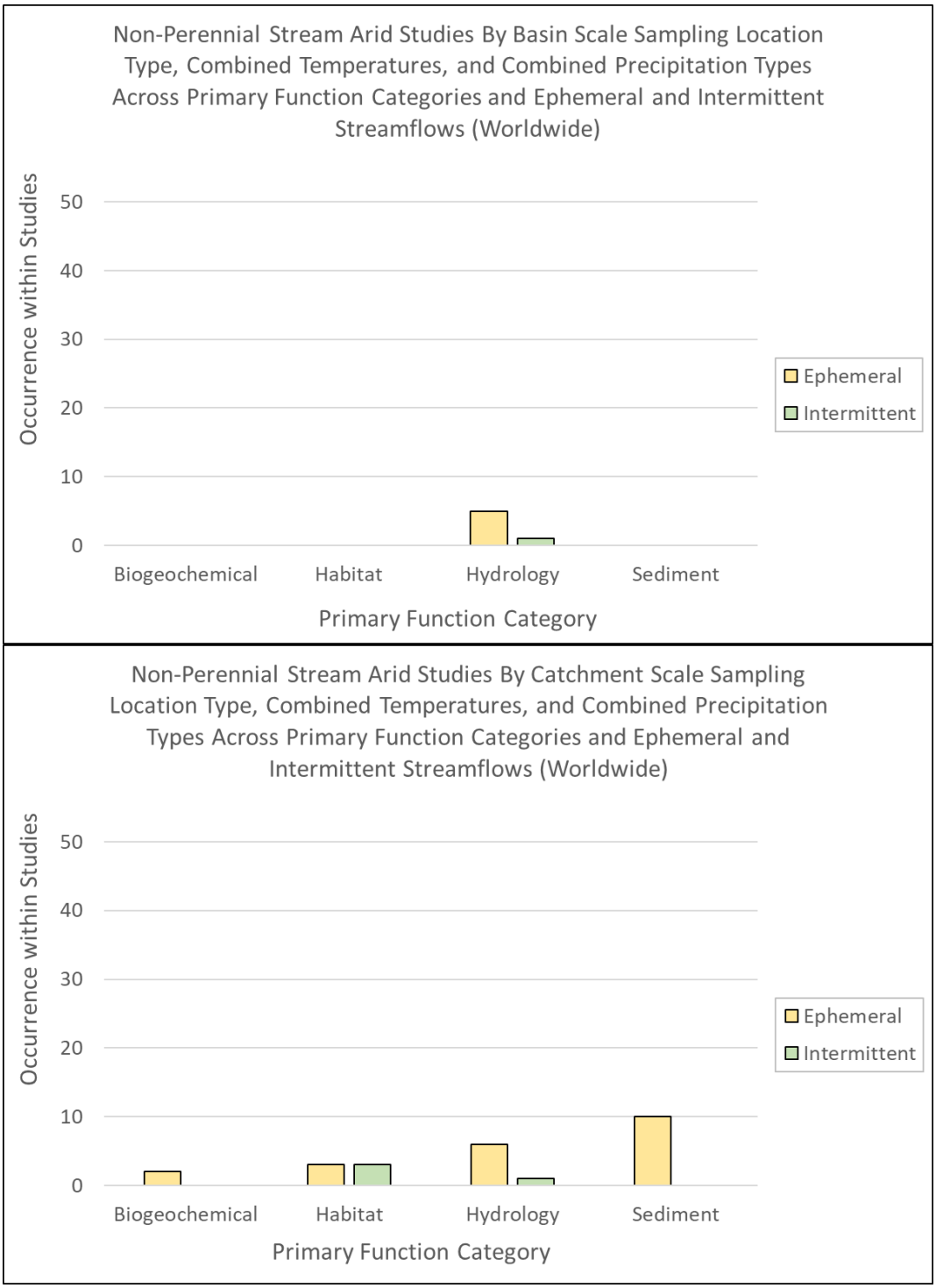


Figure 222. Sampling of each Group 1 condensed sampling location type across primary broad function categories by known streamflow types, within global arid non-perennial stream literature.

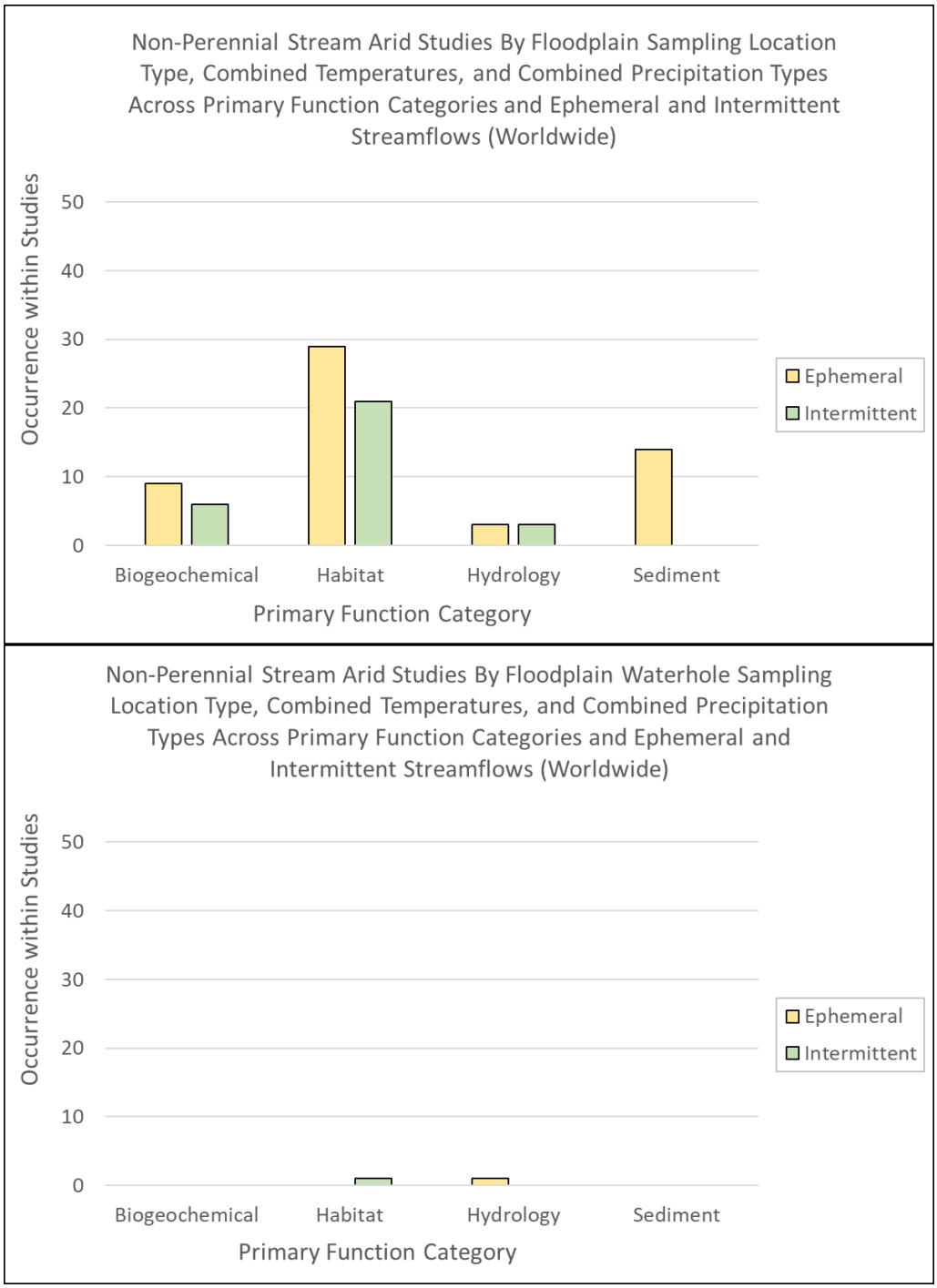


Figure 223. Sampling of each Group 2 condensed sampling location type across primary broad function categories by known streamflow types, within global arid non-perennial stream literature.

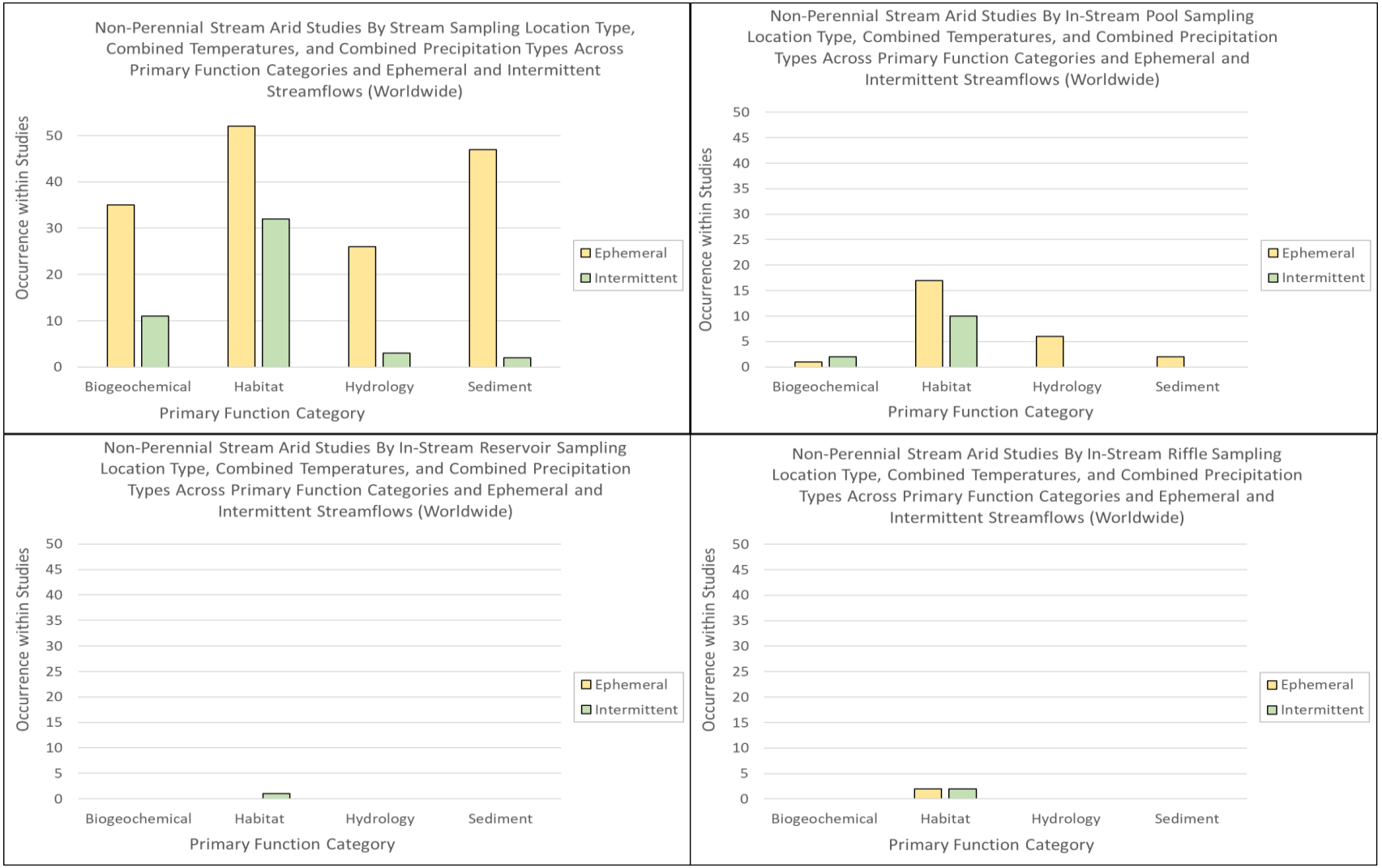


Figure 224. Sampling of each Group 3 condensed sampling location type across primary broad function categories by known streamflow types, within global arid non-perennial stream literature.

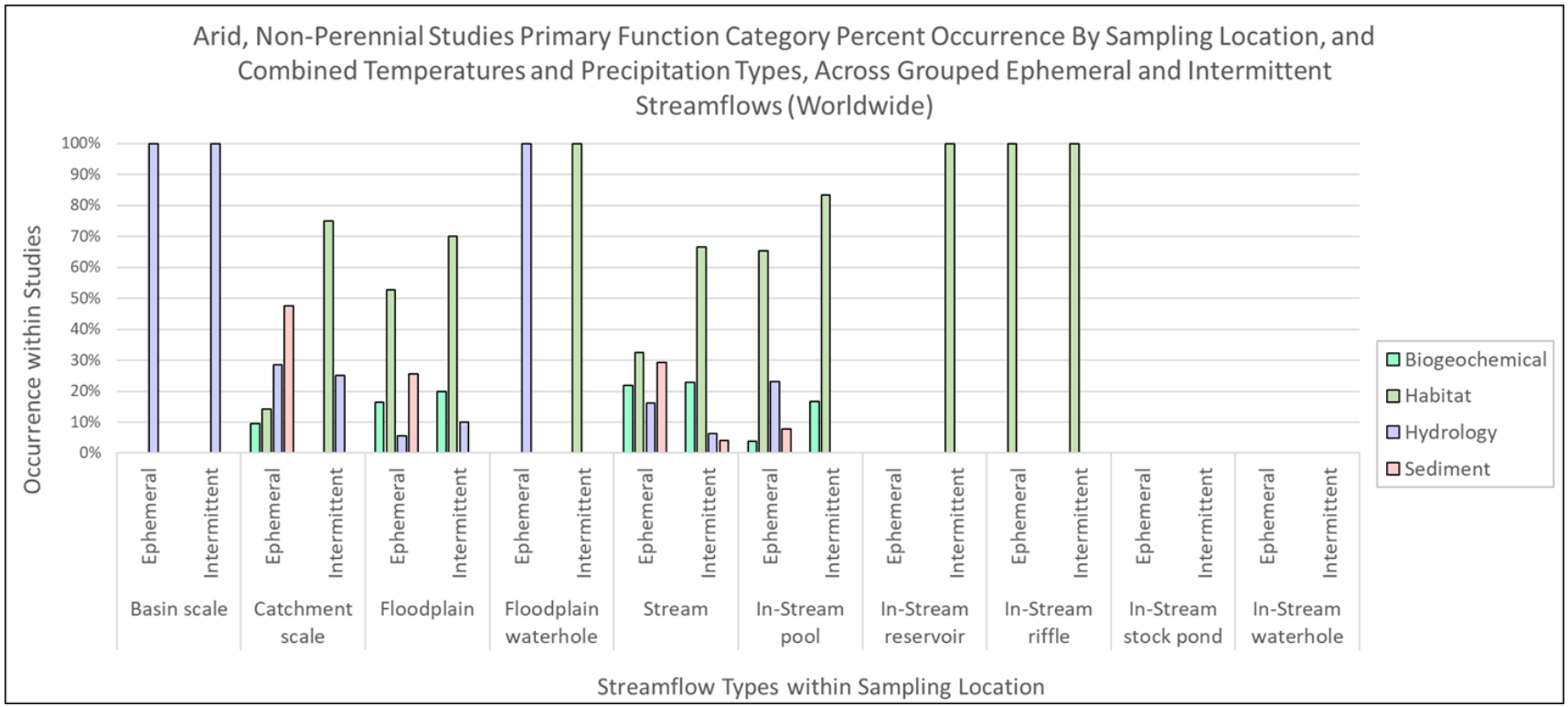


Figure 225. Sampling by condensed sampling location types across primary broad function categories by known streamflow types, within global arid non-perennial stream literature.

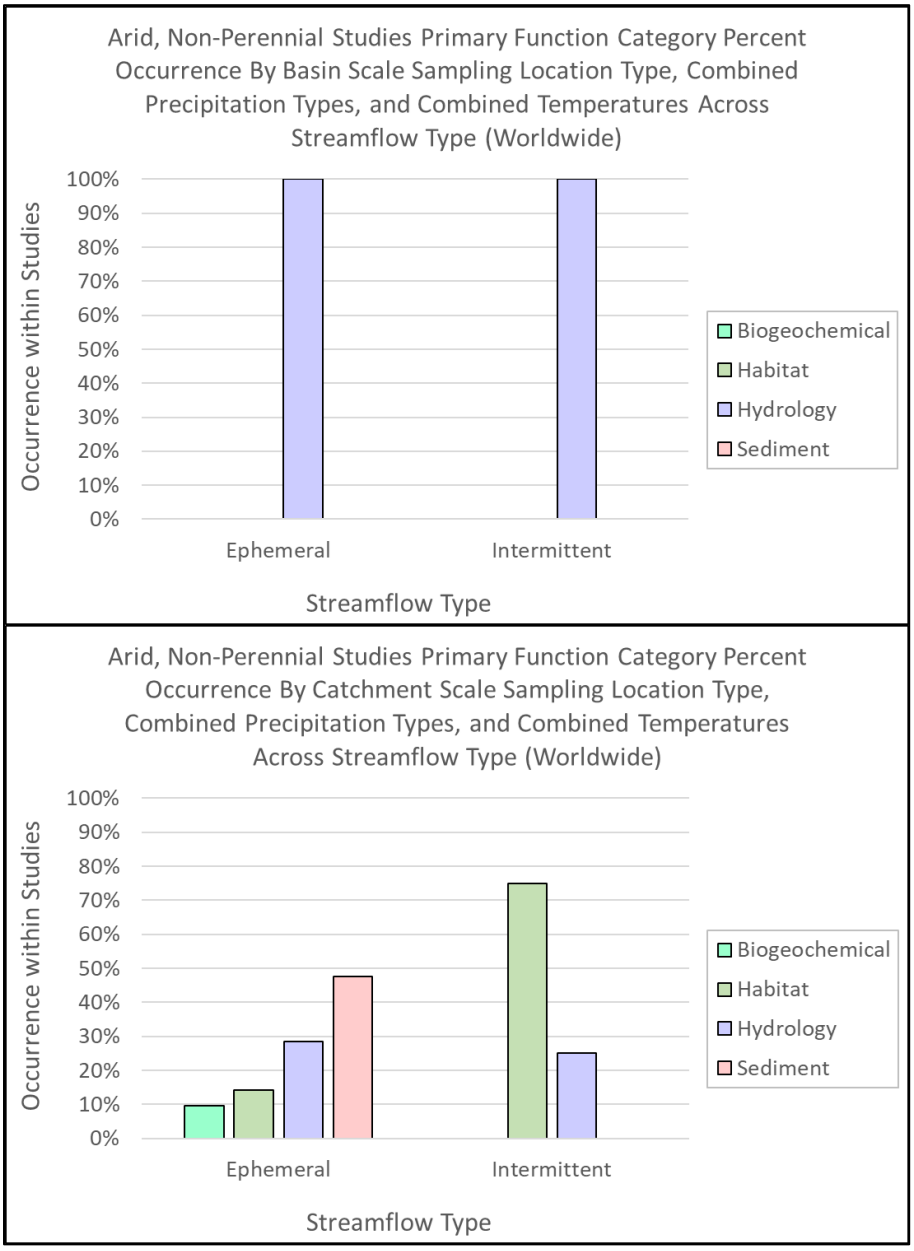
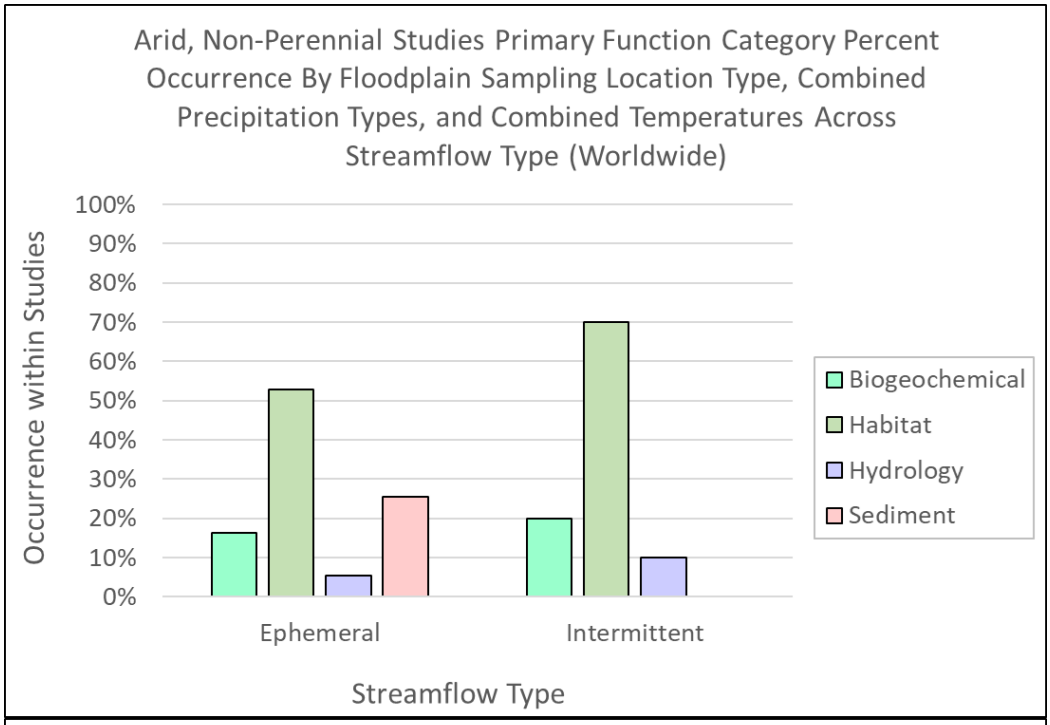


Figure 226. Sampling of each Group 1 condensed sampling location type across primary broad function categories by known streamflow types, within global arid non-perennial stream literature.



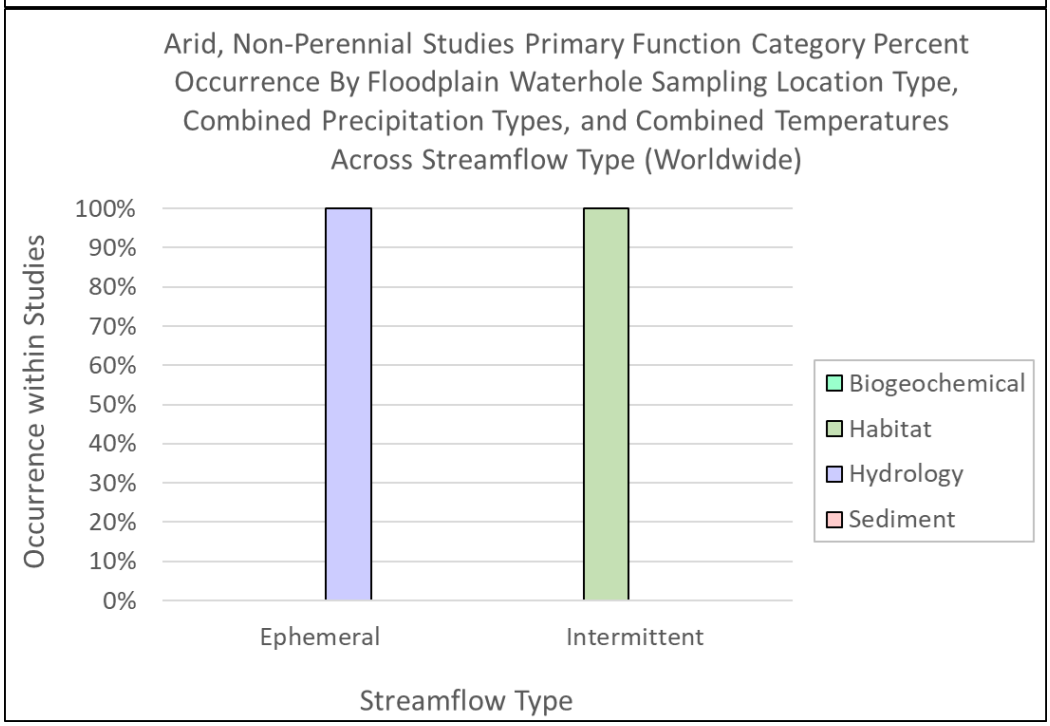


Figure 227. Sampling of each Group 2 condensed sampling location type across primary broad function categories by known streamflow types, within global arid non-perennial stream literature.

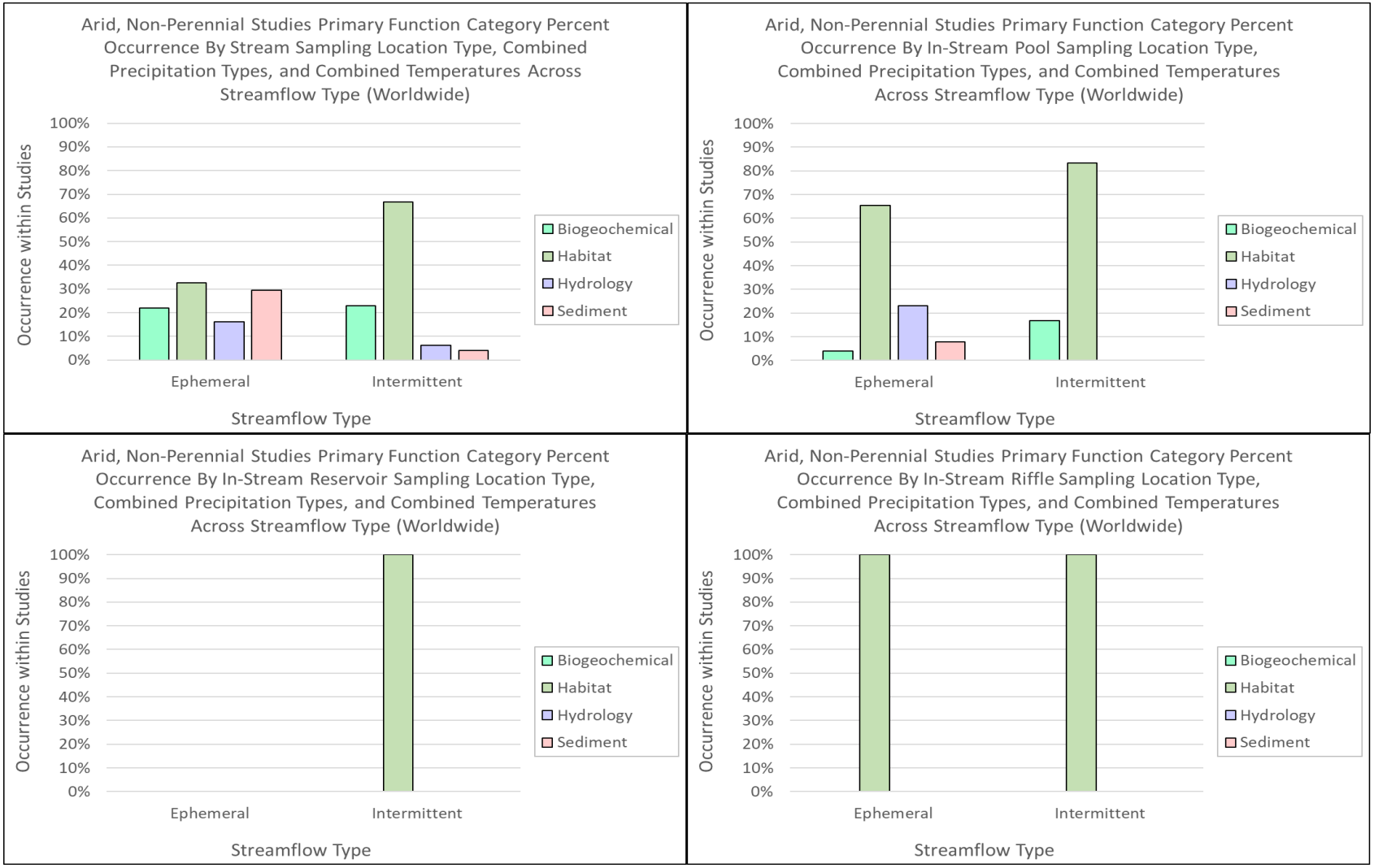


Figure 228. Sampling of each Group 3 condensed sampling location type across primary broad function categories by known streamflow types, within global arid non-perennial stream literature.

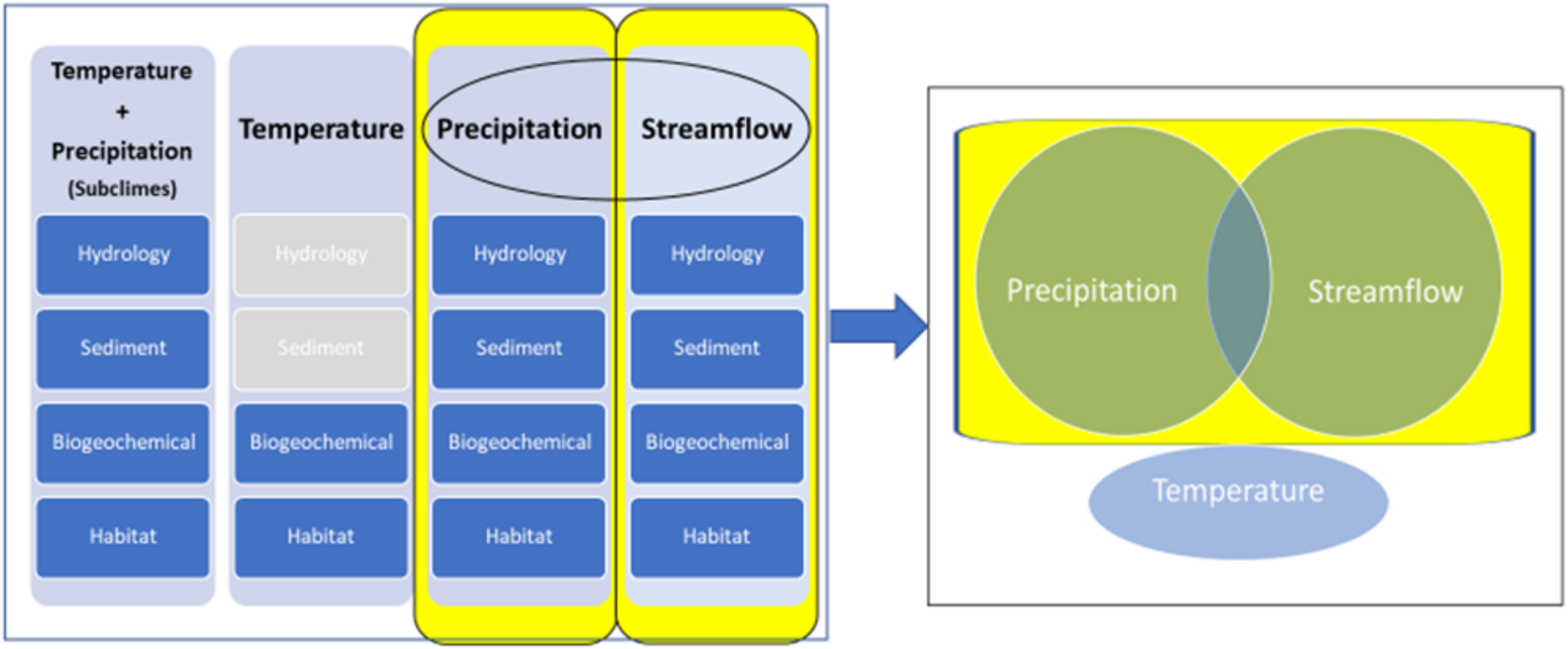


Figure 229. The conceptual relations and hierarchies of hydrology (precipitation and streamflow types) factors and their influence on broad stream function categories.

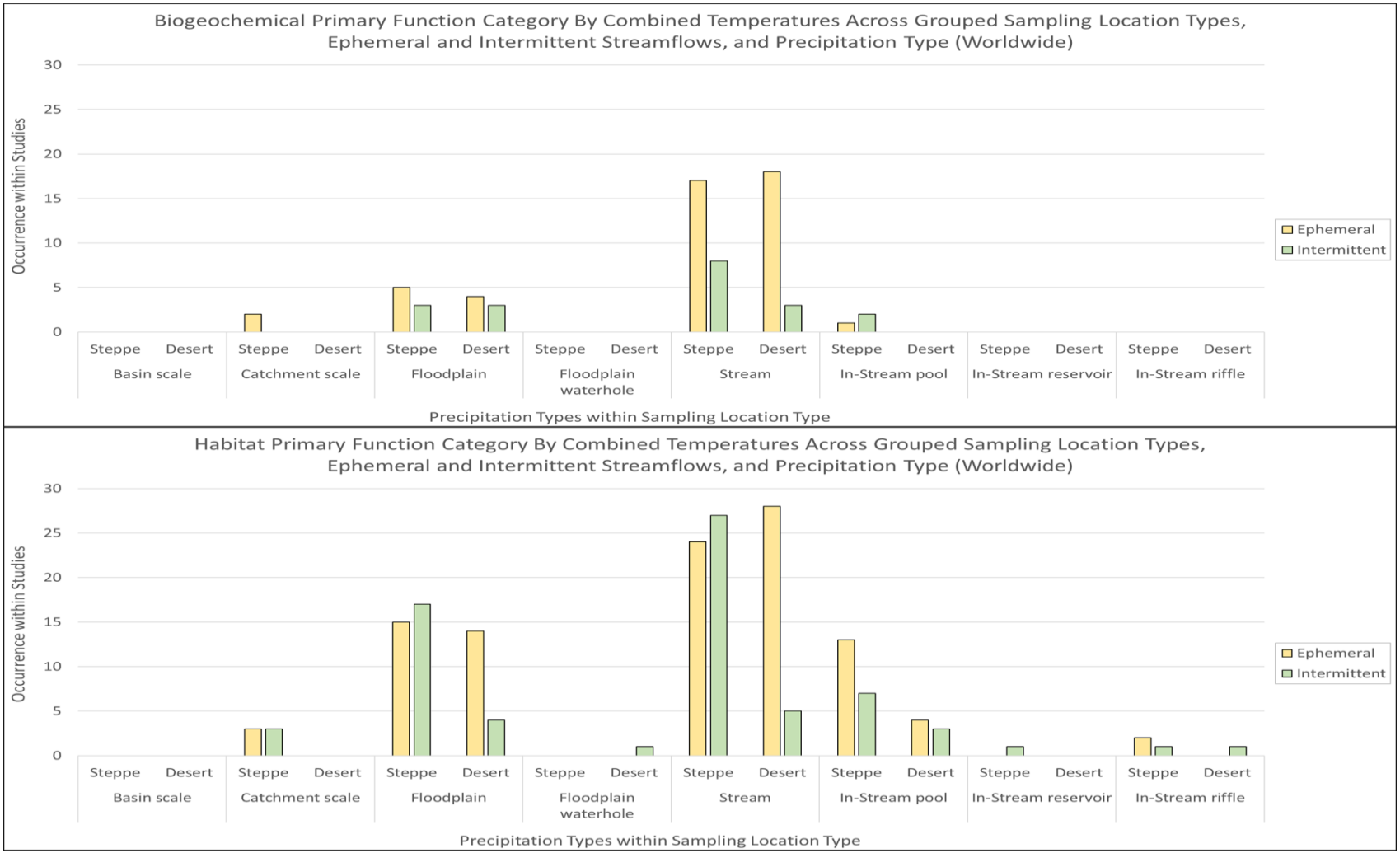


Figure 230. Sampling of Biogeochemical and Habitat function categories across condensed sampling location types and known streamflow types, by precipitation types, within global arid non-perennial stream literature.

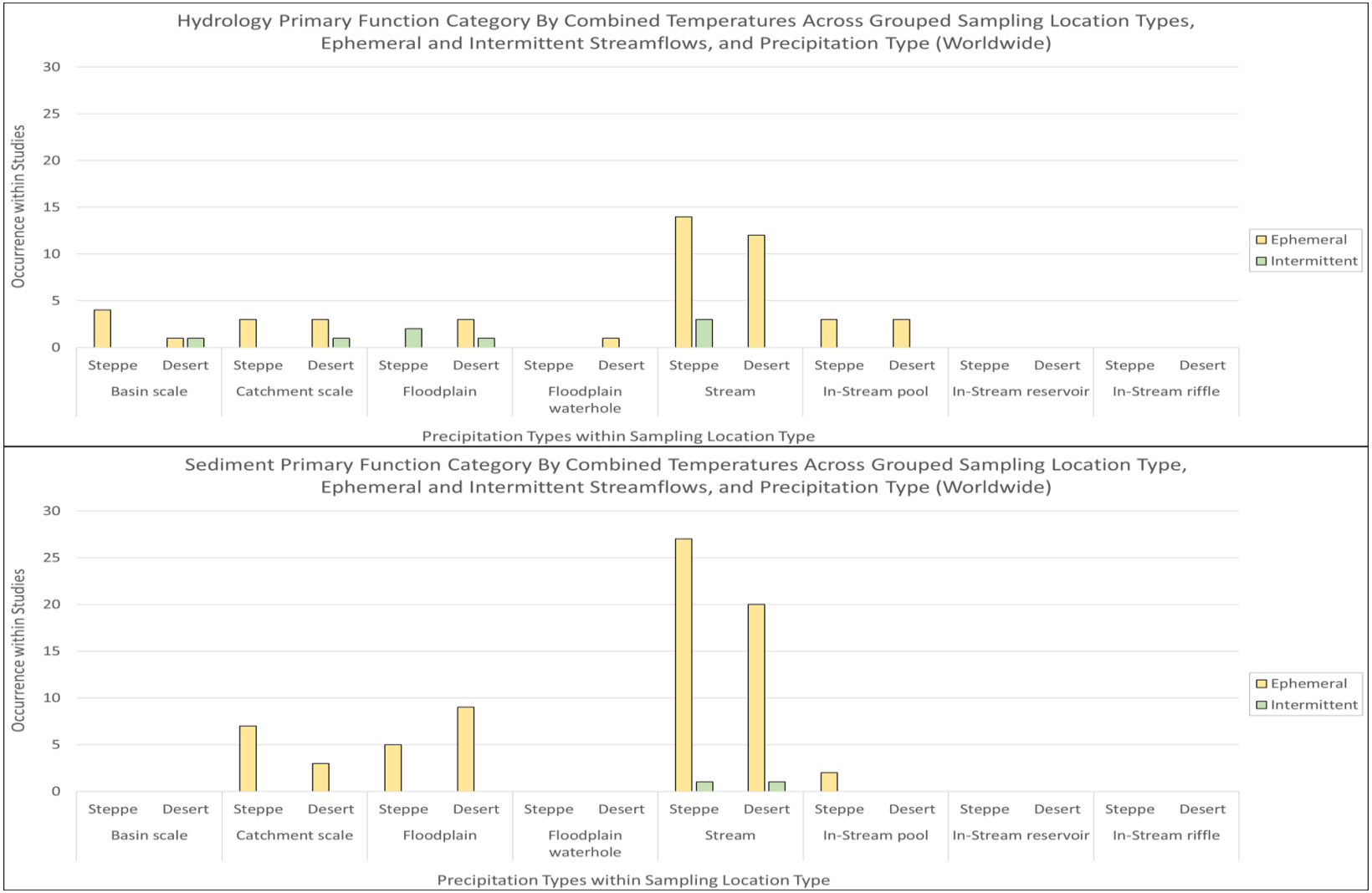


Figure 231. Sampling of Hydrology and Sediment function categories across condensed sampling location types and known streamflow types, by precipitation types, within global arid non-perennial stream literature.

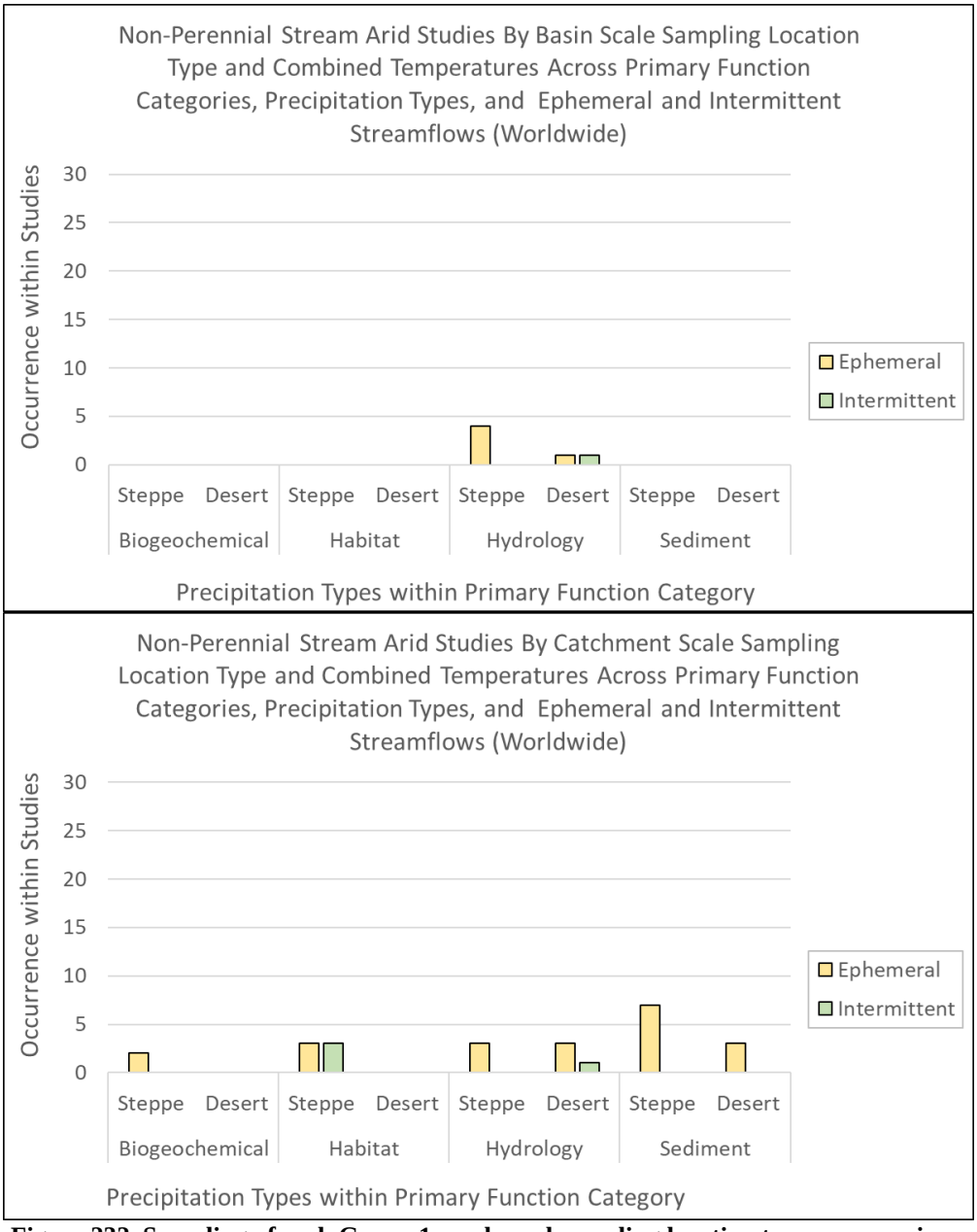


Figure 232. Sampling of each Group 1 condensed sampling location type across primary broad function categories and known streamflow types, by precipitation types, within global arid non-perennial stream literature.

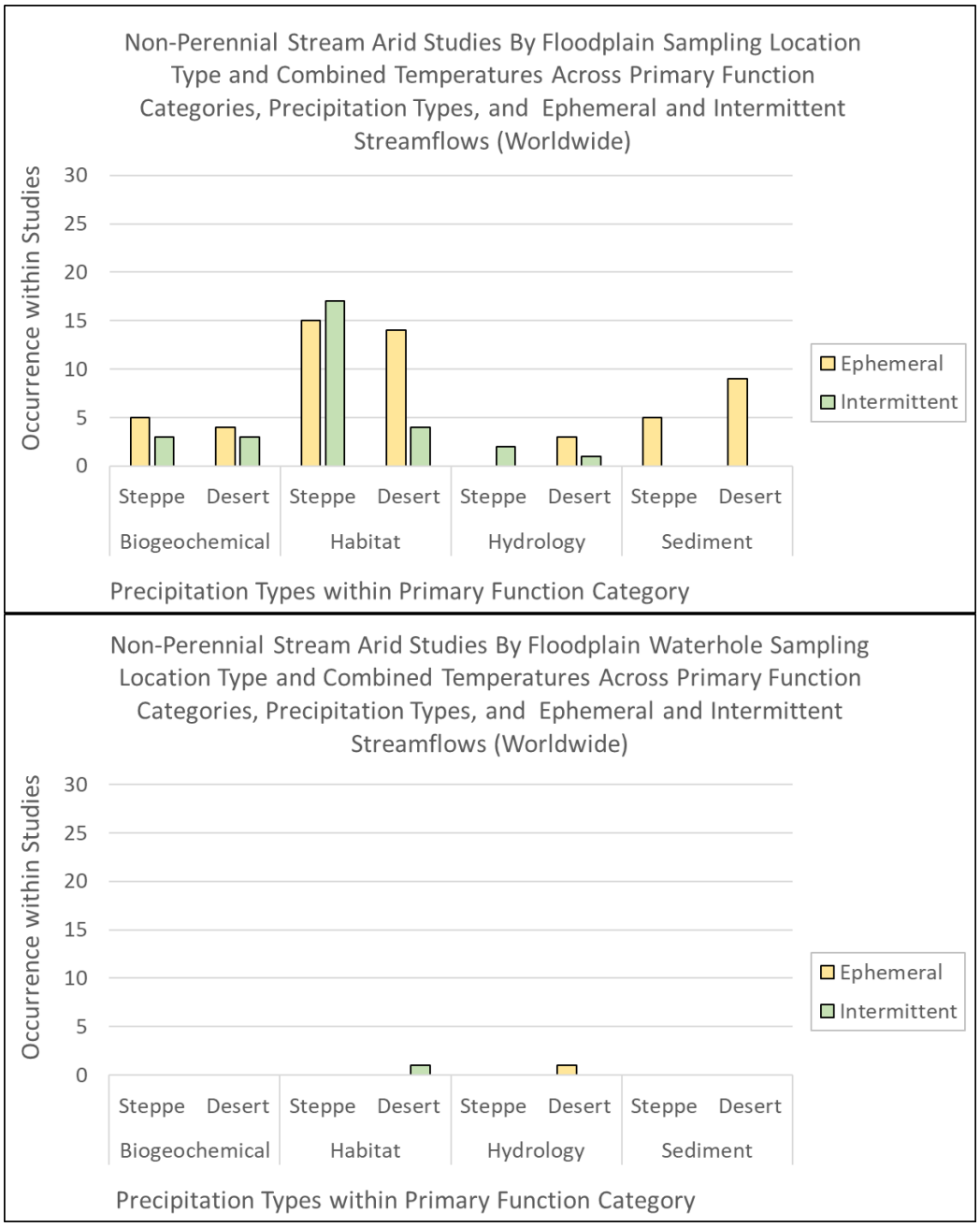


Figure 233. Sampling of each Group 2 condensed sampling location type across primary broad function categories and known streamflow types, by precipitation types, within global arid non-perennial stream literature.

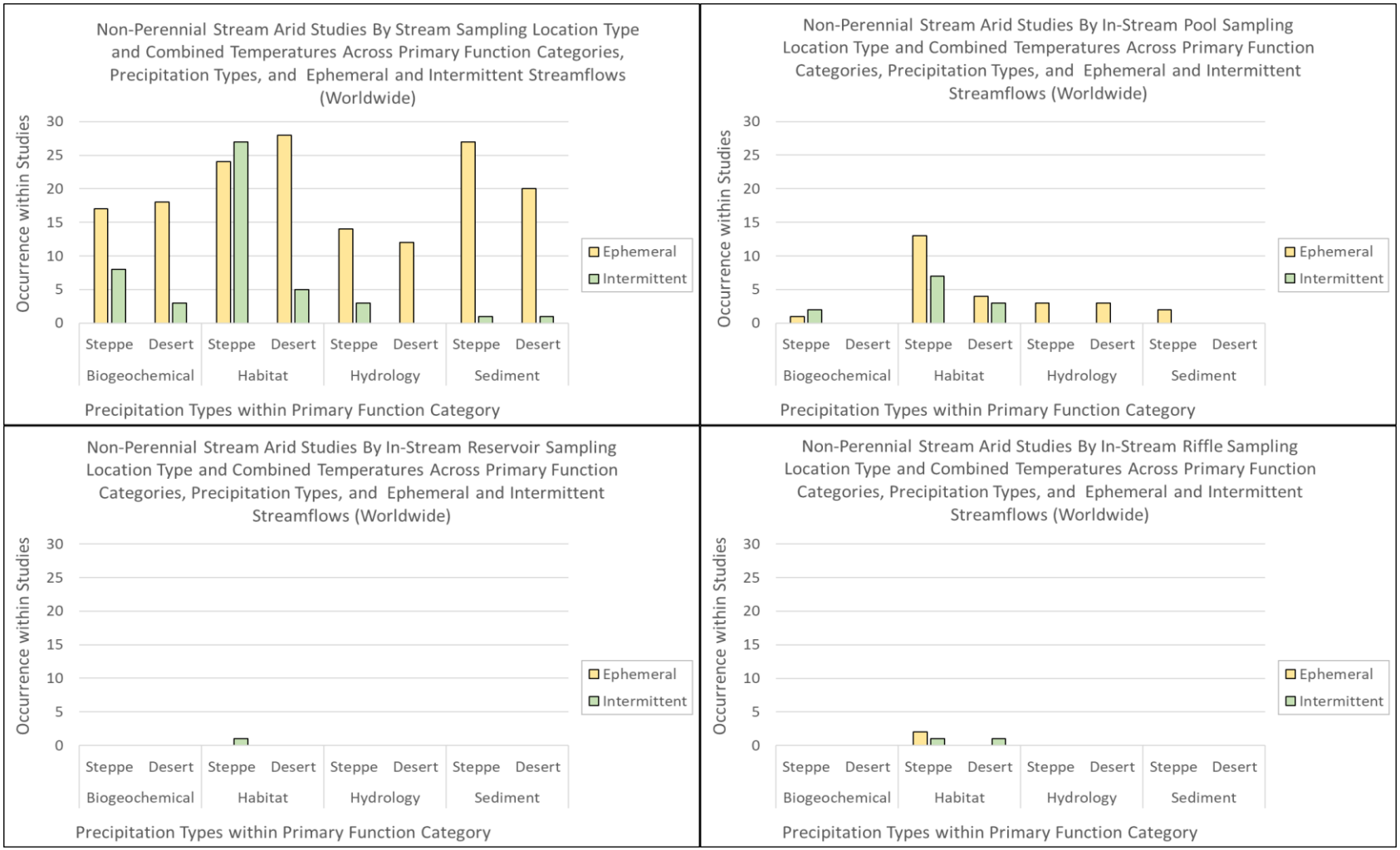


Figure 234. Sampling of each Group 3 condensed sampling location type across primary broad function categories and known streamflow types, by precipitation types, within global arid non-perennial stream literature.

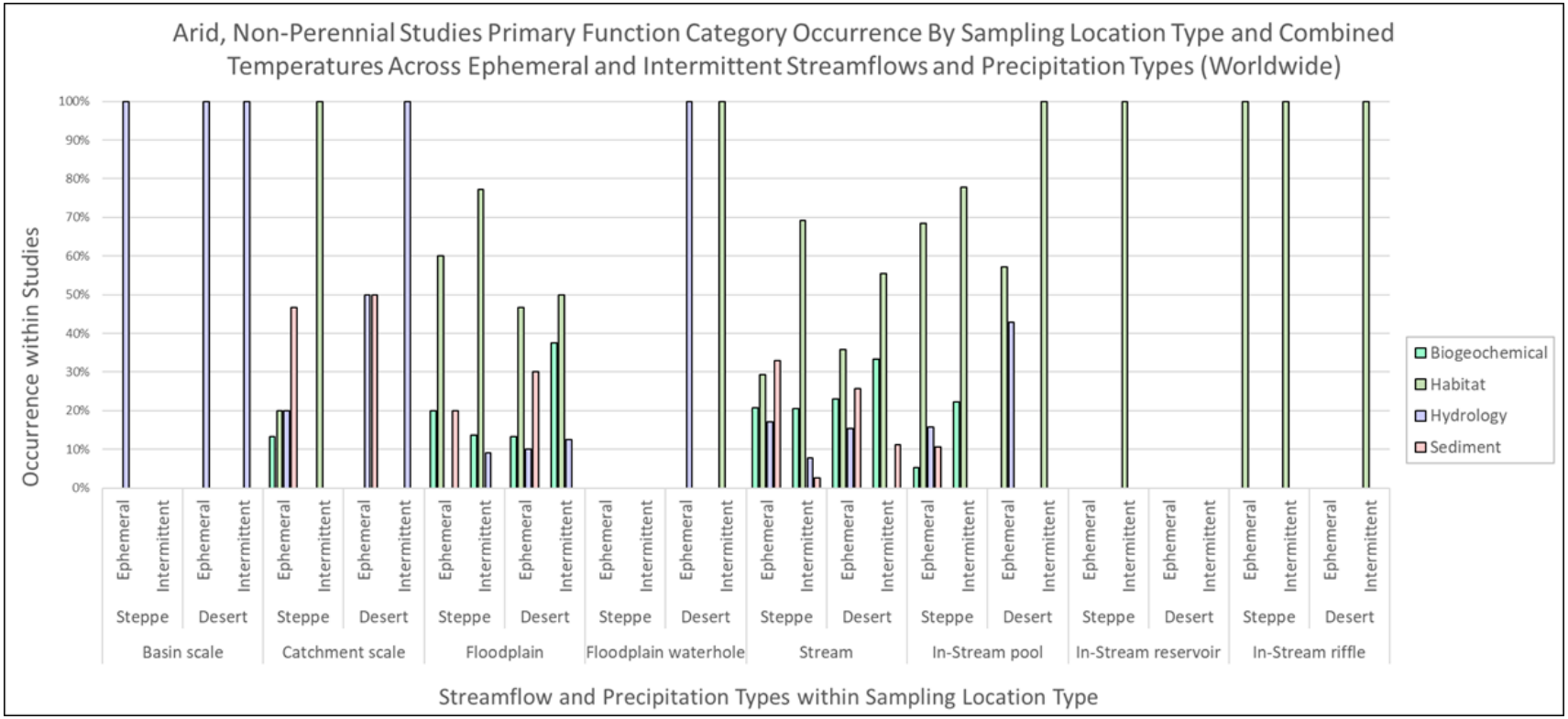


Figure 235. Sampling of condensed sampling location types across primary broad function categories and precipitation types, by known streamflow types, and precipitation types, within global arid non-perennial stream literature.

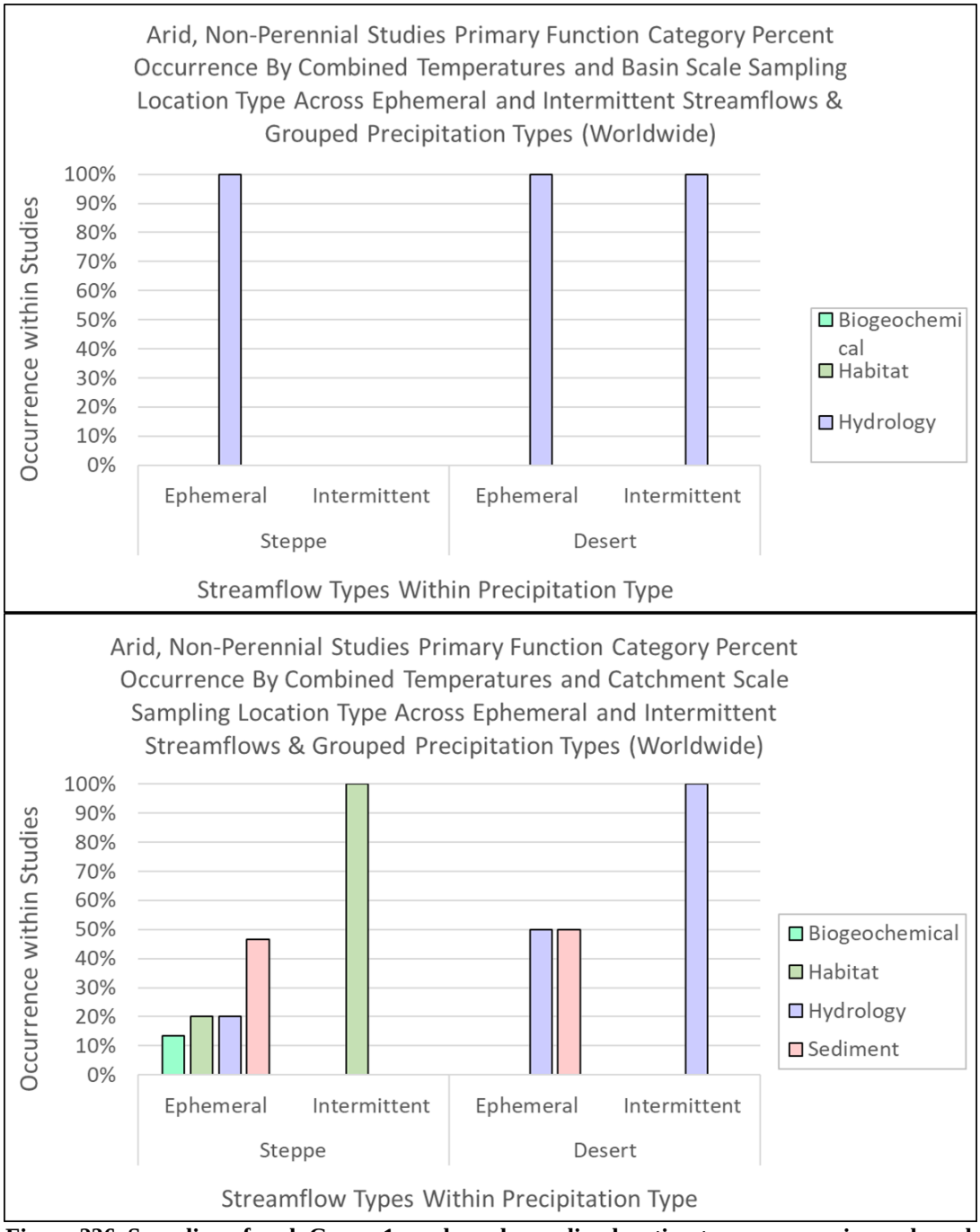


Figure 236. Sampling of each Group 1 condensed sampling location type across primary broad function categories and precipitation types by known streamflow types, within global arid non-perennial stream literature.

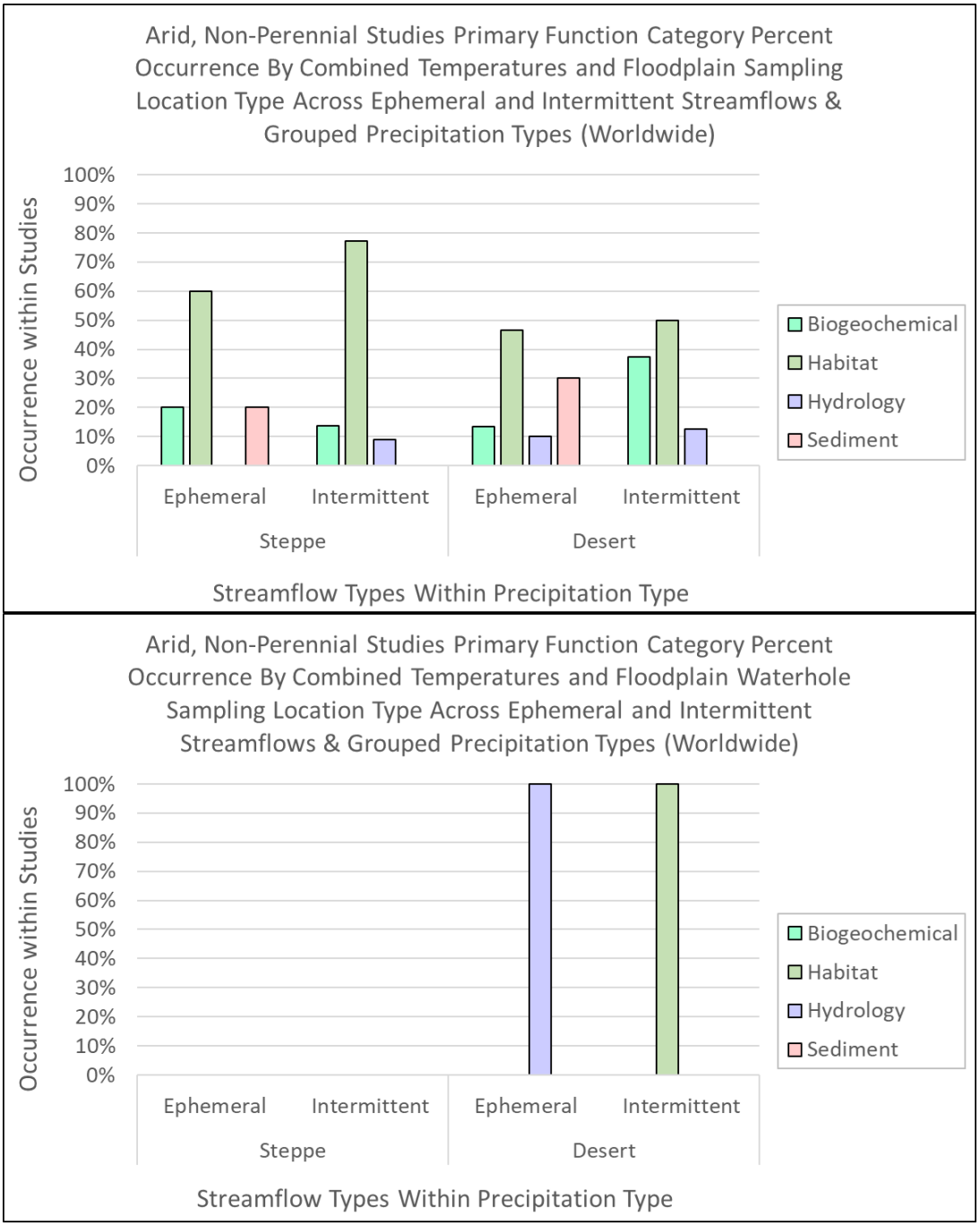


Figure 237. Sampling of each Group 2 condensed sampling location type across primary broad function categories and precipitation types by known streamflow types, within global arid non-perennial stream literature.

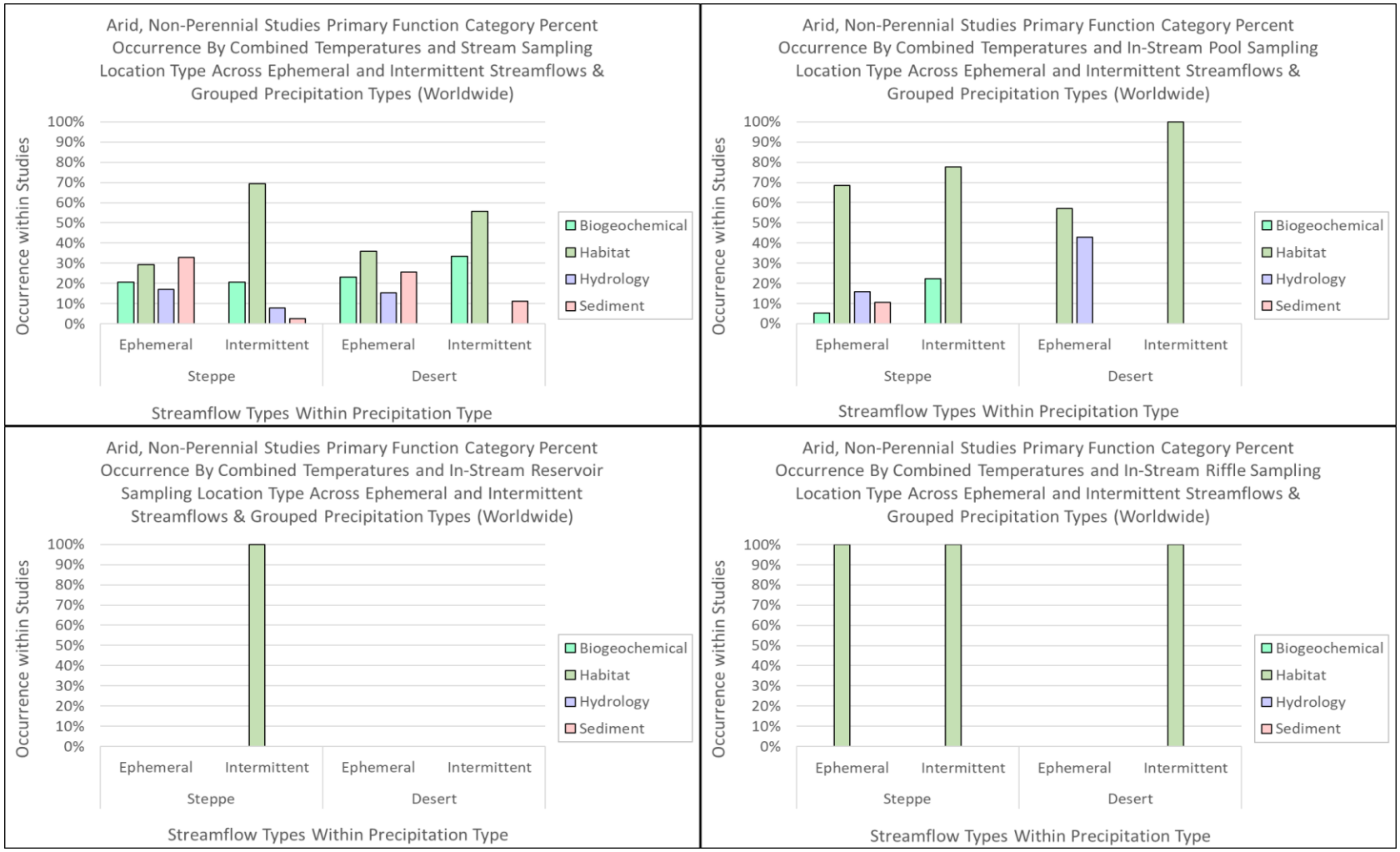


Figure 238. Sampling of each Group 3 condensed sampling location type across primary broad function categories and precipitation types by known streamflow types, within global arid non-perennial stream literature.

CHAPTER THREE: CONCLUSIONS AND RECOMMENDATIONS

Results Summary and Discussion

This study provides an extensive and comprehensive evaluation of global and U.S. studies of arid non-perennial streams, their primary functions, and the geographic distribution of research in relation to large to small scale ecosystem controls and drivers. These arid aquatic resources fall within a significant geographic portion of the U.S. (Arid West), Australia and Spain, as well as locally within California and the Corps Los Angeles District, and they comprise a significant proportion of stream types within watersheds of these regions. Moreover, with projected effects of climate change, expansion of arid climate zones, and especially of steppe areas, is expected to occur both toward the poles within higher latitudes and in lateral (longitudinal) expansions (Cui et al., 2021).

Broad function categories were developed for categorizing the literature. They consisted of the grouping of the suite of stream functions into a small number of broad categories, whereby the categories reflected both functions as well as environmental compartments and processes to a degree. Out of seven broad stream function categories examined within the literature, four function categories emerged as the primary functions researched for non-perennial stream studies across both U.S. and global literature sets: Habitat, Biogeochemical, Sediment, and Hydrology. Of note, these function categories align with the United States' CWA purposes of restoring and maintaining the physical (Hydrology and Sediment function categories), biological (Habitat function category), and chemical (Biogeochemical function category) characteristics of aquatic resources.

As mentioned above, this dissertation work did not simply capture which arid non-perennial stream functions have been addressed in the literature, as well as the relative representation among those stream functions. Rather, those arid non-perennial stream functions from both global and U.S. literature were framed and analyzed within the contexts of overall ecosystem controls (climate) (Wohl et al., 2016), the mid to small scale landscape environmental parameters influencing stream functions (David et al., 2021), and the key hydrology aspects as the main forcing function among a pyramid hierarchy of stream functions (Harman et al., 2012). These details are key to supporting or informing improvements within existing stream assessments, as well as any management and regulatory approaches that may lack incorporation of fundamental stream function controls on resultant stream form and function (Davies et al., 2000; Smith et al., 1995; D.E. Somerville, 2010). They also provide a framework for scaling up or down between site specific focuses and more regional applications, especially in terms of the three landscape and hydrogeomorphic environmental parameters included within this study, watershed position, stream planform types, and specific functions information within subareas of the riverine corridor. As depicted in the conceptual diagram of Figure 239, similar to climate and hydrology attributes (Figure 36 and Figure 37), these environmental parameters have influence over the primary stream function categories, and they operate on a spectrum of regional (watershed position) to site specific (sampling location) scales, as well as longitudinal to lateral extents.

With respect to the Harman et al. 2012 conceptual stream functions pyramid, though biological functions fall near the bottom of tiered influences, it's interesting the Habitat functions category was and is continuing to trend over time as the most heavily represented stream

functions category, within both global and U.S. literature. Habitat functions in general may be relatively easier to both field measure and collect throughout the year (D.E. Somerville, 2010), and this could be reflected in the majority of global and U.S. studies that collected data via fieldwork (Figure 15). This may also be related to the use of riparian measures as a common element in stream assessment and mitigation protocols (D.E. Somerville, 2010). Moreover, there could also be a growing research focus on site specific, smaller scale studies on feedback interactions of Habitat on both Hydrology and Sediment functions, and the need for these types of studies had been noted by Levick et al. (2008). Within the Corps since 2004, Arid West ordinary high water mark (OHWM) research has focused on these smaller feedback interactions and scales, especially between the Habitat, Sediment, and Hydrology function categories. Presence of the OHWM is the basis for Corps regulation of streams, and it also defines the lateral limits of Corps stream jurisdiction (Appendix A). As the OHWM is strictly a legal term, there has been an inherent tension in applying stream science to fit legal standards, further exacerbated by the origination of many stream function and process concepts within perennial stream systems (e.g. commonly referred to as east coast bias) (Wohl et al., 2016). Initial applications of the OHWM to natural systems utilized the east coast concept of the bankfull channel for perennial systems (Lefebvre, Lichvar, & Curtis, 2013; Wakeley, 2002), However, east coast perennial stream systems are formed and maintained by different climatic, geologic and hydrologic processes (Field & Lichvar, 2007; Mount, 1995). Therefore, direct application of eastern OHWM concepts to vastly different and highly dynamic arid non-perennial stream systems subsequently presented many challenges to OHWM identification in these systems. As a result, the U.S. Army Engineer Research and Development Center (ERDC) began researching and periodically

publishing technical manuals to fill these knowledge gaps and developing appropriate OHWM delineation guidance for the Arid West.

In consideration of all three environmental parameters, the only noted deviation from the overarching pattern of Habitat studies predominance was within global stream planform types. As an overall pattern for this parameter and amongst the individual subcategories, Sediment studies dominated over Habitat. Furthermore, in terms of all stream function categories being addressed within the subcategories of the environmental parameters, only the watershed position parameter had all subcategories covering all four primary function categories. For both planform and sampling location types, less than half of the subcategories addressed all four primary functions, which was more pronounced in the U.S. compared to global studies. Moreover, across all environmental parameters the Hydrology functions category overall was afforded the least coverage, which is unexpected given the relative importance and influence hydrology exerts as a forcing function within arid stream systems. D.E. Somerville (2010) also noted hydrological functions had the least coverage among a review of several regulatory and non-regulatory stream assessments and mitigation protocols. These results indicate future arid non-perennial stream research is needed in these least represented stream function categories, as well as among a greater diversity of stream planform types and riverine corridor sampling subareas. This would be especially useful for the Corps in developing a national OHWM framework (Mersel et al., 2014), as well as development of regional stream assessment methods (David et al., 2021).

With regards to arid non-perennial stream functions literature coverage within the Koppen-Geiger subclimes, it was unexpected that a significant portion of the U.S. was mapped within the cold steppe subclime, which consequently is the arid climate subregion where most

research on non-perennial streams occurred both globally and within the U.S. The predominance of U.S. study occurrences within the cold steppe subclime was also fairly consistent across both streamflow regimes and the watershed position, planform type, and sampling location parameters. Global studies also predominantly occurred within the cold steppe subclime, though only when considering the primary function categories across subclimes. However, global studies also had an interesting sub-trend of primary functions coverage mainly within the hot desert subclime, specifically for ephemeral flow regime studies. Global studies by stream planform type and riverine corridor sampling location also reflected this same sub-trend, both as overall parameters and by subcategories. Only the watershed position, overall and by subcategories, mirrored the largest overarching trend of a predominance of global studies within the cold steppe subclime, regardless of streamflow regime. The strongest subclime trend across U.S. and global studies, whether considering the primary functions by themselves or in combinations with streamflow regime and across the environmental parameters, is a distinct lack of study occurrences within the cold desert subclime. Based on visual estimates of mapped arid subclimes worldwide, this could be a simple matter of total cold desert subclime land coverage being less compared to the other three arid subclimes. The last large-scale subclimes trend, observed across both U.S. and global studies, was a greater coverage of individual primary function categories across all subclimes for ephemeral versus intermittent flow regime studies. This pattern was also more evident for Sediment and Hydrology studies compared to Biogeochemical and Habitat studies. This could be due to a combination of the simple dominance of ephemeral stream studies, as well as Sediment and Hydrology function studies generally being afforded least coverage. Thus, future research needs include more of a focus on

the Sediment and Hydrology function categories, especially considering their influence within the overall stream functions pyramid (Harman et al., 2012).

In terms of the separate subclime components, temperature and precipitation, global studies had an overarching pattern of occurrence within hot arid areas, with the opposite being the case for overall U.S. studies. Furthermore, though half of the U.S. primary function category studies (Biogeochemical and Hydrology) predominantly occurred within hot arid areas across both ephemeral and intermittent streamflow regimes and across all three environmental parameters (watershed position, planform type, and sampling location), there nevertheless was an overarching pattern of a predominance of U.S. studies within cold arid areas. This was likely due to the greatest number of function studies being Habitat studies that occurred predominantly within arid cold areas. Precipitation type, the other component of the subclimes, as a whole had a consistent overarching pattern of predominance within steppe precipitation areas within both U.S. and global studies, even when coupled among the primary function categories. When also including streamflow regime, however, there was more of a deviation from this pattern with a greater dominance of desert occurrences within ephemeral stream planform type studies. As a whole, greater arid non-perennial streams functions coverage within steppe precipitation areas may bode well in light of the predicted climate change expansion of these areas. Similarly, there was great coverage of ephemeral versus intermittent streamflow types. It's likely the preponderance of ephemeral stream studies is due to ephemeral streams being more common than intermittent streams throughout arid regions. This could especially be the case in consideration of widespread anthropogenic impacts of lowered groundwater tables, and reduced frequency and amount of surface water flows, from ongoing groundwater withdrawals,

competing surface water uses, and water diversion. Additionally, decreasing snowpack levels and expanding areas of aridity from global warming is also likely contributing to a reduction of surface hydrology and groundwater inputs to intermittent streams. Therefore, future research needs include more of a concentration on potentially diminishing intermittent stream resources, as well as within desert areas.

In summary, where, or the context within, these primary functions of arid non-perennial streams have been studied and documented is critical. This applies not just to non-regulatory purposes of stream assessment and management, but also for regulatory purposes in "how" these arid non-perennial stream systems should be treated and managed, as well as on a larger scope of "what" aquatic resources should be afforded regulation and protections under the CWA. These Regulatory purposes extend from a day in the life of a typical federal, state, or local Regulatory project manager making frequent project-based stream impacts and mitigation assessments, to larger scale efforts such as developing regional OHWM delineations or stream assessment methods, to the national level on what aquatic resources are defined as waters of the U.S. (WOTUS) to be afforded protections under the CWA.

National Federal Regulation and Implications

Beyond local District operations of the Regulatory Program, is the central question "Can sound science save the Arid West?" Arid non-perennial streams have a history of undervaluation, including cultural biases against dryland systems with an early lack of regulatory agency attention, coupled with the courts generally restricting regulation (Figure 3). For what is known about non-perennial streams, there are still misperceptions regarding the functions and services they provide. And the cultural devaluation of these resources compared to perennial stream

counterparts (Acuña et al., 2017; Boulton, 2014; Stein et al., 2011) even extends to a lack of agency regard for these resources (Datry et al., 2016). Regulation of non-perennial streams is further compounded by court decisions generally restricting their inclusion as WOTUS under the CWA (Figure 3). Prior to 1986, the Corps automatically allowed unlimited impacts to headwater streams under general permits. Headwater streams were defined as those streams with generally less than five cubic feet per second (cfs) of average annual flow. As this same definition encompasses the typical average annual flows of ephemeral and drier intermittent streams, the lack of Regulatory oversight had significant negative consequences for Arid West non-perennial waters. Even following litigation in 1986, the Corps had allowed up to ten acres of impacts on a project-by-project basis under general permit verifications (e.g. Nationwide Permit (NWP) No. 26) through 2000. Then the federal courts began to have a substantial role in influencing and reducing the Corps' regulation of waters through the 2001 Solid Waste Agency of Northern Cook County (SWANCC) and 2006 Rapanos Supreme Court decisions. SWANCC resulted in geographically isolated, intrastate, non-navigable waters lacking a nexus to commerce (Appendix A) as no longer being regulated under the CWA. Then Rapanos resulted in widespread confusion and complexities regarding non-relatively permanent waters (NRPWs), or non-perennial streams (e.g. ephemeral and dry intermittent streams). Under Rapanos it was not enough for a stream to have connectivity to a downstream traditional navigable water (TNW). Instead, such a connection between the evaluated NRPW and the nearest TNW had be established as "significant" (e.g. significant nexus (SN)). In a SN evaluation, the distance to the nearest TNW, and a large list of physical, chemical, biological, watershed and flow characteristics, had to be assessed for the NRPW without consideration of cumulative effects of all similar NRPWs in the

watershed. In order to make a determination that a NRPW is jurisdictional, the evaluation had to establish the individual NRPW had a more than speculative or insubstantial effect on the chemical, physical, and biological integrity of the downstream TNW. Collectively, these court decisions had a particularly significant impact within the Arid West, including local Los Angeles District portions of California and Nevada. Many Arid West desert watersheds are closed intra-state basins lacking connectivity to a downstream TNW, in addition to there being a limited number of TNWs present in the Los Angeles District. And as over 81% of streams in the Arid West are non-perennial (Levick et al., 2008), those watersheds with downstream connectivity to a TNW required time consuming and extensive SN evaluations on a project-by-project basis. Moreover, for the relatively limited number of TNWs present within the Los Angeles District, the distance is typically far between a NRPW and the nearest TNW, thus further reducing the likelihood of a SN evaluation resulting in the determination that the NRPW connection is significant and thus is a regulated WOTUS.

Following Rapanos and the reduced CWA protections of non-perennial stream systems, there were increased efforts by agencies and the scientific community at large to develop and document more information on NRPW aquatic resources, including their functions, collective importance and connectivity within watersheds, ultimately for informing and supporting regulation of non-perennial wetlands and streams (Leibowitz et al., 2008; Leigh et al., 2016). In 2015 under the Obama administration, the Corps and USEPA undertook joint rulemaking in the aftermath of Rapanos to clarify and re-define WOTUS via the Clean Water Rule (CWR). The

CWR and its support documents[5] essentially provide arguments for various waters that should be defined automatically (by rule) as WOTUS without needing a significant nexus evaluation, including non-perennial streams. The rulemaking also made an obvious attempt to bring science back into the regulatory process, with the text extensively citing available published scientific information from over a thousand studies. Of note, the CWR also addressed a few aquatic resource types for which a significant nexus evaluation would still be required and thus conducted on a case-by-case basis. But those circumstances would be limited, allow the same type of aquatic resource to be aggregated for analysis within the watershed, and more appropriately capture the real cumulative effect of the aquatic resource functions from the same resource type on the downstream TNW (Levick et al., 2008). Nonetheless, the CWR was litigated immediately once it became effective. By midway through the Trump administration, various district court district decisions on whether a stay of the CWR was granted resulted in roughly half of the country continuing to be regulated by the CWR while the other half reverted back to regulation under the 1986 CWA as modified by SWANCC and Rapanos. Then through a whiplash series of rapid actions by the subsequent White House administration and the courts, the CWR was ultimately repealed and replaced by the Navigable Waters Protection Rule (NWPR), which itself was then revoked and vacated by a District Court. Therefore, once again aquatic resources are regulated under the 1986 CWA modified definitions of WOTUS.

Unfortunately, it appears that efforts to establish more concrete and consistent CWA regulation and protection for non-perennial aquatic resources, by primarily relying on the

[5] USEPA and U.S. Department of Army. (2015). Technical Support Document for the Clean Water Rue: Definition of Waters of the United States. As stated in the Technical document, "The Preamble, the Science Report, this Technical Support Document, the Response to Comments, and the rest of the administrative record provide the basis for the definition of "waters of the United States" established in the rule."

considerable inclusion of the best available science as attempted under the CWR, do not have a high likelihood of prevailing with dated CWA regulations and dysfunctional Congresses. In a perfect storm, the roles of politics and the judicial system seem to have overtaken and unbalanced the realm of regulating aquatic resources between Congress, White House administrations, and the courts (Figure 3). In light of today's extremely polarized politics, various Congresses have not been able to pass significant new or modified environmental laws. As a result, larger CWA issues on the scope of WOTUS jurisdiction under the CWA and the original CWA intent are caught in a loop spiraling between the administration that's currently in power and an increasingly politicized court. And in this climate, the major shift in the composition of the Supreme Court to a conservative majority under the Trump administration will have long-lasting impacts on environmental regulation. In a short time, the current Court has given many indications it is not functioning as past Supreme Courts have, including: openness to revisit and potentially over-turn prior precedent, taking up key environmental cases addressing regulations already undergoing rulemaking processes to be changed by the current administration, and signaling a general change in no longer granting agencies the long-standing practice of deference as subject matter experts. These are all early indicators future regulation and protection of aquatic resources as defined as WOTUS under the CWA may be reduced or eliminated in part, especially for arid non-perennial streams as they had been considered under the NWPR. However, due to the time it would take for the current administration's WOTUS rulemaking, the Supreme Court not issuing any decisions until roughly mid-2023, and the high likelihood litigation would be forthcoming once the Biden administration's WOTUS rule becomes effective, it will be some time until the ultimate regulatory scenario plays out.

Federal and State Local Regulation and Applications

Despite uncertainties on the future extent of regulation of these important and widespread arid non-perennial stream resources under the CWA, this work has applications to several different aspects of the Regulatory program (Figure 2) in "how" these resources should be treated and managed. These include larger scale efforts to develop regional OHWM delineation guides and regional assessment methods, as well as local Corps District SN jurisdictional determinations, early permit process considerations, what aquatic resources are important on a watershed basis and from cumulative impacts perspectives, what project impacts to avoid and minimize, and compensatory mitigation considerations on a watershed level, all ultimately culminating in Regulatory permit decisions. Applications also extend to state regulatory agencies and others (local government entities, scientific community) outside the regulatory realm of the CWA, including mitigation, stream assessment and management.

As mentioned above, arid non-perennial stream functions from both global and U.S. literature were analyzed around a framework developed consisting of the contexts of overall ecosystem controls (climate), the mid to small scale landscape environmental parameters influencing stream functions, and the key hydrology aspects as the main forcing function among a pyramid hierarchy of stream functions. As such, this work is a first step in aiding efforts to develop national OHWM guidance, in providing the baseline first steps for identifying the associations of existing non-perennial stream functions information to the critical hydrology, climate, and hydrogeomorphic settings within different landscape scales. It provides direction on what existing quantitative information could likely be explored for availability and application with regionalized OHWM identification efforts, within existing literature and any other available

data sets. Subsequent extensions of this work would be to gather quantitative information on these function categories in relation to the various environmental settings. And though care must be taken that the distribution and occurrence of studies in this work does not necessarily translate into how complete the knowledge base is of the function categories, the results could serve as coarse indicators in preliminarily exploring what functions information potentially may be lacking within the various environmental settings, for further research to fill in any data gaps. These same OHWM applications extend to stream assessment methods, especially as further Hydrogeomorphic (HGM) Approach guidebooks are developed.

HGM was originally developed in support of inventorying wetlands nationwide through wetland classifications, and then was further modified to support functional wetland assessments for Corps Regulatory purposes (Natural Resources Conservation Service, 2008). Similar to this dissertation work, the HGM approaches recognize the importance of geomorphic and hydrologic aspects in relation to arid non-perennial stream functions, including the surrounding landscape, and they address the Habitat, Biogeochemical, and Hydrology primary function categories reflected in U.S. and global literature for non-perennial streams. Unfortunately, developing HGM regional approaches requires forming and collecting field data within a larger reference domain, and overall, due to the significant level of effort, time and cost involved the development of these limited regional approaches, is not widespread. There are only five operational draft HGM regional guidebooks nationwide that had been developed specifically for use with non-perennial streams. Two occur far outside of the Arid West within warm temperate climate regions of the Appalachian Mountains within western West Virginia, eastern Kentucky, and parts of Tennessee, Ohio, Pennsylvania, and Virginia (Noble et al., 2010; Summers et al.,

2017). There are three located within southern California, but they mostly occur within warm temperate subclimes.(L.C. Lee & Associates & National Wetland Science Training Cooperative, 2001; Lee et al., 1997) and only one in its entirety is within the cold steppe subclime yet encompasses a very small coastal watershed (MacNeil, 2001). They are also applicable only to high gradient (upper watershed) headwater stream types of ephemeral and intermittent flow regimes, as well as to the subclass of perennial streams of less than 4% slopes (lower watershed areas) with relatively narrow and shallow channel forms.

Regarding stream assessments, the federal 2008 Mitigation rule jointly issued by the Corps and USEPA provided key guidance and requirements for compensatory mitigation projects, as well as for the development and operation of mitigation banks and in-lieu fee programs. The Rule also focused on use of an overall watershed approach and encouraged practical use of quantitative and qualitative stream assessments for both assessment of aquatic resource impacts and compensatory mitigation. Locally, the Corps' South Pacific Division also issued further guidance in 2015, summarizing the lengthy rule and providing Division specific guidance (2015 Corps South Pacific Division (SPD) "Regional Compensatory Mitigation and Monitoring Guidelines for South Pacific Division"). However, the regulations and guidance incidentally also served to highlight the overall lack of adequate assessment methods for arid non-perennial streams, especially within California. To-date, the episodic CRAM module is still the only available and accepted stream assessment method within the Corps Regulatory Los Angeles District for California. Around the time of the 2008 Rule and 2015 SPD guidelines, only one wetland and stream method, the California Rapid Assessment Method (CRAM), existed. As a condition assessment method with broad scoring categories, CRAM was intended to be

sensitive to ecosystem forcing functions and was loosely based on the HGM Approach, as well as on USEPA's Level 1-3 Framework for assessing and monitoring wetlands. However, the riverine CRAM module was originally developed for more perennially flowing streams with weighting on diversity, and as such had noted inadequacies for appropriately assessing less diverse arid non-perennial waters (California Wetlands Monitoring Group, 2013; Southern California Coastal Water Research Project, 2010; Technical Advisory Committee, 2013). A new episodic riverine CRAM module was later released in 2016, with application to arid episodic ephemeral streams and drier intermittent streams. It does include consideration of most of the fundamental primary function categories reviewed within this study (Habitat, Sediment, and Hydrology). Yet as a newer stream assessment method it has not gained widespread use, as indicated through electronically available (eCRAM) data (EcoAtlas.org), it has not yet been utilized for state or regional ambient surveys to verify results reliability, and the acceptance and use of this assessment method is not widespread across the board for state agency personnel (personal observation). And due to the large bucket scoring approach, there are limitations in the sensitivity of measuring small changes in functional over relatively shorter periods of time, as well as limitations with applications to single thread, compound, braided, discontinuous, and upper area alluvial fan channels (not necessarily all planform types). Therefore, to have quantitative tools available that provide scoring sensitivity, can include detailed hydrogeomorphic stream settings, and have been well established as functional assessment methods across various regions, I recommend the development of non-perennial stream HGM guidebooks within arid regions of the Los Angeles District. The development priorities of HGM

guidebooks can be guided by an assessment of current and projected future impacts among intermittent and ephemeral streams, watershed positions, and stream planform types.

On a similar yet informal and highly qualitative manner of stream assessment, Corps Regulatory project managers within the Los Angeles District (and larger SPD) utilize a standard operating procedure for determining mitigation ratios when project impacts result in functional losses to WOTUS that must be offset. This procedure is known as the SPD mitigation checklist ratio procedure, with a step that either incorporates available quantitative CRAM scores or requires a project manager to conduct a desktop qualitative assessment of the functions provided by a stream, how those functions may be impacted by the proposed project impacts, and the expected functional gains through the proposed method(s) of compensatory mitigation. Though there is a structure for decision making, this qualitative assessment only includes a suggested list of nine stream ecosystem services (short- or long-term surface water storage, subsurface water storage, moderation of groundwater flow or discharge, energy dissipation, nutrient cycling, removal of elements and compounds, particulates retention, export of organic carbon, and maintenance of plant and animal communities) for consideration by project managers. Aside from the functions covered, other hydrogeomorphic aspects where impacts to WOTUS may occur, such as watershed position, planform type, and the stream subarea(s), do not explicitly come under consideration for qualitative functions assessment. To be clear, the procedure states this functions list is not all-encompassing and others may be considered as appropriate. Yet from a practical perspective it is a very subjective process with inconsistencies across project managers, who are not likely to deviate from a provided list of functions to choose from for a variety of reasons, including those that may lack more experience as a regulator, those who may

not have a background on fluvial geomorphology and other stream science subjects, or those who are otherwise simply under time constraints for providing timely permit decisions to project applicants. This list of ecosystem services appears exactly the same in the CRAM manual, as both CRAM and the mitigation checklist ratio procedure adopted the original HGM list of wetland functions as provided by Smith et al. (1995). However, this list essentially omits the Sediment functions category covered in this dissertation work, as well as Geomorphology functions (sediment continuity, maintain substrates and structural processes, quality and quantity of sediments) as described by Fischenich (2006), and Geomorphology functions (including transport of sediment and lard woody debris, creation of channel forms, and dynamic equilibrium) from Harman et al. (2012). Therefore, I highly recommend to the Los Angeles District Regulatory Program some improvements to this critical assessment step of the mitigation checklist ratio procedures. First, the Sediment functions category can and should be incorporated into the checklist procedure so all four primary functions are appropriately considered, either within the qualitative assessment step or as an additional factor if CRAM scores are utilized. Second, comprehensive guidance should be developed that isn't solely a new supplemental and comprehensive list of applicable stream functions across all primary function categories, but provides quick yet accurate reference contexts (e.g. decision tree) for the appropriate considerations relative to watershed position, stream planform type, site specific impact locations, and streamflow regimes among likely functions and level of functions. Regulator training should also be provided at least annually for ensuring as much consistency in mitigation determinations between project managers over time.

In a very similar fashion, local District guidance of the same nature can be developed and provided for determining and documenting jurisdiction regarding the Rapanos JD form. In its current form, the Rapanos JD form is essentially a list of physical, biological, and chemical aspects to consider for the streams and wetlands. Both the four primary function categories and the functions pyramid concept can be incorporated in the development of District how-to guidance for regulators, in translating a list of stream characteristics and functions into a jurisdictional determination based on the best available science.

Even if the Supreme Court further reduces federal regulation of waters by excluding non-perennial streams from WOTUS, states do have options to step in and utilize existing or new regulation to cover federal regulation gaps (Springer, 2007). Under California state law these resources would still be regulated by state agencies. For instance, when non-perennial streams were deemed for the Corps as non-jurisdictional waters under some Rapanos SN determinations or NWPR jurisdiction situations, the California Regional Water Quality Control Boards (RWQCBs) continued to regulate those streams under the state Porter-Cologne Act. The California Department of Fish and Wildlife is another partner agency involved in the regulation of state waters, habitat and species. Similar to the Corps, these state agencies must make assessments of the aquatic resources for which they permit impacts, as well as determinations of the compensatory mitigation required for those impacts. Some RWQCB staff have also generally accepted and informally adopted use of the Corp's mitigation checklist ratio procedures for various aquatic resources, and improvements to this process developed from the results of this work, would translate benefits beyond the Corps. Moreover, the utility of the mitigation checklist procedures for the Corps with non-perennial streams would remain, regardless of their

WOTUS status. Local Districts have flexibility and discretion on overall compensatory mitigation priorities, and an interesting component of the 2008 Rule is allowance of compensatory mitigation for both aquatic and non-aquatic resources, irrespective of jurisdictional status. Also, all resources of a mitigation project are afforded mechanisms of long-term management and long-term site protection as required elements of mitigation plans under the 2008 Rule, in order for the functional gains to be maintained in light of the functional losses from permanent impacts. As a typical practice for acceptance of non-jurisdictional upland areas as part of an overall mitigation proposal, this usually extends to adjacent upland buffer areas that surround and contribute to the on-going functioning of aquatic resources. It had also extended to ephemeral streams during the relatively brief period the NWPR was in effect, which was especially significant to the mitigation banking community as there are also several banks both already established and in development phases that contain to a small or large degree non-perennial resources.

In summary, this dissertation work has various applications to regulatory processes of arid non-perennial steams within the Arid West, and it provides a stepping stone for future advances in stream function assessments and management.

Figures

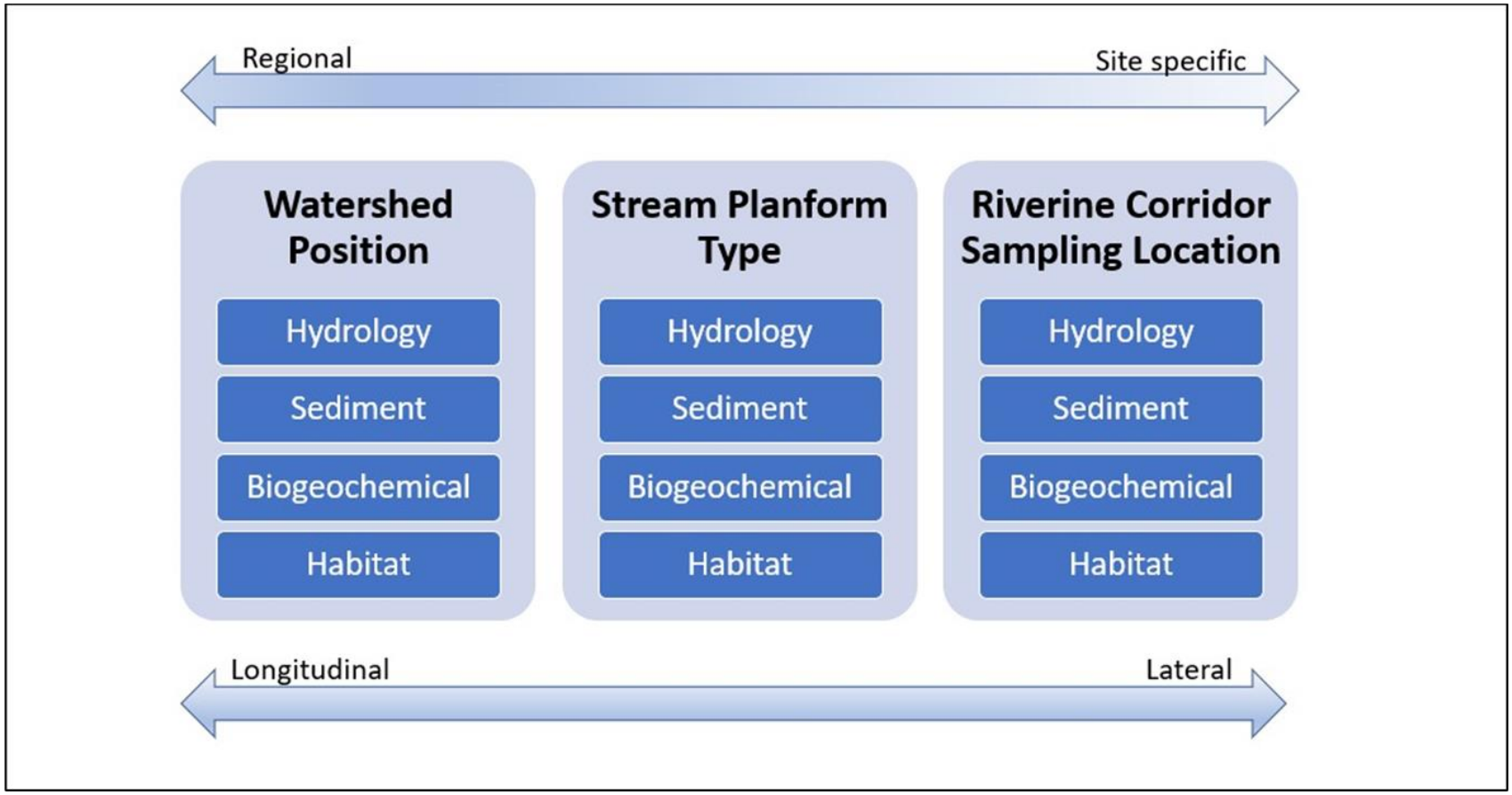


Figure 239. Conceptual relations and scales of influence of watershed position, planform type, and sampling location environmental parameters to broad function categories.

Appendix A: The Clean Water Act and WOTUS Definitions

Historically, the U.S. Army Corps of Engineers (USACE)(Corps) became a branch of the U.S. Army in 1802, participating in both military and civil construction and works projects. The first regulation of waterways by the Corps began with the Rivers and Harbors Act of 1890 and 1899 (Sections 9 and 10). The 1890 act version concerned dam regulation. The 1899 version concerned the regulation of the discharge of fill materials into navigable waters (Section 10), as well as construction activities in and surrounding (Section 9) navigable waters. The Oil Pollution Act of 1924 gave the Corps the authority to partially address water quality by allowing the apprehension of persons discharging oil into tidal waters. However, it was Section 404 of the Federal Water Pollution Control Act of 1948 (FWPCA) that gave the Corps the first authorization to additionally regulate the discharge of dredged or fill material into non-navigable waters of the U.S. (WOTUS), such as wetlands and other aquatic resources ("A Brief History," n.d.) other than major waterways. The subsequent FWPCA Amendments of 1972 have become known as the Clean Water Act (CWA).

The regulation of Section 10 and 404 waters of the U.S. is performed by the Civil Works Directorate of the Corps under the Regulatory Program (Regulatory). The mission of Regulatory is to balance reasonable development with the protection of national aquatic resources, termed waters of the U.S. (WOTUS)[6]. WOTUS for the Regulatory Program are defined in Code of Federal Regulations (CFR), at 33 CFR Part 328.3(a)-(f) as follows:

[6] Common acronyms used for "waters of the U.S." by regulatory agencies, the general public and the scientific community include WOTUS and WOTUS. However, as WOTUS is the acronym more commonly used by the Corps and regulated public, WOTUS is the acronym utilized in this dissertation prospectus.

"(a) The term *waters of the United States* means

(1) All waters which are currently used, or were used in the past, or maybe susceptible to use in interstate or foreign commerce, including all waters which are subject to the ebb and flow of the tide;

(2) All interstate waters including interstate wetlands;

(3) All other waters such as intrastate lakes, rivers, streams (including intermittent streams), mudflats, sandflats, wetlands, sloughs, prairie potholes, wet meadows, playa lakes, or natural ponds, the use, degradation or destruction of which could affect interstate or foreign commerce including any such waters:

(i) Which are or could be used by interstate or foreign travelers for recreational or other purposes; or

(ii) From which fish or shellfish are or could be taken and sold in interstate or foreign commerce; or

(iii) Which are used or could be used for industrial purpose by industries in interstate commerce;

(4) All impoundments of waters otherwise defined as waters of the United States under the definition;

(5) Tributaries of waters identified in paragraphs (a) (1) through (4) of this section;

(6) The territorial seas;

(7) Wetlands adjacent to waters (other than waters that are themselves wetlands) identified in paragraphs (a)(1) through (6) of this section.

(8) Waters of the United States do not include prior converted cropland. Notwithstanding the determination of an area's status as prior converted cropland by any other Federal agency, for the purposes of the Clean Water Act, the final authority regarding Clean Water Act jurisdiction remains with EPA. Waste treatment systems, including treatment ponds or lagoons designed to meet the requirements of CWA (other than cooling ponds as defined in 40 CFR 423.11(m) which also meet the criteria of this definition) are not waters of the United States.

(b) The term *wetlands* means those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas.

(c) The term *adjacent* means bordering, contiguous, or neighboring. Wetlands separated from other waters of the United States by man-made dikes or barriers, natural river berms, beach dunes and the like are ''adjacent wetlands.''

(d) The term *high tide line* means the line of intersection of the land with the water's surface at the maximum height reached by a rising tide. The high tide line may be determined, in the absence of actual data, by a line of oil or scum along shore objects, a more or less continuous deposit of fine shell or debris on the foreshore or berm, other physical markings or characteristics, vegetation lines, tidal gages, or other suitable means that delineate the general height reached by a rising tide. The line encompasses spring high tides and other high tides that occur with periodic frequency but does not include storm surges in which there is a departure

from the normal or predicted reach of the tide due to the piling up of water against a coast by strong winds such as those accompanying a hurricane or other intense storm.

(e) The term *ordinary high water mark* means that line on the shore established by the fluctuations of water and indicated by physical characteristics such as clear, natural line impressed on the bank, shelving, changes in the character of soil, destruction of terrestrial vegetation, the presence of litter and debris, or other appropriate means that consider the characteristics of the surrounding areas.

(f) The term *tidal waters* means those waters that rise and fall in a predictable and measurable rhythm or cycle due to the gravitational pulls of the moon and sun. Tidal waters end where the rise and fall of the water surface can no longer be practically measured in a predictable rhythm due to masking by hydrologic, wind, or other effects."

References for definitions of WOTUS, as listed in the electronic Code of Federal Regulations (e-CFR), were originally provided at 51 FR 41250 on November 13, 1986 as a consolidated section of definitions. These were later amended at 58 FR 45036 (August 25, 1993) to add a new definition, 328.3(a) (8), for the exclusion of prior converted cropland, as listed in the paragraph above. Despite various rulemaking changes by White House administrations since the Rapanos Supreme Court case, the above 1993 WOTUS definitions are still in effect nationwide.

Appendix B: Literature Database and Data Sources List

Table 41. Literature database and search engine content descriptions.

Literature Database/ Search Engine	Name	Description
Literature Database	Academic Search Complete**	Multi-disciplinary full-text database including engineering, law, science and social sciences. Indexes and abstracts over 10,000 publications, with the complete text of over 5,500 periodicals, including 4,600 peer-reviewed journals. Designed for academic institutions, provides full text for more than 7,800 peer-reviewed journals and PDFs dating back to 1887. Updated daily, with searchable cite reference for over 1,400 journals.
Literature Database	BioOne Complete	Provides aggregation of high-impact bioscience research journals, with over 180 journals of peer-reviewed research focused in the biological, ecological, and environmental sciences.
Literature Database	BIOSIS Previews	Content from present dating back to 1926, with integrated access to other Web of Science databases. Covers multiple life science research fields. Indexed to Biological Abstracts, with almost 5,000 primary peer-reviewed journal and monograph titles.
Literature Database	Ecology Abstracts*	Ecology research over a wide range of fields, including resource and ecosystems management, pollution, economics, environment, water resources, invertebrates, plants, microbes, soil, vertebrates, conservation. 1982-current, with over 237,000 records.
Literature Database	Environmental Sciences and Pollution Management*	This multidisciplinary database with comprehensive coverage of environmental sciences, including aquatic pollution, ecology, energy resources, environmental engineering, microbiology, and water resource issues. Abstracts and citations from over 6,000 serials including scientific journals, conference proceedings, reports, monographs, books and government publications.
Literature Database	GeoRef*	Established by the American Geosciences Institute, with over 3.6 million references to journals, books, maps, conference papers, repots and theses. Index to

Literature Database/ Search Engine	Name	Description
		publications in geology, geophysics, and the history of the earth, with references to USGS publications. Covers North America from 1669 to present, with world coverage from 1933 to present
Literature Database	JSTOR	Over 1,800 academic journals available. Coverage includes the fields of botany, business, ecology, general science, humanities, mathematics, social sciences, and statistics. Full-text search enabled across all fields.
Literature Database	Science Direct	Multidisciplinary with coverage in the fields of Physical Sciences and Engineering, Life Sciences and Environmental Science, Health Sciences, and Social Sciences and Humanities. Content includes full-text articles and e-books in the sciences, technology, medicine and social sciences, with over 2,500 journals. Contains nearly 25% of peer-reviewed full-text scientific content, linking to Scopus abstract and indexing data. Also includes pre-publication articles.
Literature Database	Web of Science	Multidisciplinary database and the world's leading source of scholarly research, with the most complete subject records in over 250 categories. Enabled unbiased searches for high impact articles and conference proceedings. Covers journal literature of the sciences, social sciences, and arts and humanities. Users can also access the three ISI Citation Databases: Science Citation Index Expanded, Social Sciences Citation Index, and Arts & Humanities Citation Index.
Literature Database	Wiley Online Library	Covers a broad and multidisciplinary global collection covering technical, scientific, social science literature, including water resources related topics. Other subjects covered include the physical sciences, life sciences and humanities.

* ProQuest search engine hosts multiple databases, including: Ecology Abstracts, Environmental Sciences and Pollution Management, GeoRef, and Water Resources Abstracts.

** EBSCO search engine hosts 58 separate databases, with the capability to search multiple or single databases for peer-reviewed literature. Relevant search databases include: Academic Search Complete, GreenFILE, and History of Science, Technology and Medicine, Ecology Abstracts, Environmental Science and Pollution Management, and GeoRef.

Appendix C: General Schematics of Literature Searches Through Databases

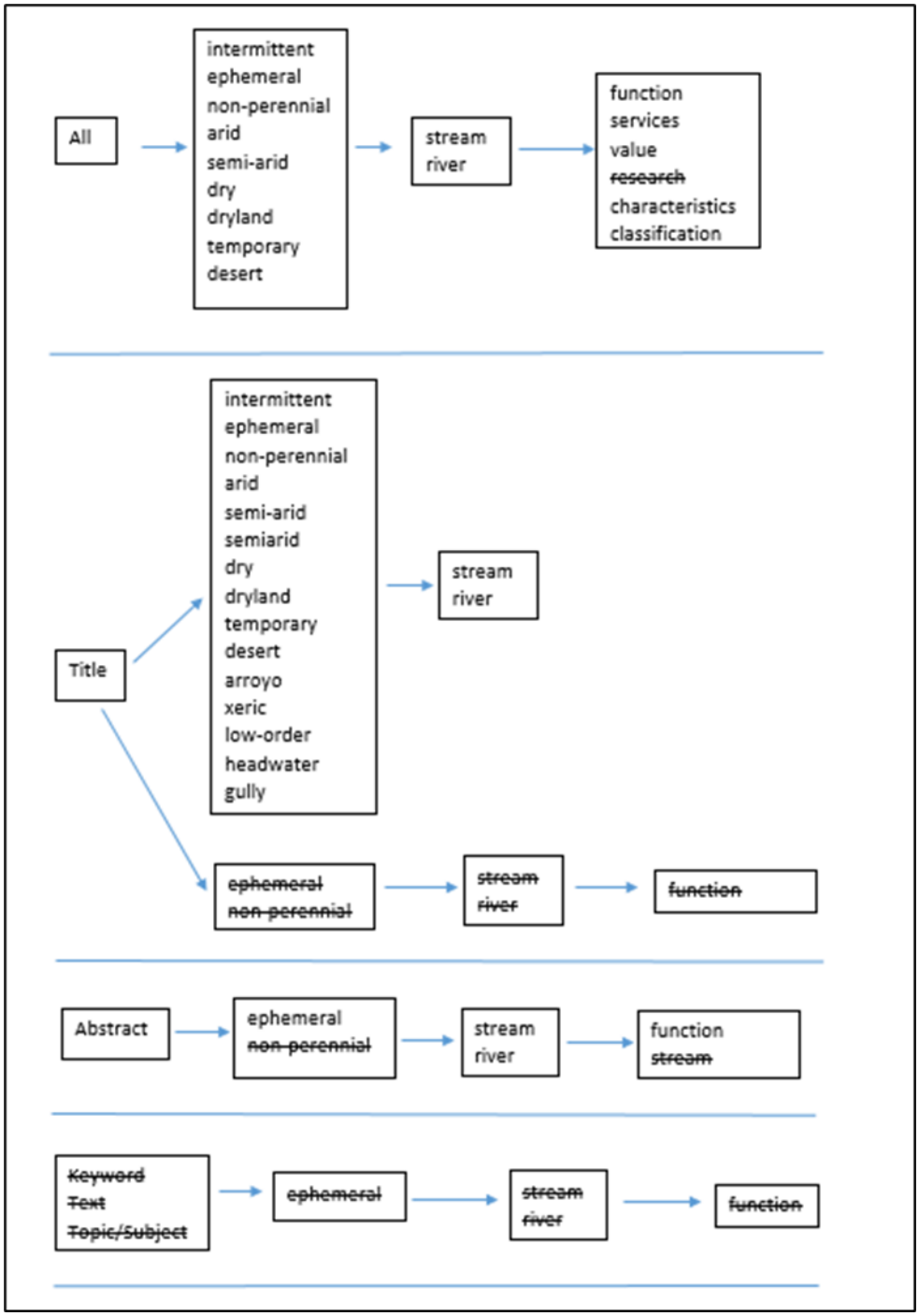


Figure 240. General schematic of ASC database literature searches. Crossed out lines were either not available to be searched within the database or returned none or far too many reference results.

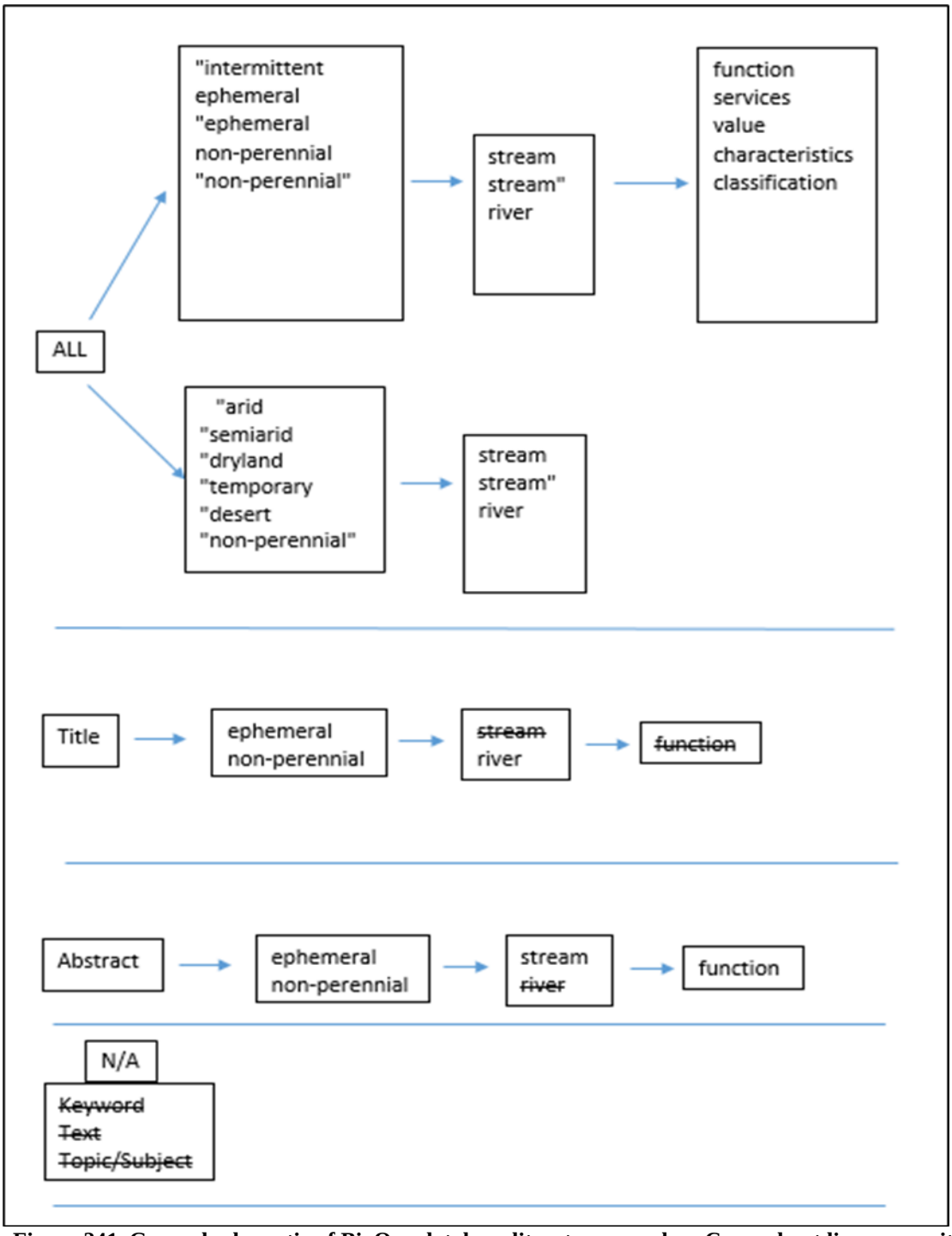


Figure 241. General schematic of BioOne database literature searches. Crossed out lines were either not available to be searched within the database or returned none or far too many reference results.

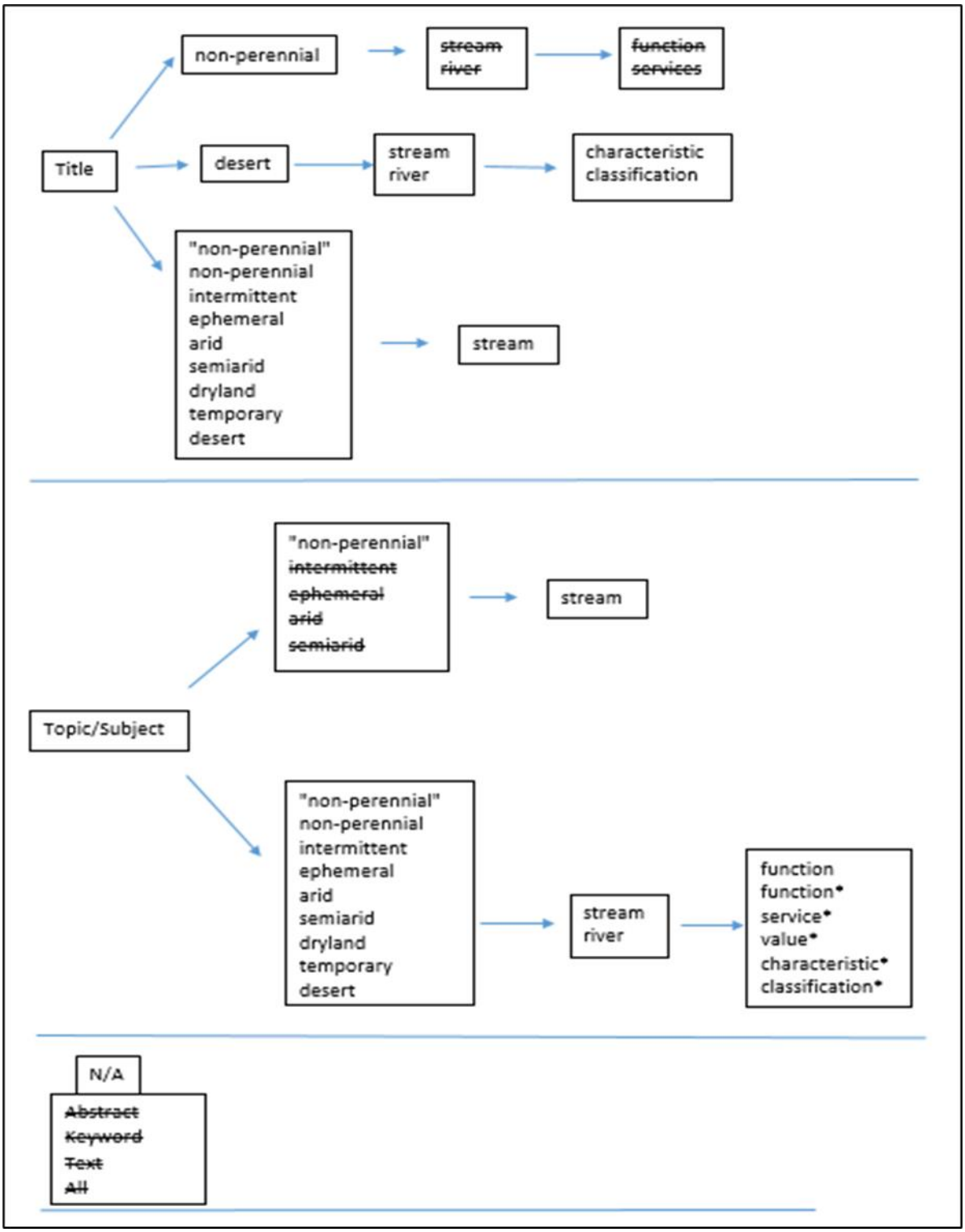


Figure 242. General schematic of BIOSIS database literature searches. Crossed out lines were either not available to be searched within the database or returned none or far too many reference results.

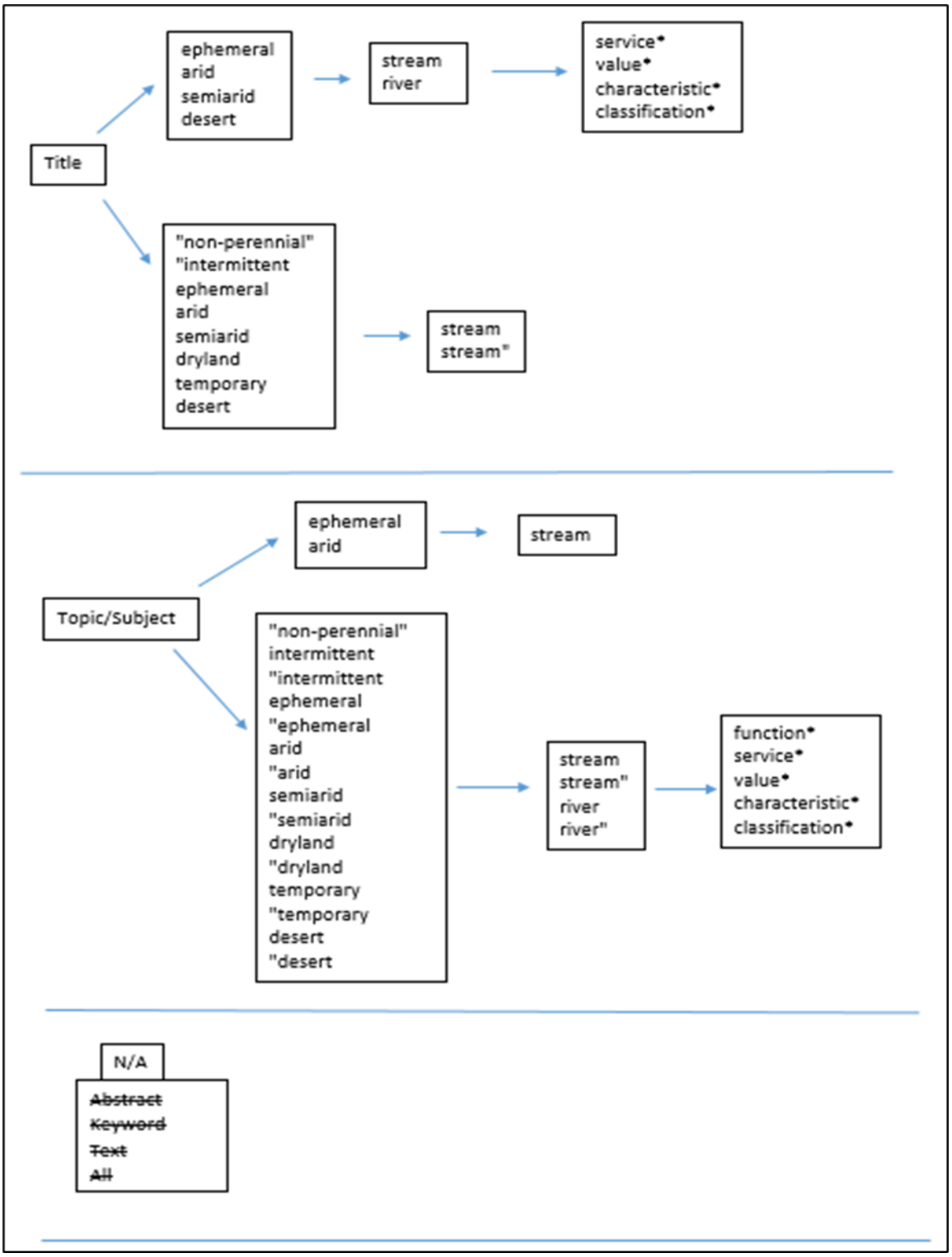


Figure 243. General schematic of Web of Science database literature searches. Crossed out lines were either not available to be searched within the database or returned none or far too many reference results.

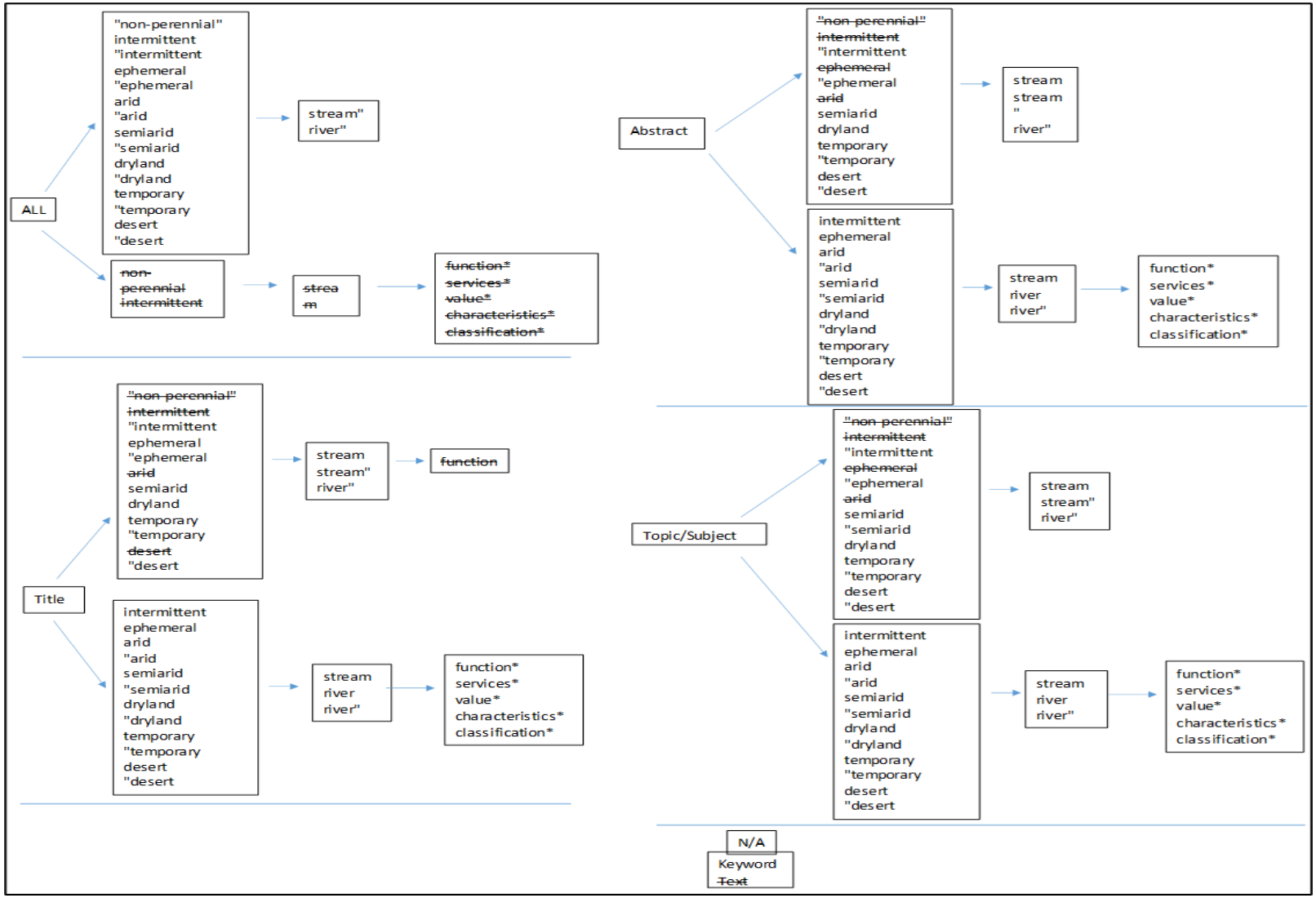


Figure 244. General schematic of Ecology Abstracts database literature searches. Crossed out lines were either not available to be searched within the database or returned none or far too many reference results.

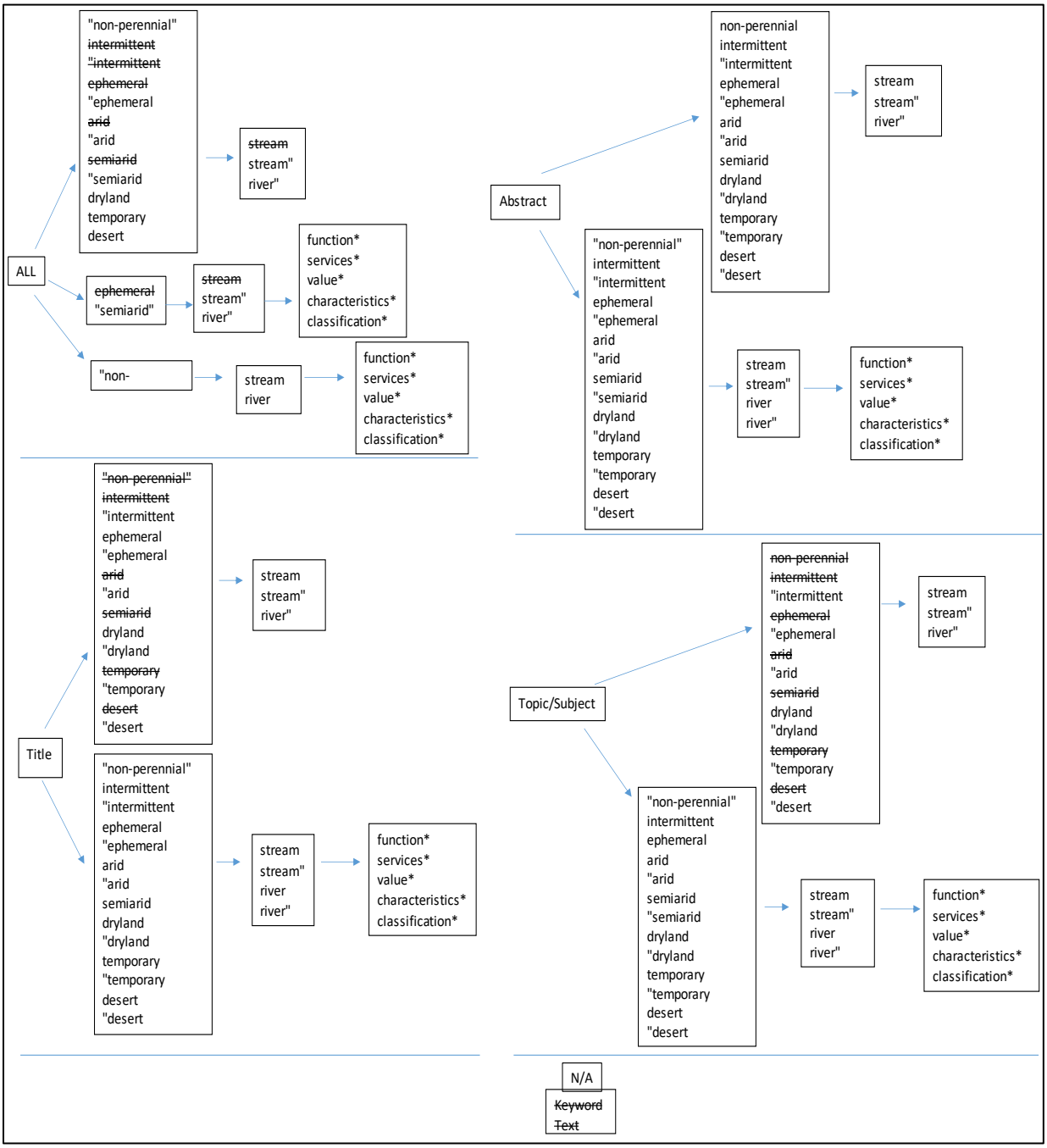


Figure 245. General schematic of Environmental Sciences & Pollution Management database literature searches. Crossed out lines were either not available to be searched within the database or returned none or far too many reference results.

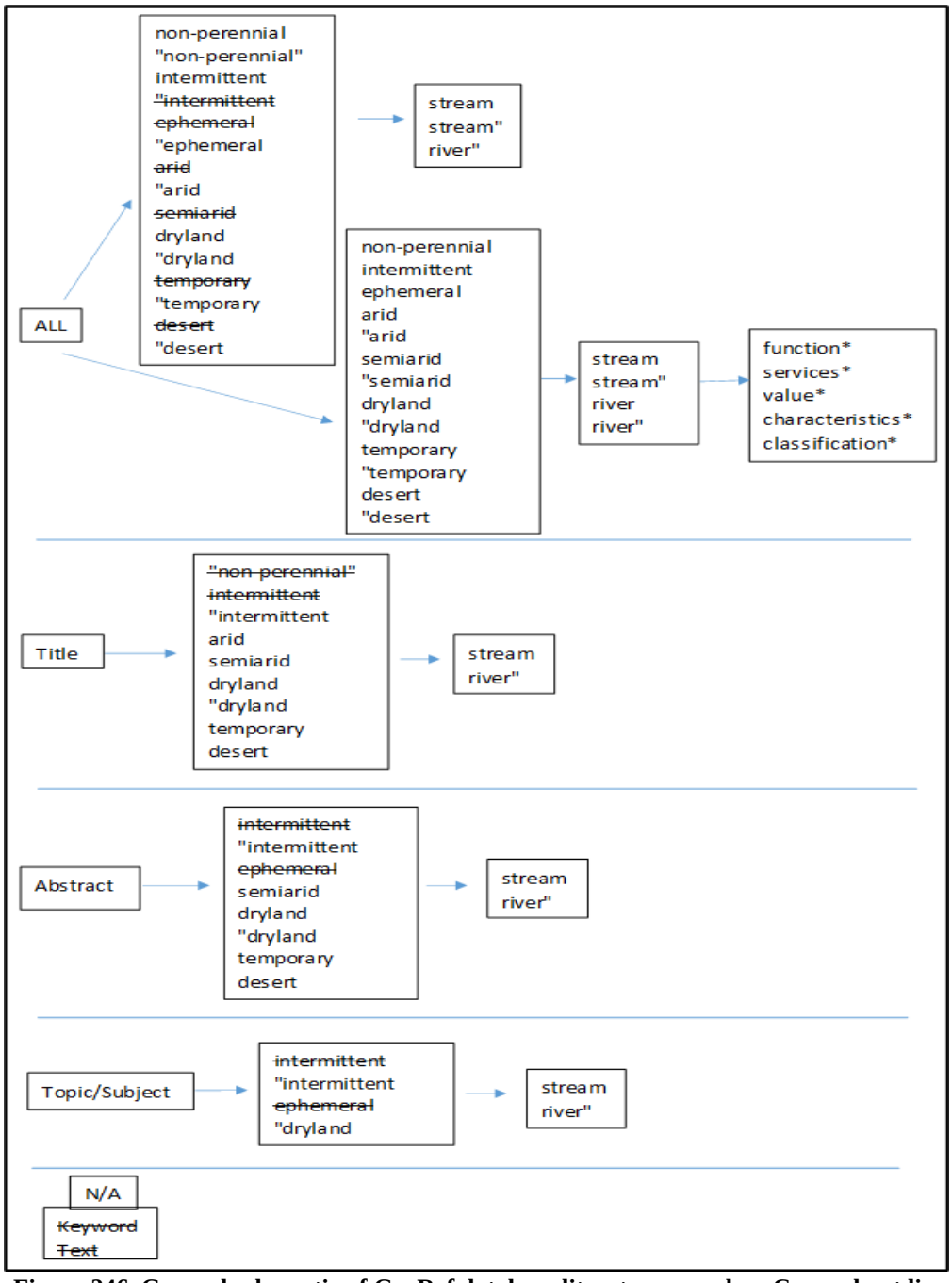


Figure 246. General schematic of GeoRef database literature searches. Crossed out lines were either not available to be searched within the database or returned none or far too many reference results.

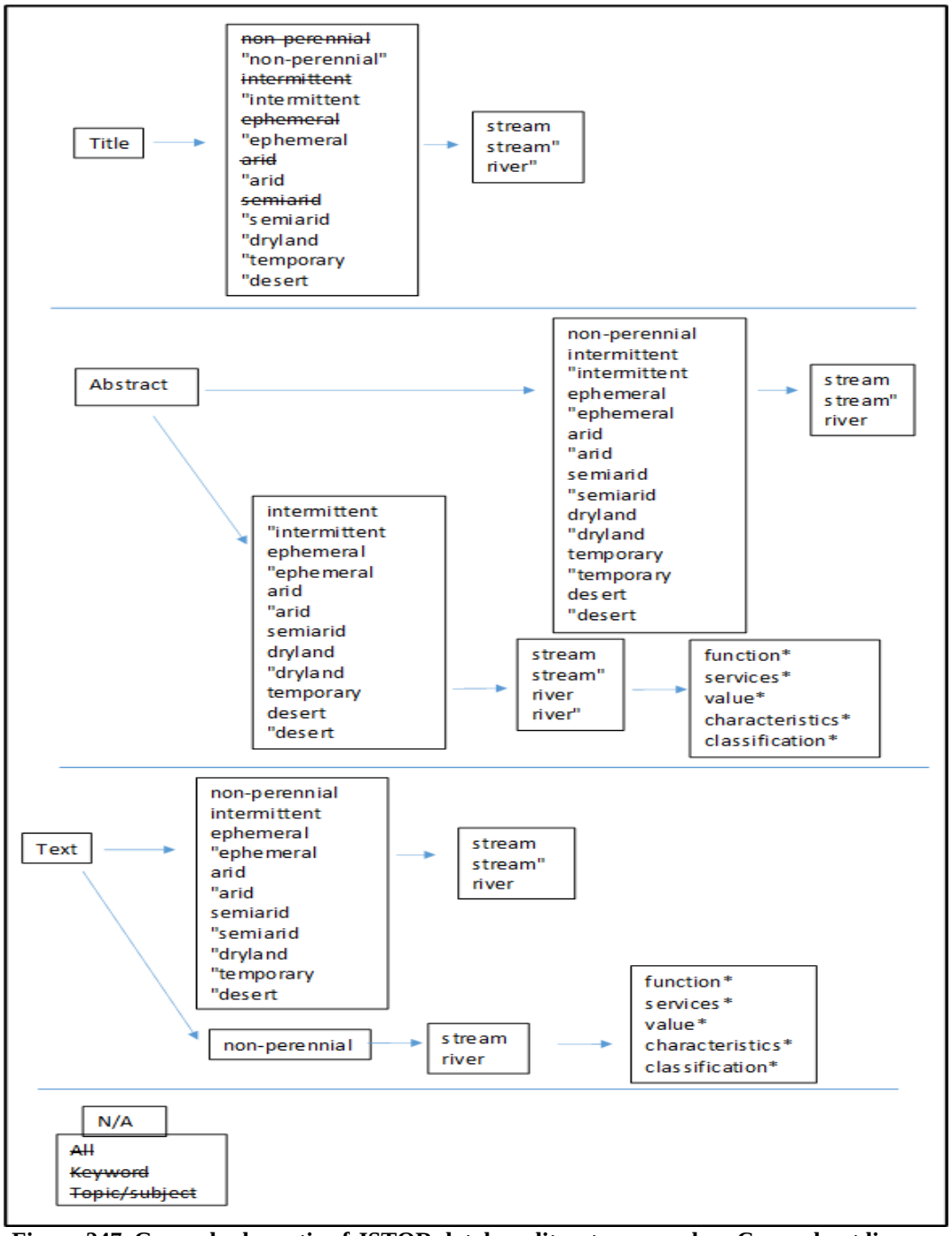


Figure 247. General schematic of JSTOR database literature searches. Crossed out lines were either not available to be searched within the database or returned none or far too many reference results.

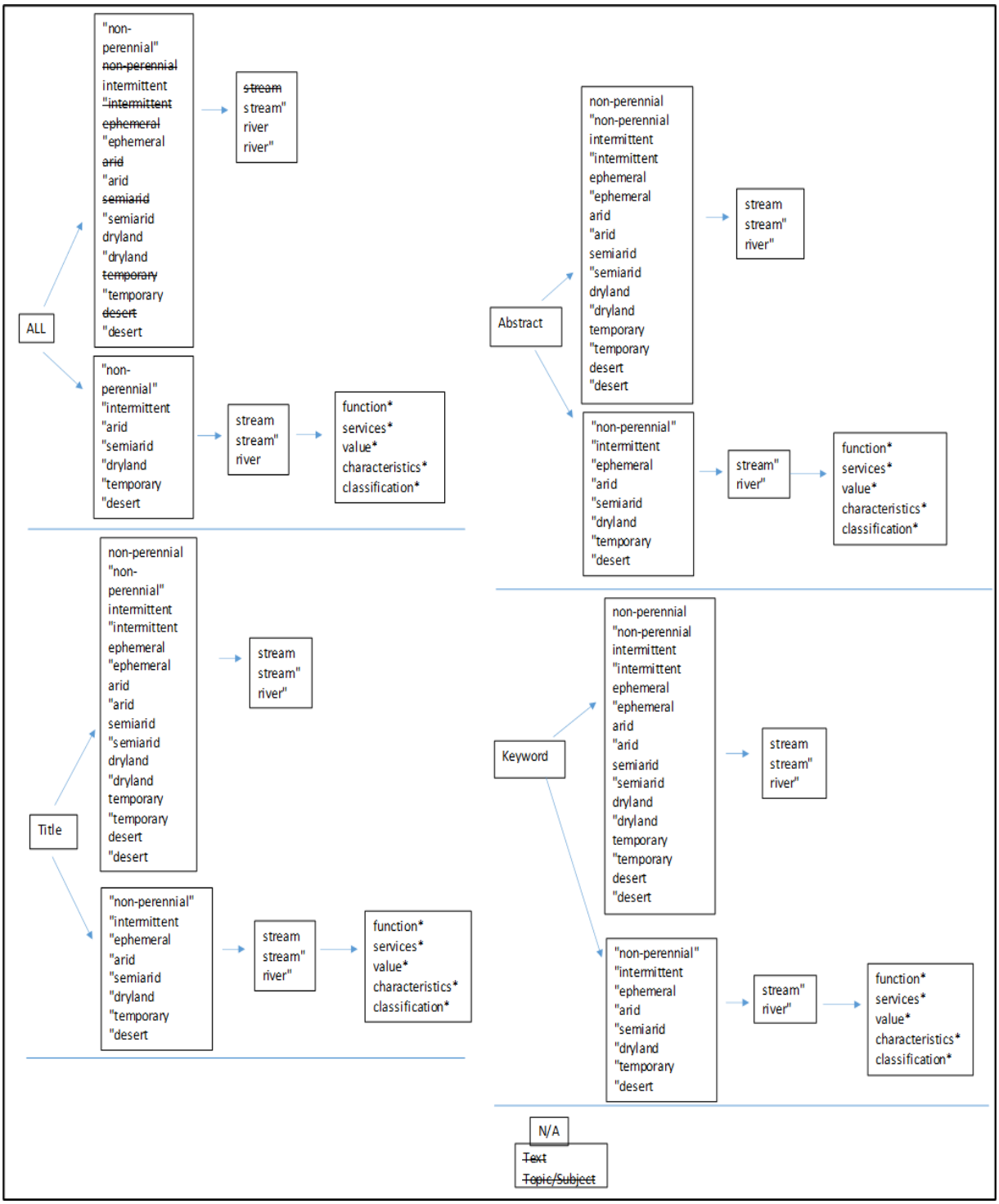


Figure 248. General schematic of Science Direct database literature searches. Crossed out lines were either not available to be searched within the database or returned none or far too many reference results.

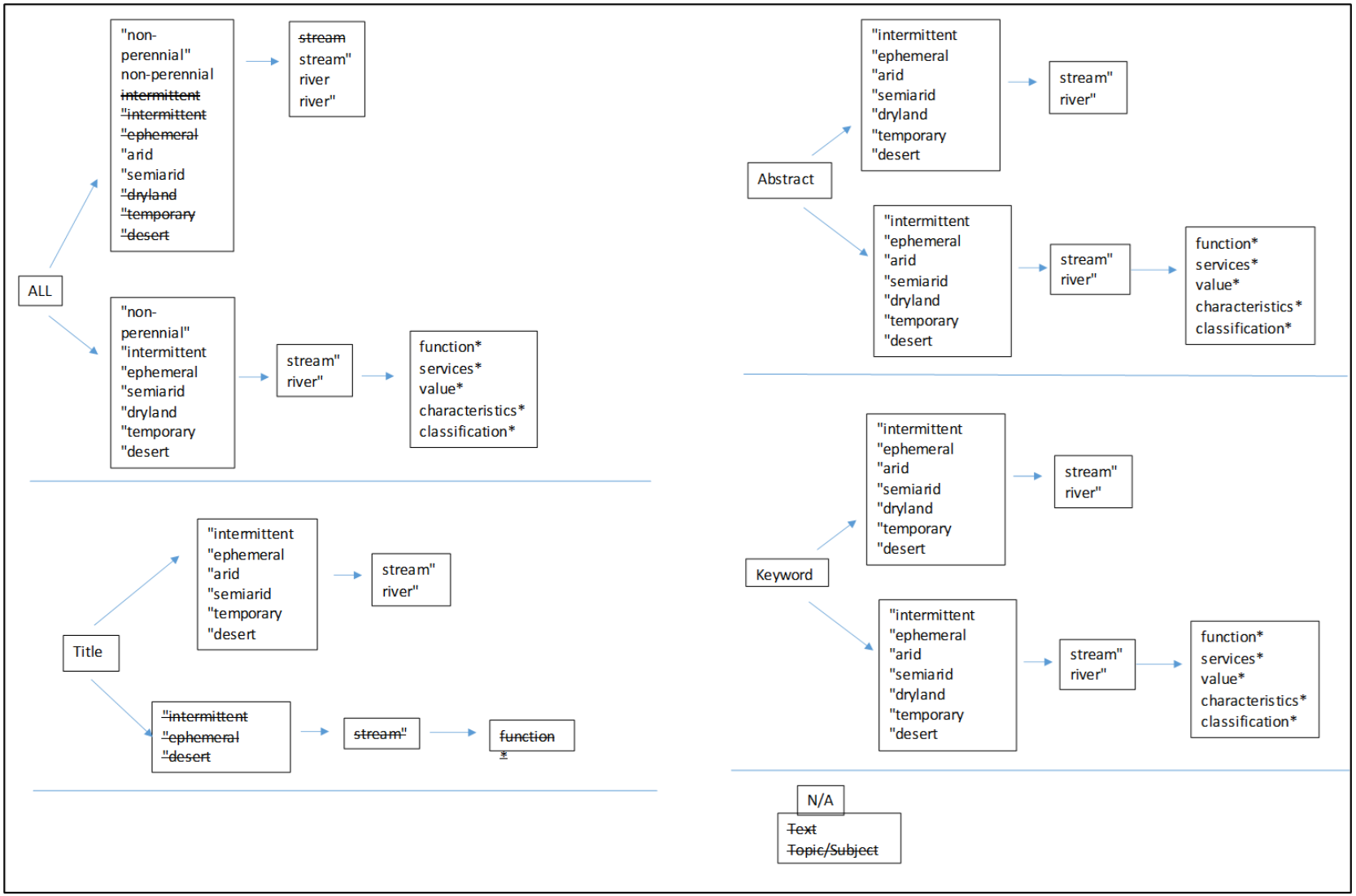


Figure 249. General schematic of Wiley Online database literature searches. Crossed out lines were either not available to be searched within the database or returned none or far too many reference results.

Appendix D: Supplemental Methods Table and Figures

Table 42. Stream and wetland* ecosystem functions, services and values as initially identified through a variety of background scientific literature.

Broad Category of Function, Service, or Value**	**Specific Function, Service, or Value**	(Levick et al., 2008)	(Meyer et al., 2003)	(Nadeau & Rains, 2007)	(Smith et al., 1995)*	(Brinson et al., 1995)*	(Noble et al., 2010)	(U.S. Evironmental Protection Agency, 2015)	(Vyverberg, 2010)	(Harman et al., 2012)	(Stein et al., 2011)	(Rowe et al., 2009)	(James H. Thorp et al., 2010)	(Fischenich, 2006)
Connectivity	Landscape Ecological Connectivity	X	X	X	X	X	X	X	X	X	X	X		X
	Landscape Hydrological Connectivity	X	X	X	X		X	X		X	X	X	X	X
	Longitudinal watershed connectivity	X	X	X				X	X	X				X
	Sustain biological productivity downstream	X	X		X	X	X	X		X		X		X

Broad Category of Function, Service, or Value[**]	**Specific Function, Service, or Value**	(Levick et al., 2008)	(Meyer et al., 2003)	(Nadeau & Rains, 2007)	(Smith et al., 1995)[*]	(Brinson et al., 1995)[*]	(Noble et al., 2010)	(U.S. Evironmental Protection Agency, 2015)	(Vyverberg, 2010)	(Harman et al., 2012)	(Stein et al., 2011)	(Rowe et al., 2009)	(James H. Thorp et al., 2010)	(Fischenich, 2006)
	Surface and Subsurface Water Connections	X	X					X		X				X
	Sediment Transport/Storage/Deposition for Lateral Floodplain maintenance/development	X		X				X		X		X		X
Energy	Energy Dissipation	X			X[h]	X[h]	X[h]			X				X
Groundwater Recharge	Groundwater Recharge	X	X	X		X		X		X	X		X	
Regulation	Regulation of Flow regimes	X	X				X	X		X		X		X
	Regulation of sedimentation rates	X	X	X			X	X		X	X			
	Regulation of peak flows downstream	X			X[h]	X[h]		X			X			X
	Moderation of GW flow/discharge				X[h]	X[h]		X		X				

Broad Category of Function, Service, or Value[**]	**Specific Function, Service, or Value**	(Levick et al., 2008)	(Meyer et al., 2003)	(Nadeau & Rains, 2007)	(Smith et al., 1995)[*]	(Brinson et al., 1995)[*]	(Noble et al., 2010)	(U.S. Evironmental Protection Agency, 2015)	(Vyverberg, 2010)	(Harman et al., 2012)	(Stein et al., 2011)	(Rowe et al., 2009)	(James H. Thorp et al., 2010)	(Fischenich, 2006)
	Regulation of erosive conditions						X	X		X	X			X
	Regulation of OM downstream transport					X[h]	X[h]	X		X				
	Regulation of Nutrient downstream transport					X[h]	X[h]	X						X
Diversity	Biodiversity, create/maintain	X	X	X	X			X	X	X	X		X	X
	Support Wildlife Diversity vs uplands	X												
	Support Vegetation Diversity In-Channel vs uplands	X												
Habitat	General Support/Maintenance of Plant Communities (Habitat)	X	X	X	X			X		X	X	X		X

Broad Category of Function, Service, or Value[**]	**Specific Function, Service, or Value**	(Levick et al., 2008)	(Meyer et al., 2003)	(Nadeau & Rains, 2007)	(Smith et al., 1995)[*]	(Brinson et al., 1995)[*]	(Noble et al., 2010)	(U.S. Evironmental Protection Agency, 2015)	(Vyverberg, 2010)	(Harman et al., 2012)	(Stein et al., 2011)	(Rowe et al., 2009)	(James H. Thorp et al., 2010)	(Fischenich, 2006)
	General Maintenance/Support of Wildlife (fauna) Habitat	X	X	X	X			X	X	X	X	X		X
	Microbial Habitat	X	X	X				X		X				X
	Primary Productivity support	X				X		X		X		X	X	X
	Maintain characteristic plant communities					X	X	X		X		X	X	
	Maintain (plant) characteristic detrital biomass					X								
	Maintain (animal) habitat spatial structure					X				X				
	Maintain (animal) interspersion and connectivity					X		X		X				

Broad Category of Function, Service, or Value[**]	**Specific Function, Service, or Value**	(Levick et al., 2008)	(Meyer et al., 2003)	(Nadeau & Rains, 2007)	(Smith et al., 1995)[*]	(Brinson et al., 1995)[*]	(Noble et al., 2010)	(U.S. Evironmental Protection Agency, 2015)	(Vyverberg, 2010)	(Harman et al., 2012)	(Stein et al., 2011)	(Rowe et al., 2009)	(James H. Thorp et al., 2010)	(Fischenich, 2006)
	Maintain Distribution/Abundance of Invertebrates					X	X	X		X		X	X	X
	Maintain Distribution/Abundance of Vertebrates					X	X	X		X		X	X	X
	Supports downstream food webs			X	X	X	X	X		X		X		X
	Species/genetic diversity support	X				X	X	X		X		X		X
	Maintenance of soil seed banks	X						X						
	Support Biological crust habitat	X												
	Support Secondary Productivity					X		X				X	X	X
	Vegetative bank stabilization	X					X	X		X				
Wildlife Habitat Uses	Wildlife Migration Corridors	X				X		X			X	X		X
	Wildlife Movement Corridors	X	X		X	X		X		X	X			X

Broad Category of Function, Service, or Value**	Specific Function, Service, or Value	(Levick et al., 2008)	(Meyer et al., 2003)	(Nadeau & Rains, 2007)	(Smith et al., 1995)*	(Brinson et al., 1995)*	(Noble et al., 2010)	(U.S. Evironmental Protection Agency, 2015)	(Vyverberg, 2010)	(Harman et al., 2012)	(Stein et al., 2011)	(Rowe et al., 2009)	(James H. Thorp et al., 2010)	(Fischenich, 2006)
	Wildlife Forage	X	X				X	X		X	X			X
	Wildlife Cover/Shelter/Shade/Refuge	X	X	X		X	X	X		X	X			X
	Wildlife Nesting/Spawning/Breeding	X	X	X		X	X	X		X	X	X		X
	Wildlife/Invertebrate Life Cycle support	X	X	X				X		X	X			X
Storage	Surface and/or Subsurface Water Storage; Short/Long-term	X	X		X[h]	X[h]		X		X		X	X	X
	Seed Bank Source	X				X		X						
	Sediment/particulate storage/reduction in loading	X	X		X	X	X	X		X	X		X	X
	Elements and compounds storage	X						X						X

Broad Category of Function, Service, or Value[**]	**Specific Function, Service, or Value**	(Levick et al., 2008)	(Meyer et al., 2003)	(Nadeau & Rains, 2007)	(Smith et al., 1995)[*]	(Brinson et al., 1995)[*]	(Noble et al., 2010)	(U.S. Evironmental Protection Agency, 2015)	(Vyverberg, 2010)	(Harman et al., 2012)	(Stein et al., 2011)	(Rowe et al., 2009)	(James H. Thorp et al., 2010)	(Fischenich, 2006)
	OM storage/Carbon sequestration	X	X	X		X	X	X		X			X	
	Nutrient Storage	X	X			X	X	X		X		X		
Source	Groundwater Discharge	X				X		X		X				
	Water Runoff Supply (Source)	X	X				X	X						
	Subsurface Water Supply	X						X						
	Sediment Source	X						X		X				
	Nutrient/Dissolved Nitrogen Source	X		X		X	X	X		X				X
	Organic Matter/Dissolved organic carbon/Coarse particulate OM Source	X	X	X		X	X	X		X				
	Seed Source	X				X		X						
Transport	Water Transport/Maintain base flows and seasonal flows	X	X			X	X[h]	X	X	X	X	X		X

Broad Category of Function, Service, or Value[**]	**Specific Function, Service, or Value**	(Levick et al., 2008)	(Meyer et al., 2003)	(Nadeau & Rains, 2007)	(Smith et al., 1995)[*]	(Brinson et al., 1995)[*]	(Noble et al., 2010)	(U.S. Evironmental Protection Agency, 2015)	(Vyverberg, 2010)	(Harman et al., 2012)	(Stein et al., 2011)	(Rowe et al., 2009)	(James H. Thorp et al., 2010)	(Fischenich, 2006)
	Nutrient Transport via Surface/Subsurface flows	X		X	X			X	X	X	X			
	Elements and compounds	X						X						
	OM/debris/organic carbon transport	X	X	X	X		X	X	X	X				
	Sediment Transport; water/aeolian	X						X	X	X	X			X
	Suspended/Dissolved Chemical Constituent Transport	X						X						
	Plant propagules/seed export					X		X						X
Water Quality	Water Quality Improvement	X	X		X	X	X	X		X				X
	Water Quality-Filtering	X				X					X			
	Particulate Detention	X	X			X		X		X	X			X
	Removal/Detention of Imported Elements and Compounds	X	X			X		X						X

Broad Category of Function, Service, or Value[**]	**Specific Function, Service, or Value**	(Levick et al., 2008)	(Meyer et al., 2003)	(Nadeau & Rains, 2007)	(Smith et al., 1995)[*]	(Brinson et al., 1995)[*]	(Noble et al., 2010)	(U.S. Evironmental Protection Agency, 2015)	(Vyverberg, 2010)	(Harman et al., 2012)	(Stein et al., 2011)	(Rowe et al., 2009)	(James H. Thorp et al., 2010)	(Fischenich, 2006)
	Nitrogen/Phosphorous Retention	X	X					X		X				
	Maintain/regulate water temperature/oxygen				X	X	X	X		X		X		X
	Removal/Storage of suspended sediment	X	X			X	X	X						X
Biogeochemical/Cycling	Nutrient Transformation/Cycling/Spiraling	X	X		X	X	X	X		X	X	X	X	X
	Cycling/Transformation of elements and Compounds	X			X			X		X		X		X
	OM breakdown/transformation/export	X	X			X		X		X		X		
	Dissolved Constituents biogeochemical processing			X	X			X		X				X

Broad Category of Function, Service, or Value[**]	**Specific Function, Service, or Value**	(Levick et al., 2008)	(Meyer et al., 2003)	(Nadeau & Rains, 2007)	(Smith et al., 1995)[*]	(Brinson et al., 1995)[*]	(Noble et al., 2010)	(U.S. Evironmental Protection Agency, 2015)	(Vyverberg, 2010)	(Harman et al., 2012)	(Stein et al., 2011)	(Rowe et al., 2009)	(James H. Thorp et al., 2010)	(Fischenich, 2006)
	Removal/Detention of (Imported) Elements and Compounds	X	X	X	X	X		X		X		X		X
	Particulate detention/retention	X	X	X	X	X		X		X		X		X
	Carbon cycling						X	X						
	Organic Carbon export				X	X		X		X				
Human Use/Value	Non-crop Food and fiber production												X	X
	Water Source/Supply	X						X			X		X	X
	Recreation	X			X			X		X		X	X	X
	Flood/hazard control	X	X					X	X				X	X
	Transportation												X	X
	Aesthetic	X			X			X				X	X	X
	Education				X								X	

Broad Category of Function, Service, or Value[**]	**Specific Function, Service, or Value**	(Levick et al., 2008)	(Meyer et al., 2003)	(Nadeau & Rains, 2007)	(Smith et al., 1995)[*]	(Brinson et al., 1995)[*]	(Noble et al., 2010)	(U.S. Evironmental Protection Agency, 2015)	(Vyverberg, 2010)	(Harman et al., 2012)	(Stein et al., 2011)	(Rowe et al., 2009)	(James H. Thorp et al., 2010)	(Fischenich, 2006)
	Cultural	X								X		X	X	

** The superscript "h" identifies multiple functions categorized by specific literature under a single overarching Hydrologic functions category.
*** Function redundancies have been retained for illustrative purposes

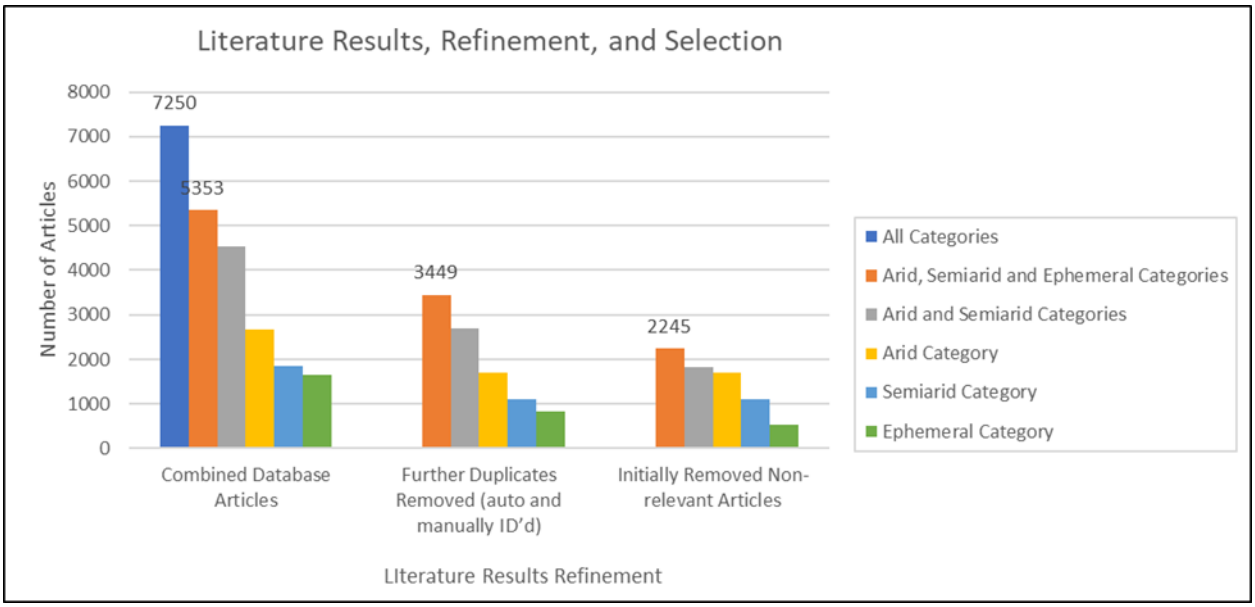


Figure 250. Comparison of initial literature results, refinement, and selection among select main search category terms and groupings.

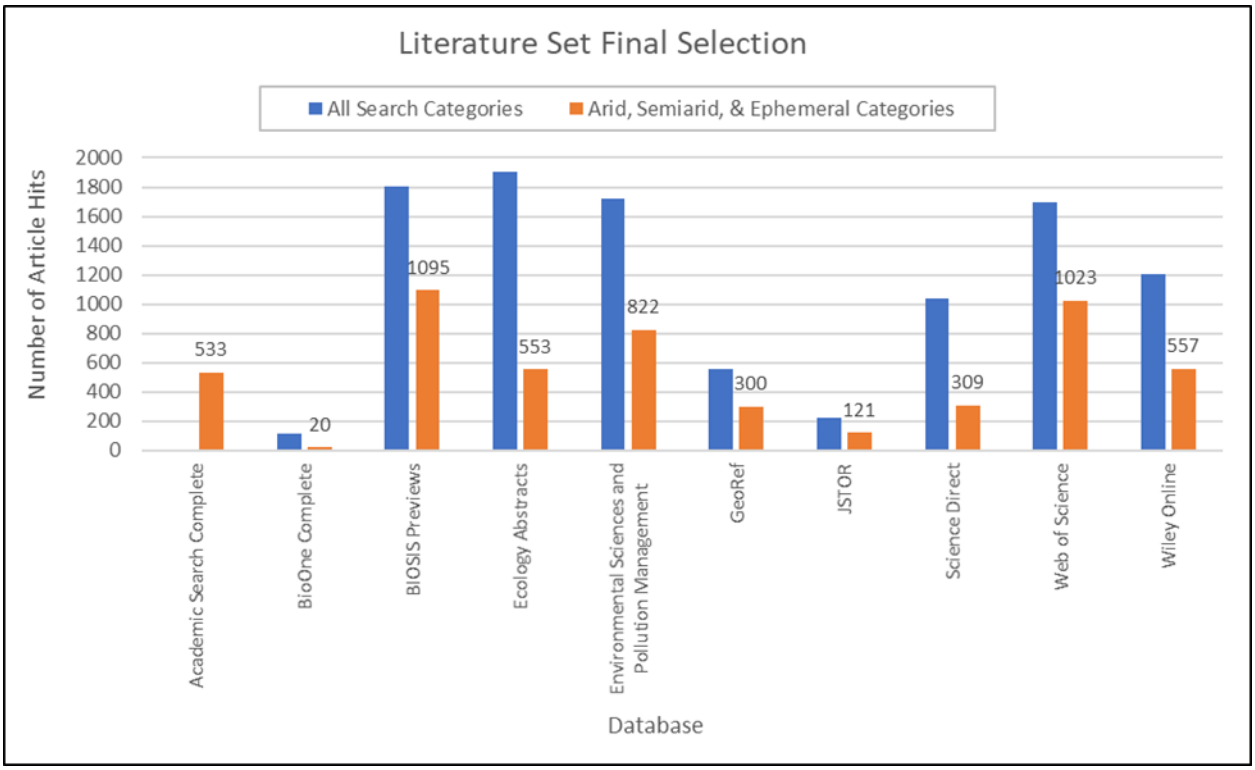


Figure 251. Comparison of selected main search term category results among all literature main search term results.

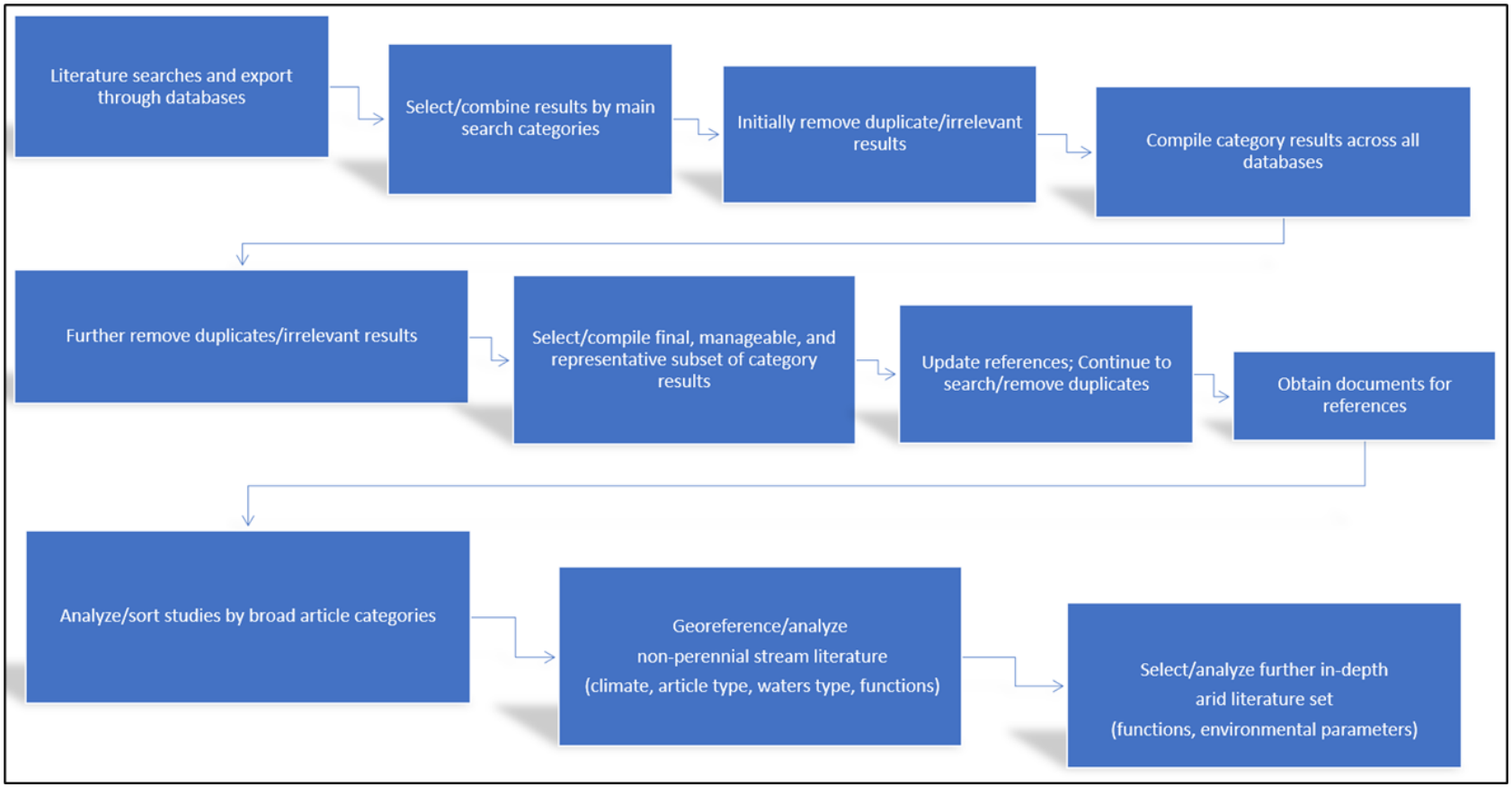


Figure 252. Flowchart of the process of literature gathering, selection, and analysis.

Appendix E: Supplemental Georeferencing Results of Non-Perennial Literature Across All Climate Types

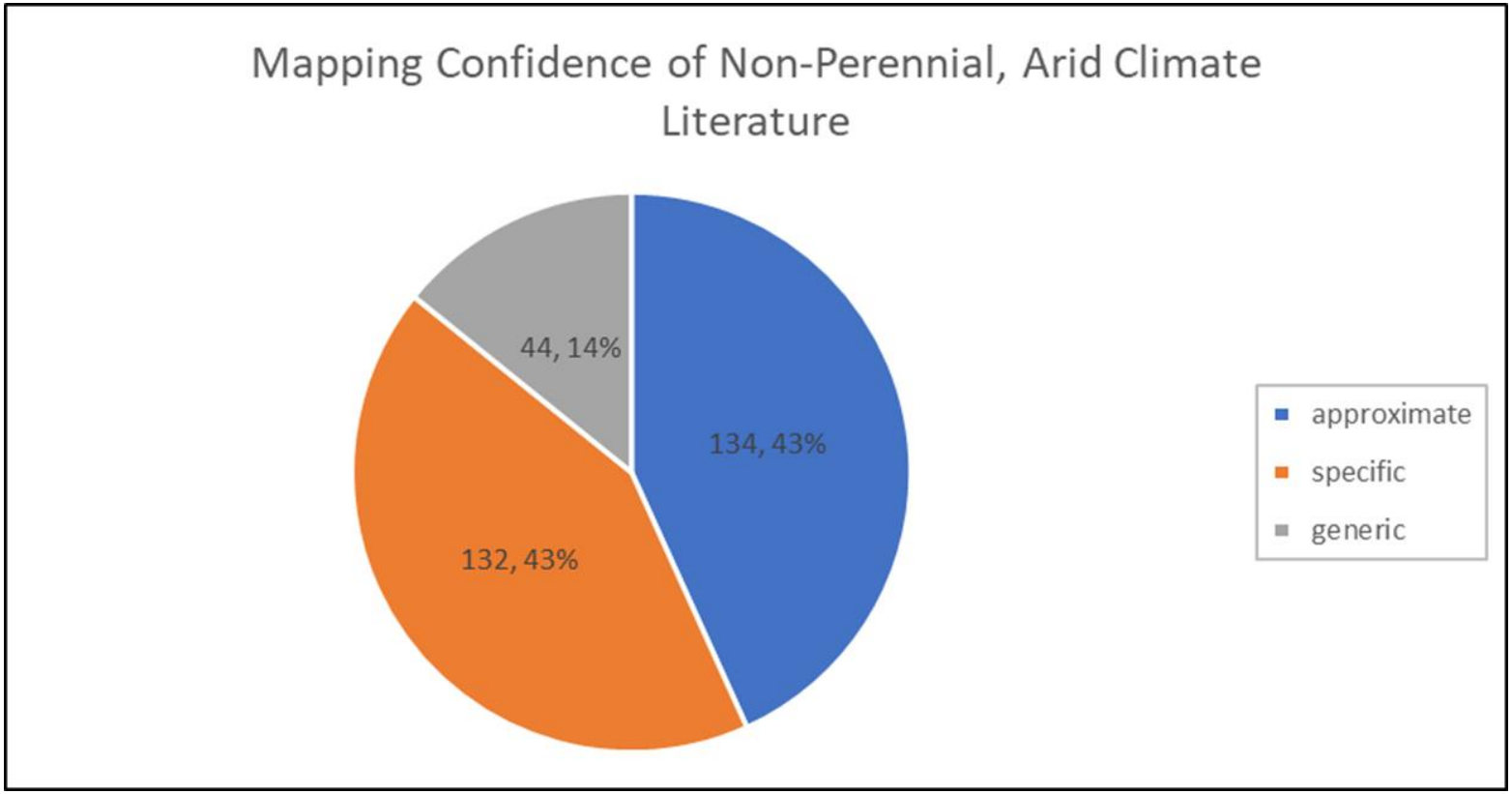


Figure 253. Mapping confidence of arid non-perennial literature study locations worldwide.

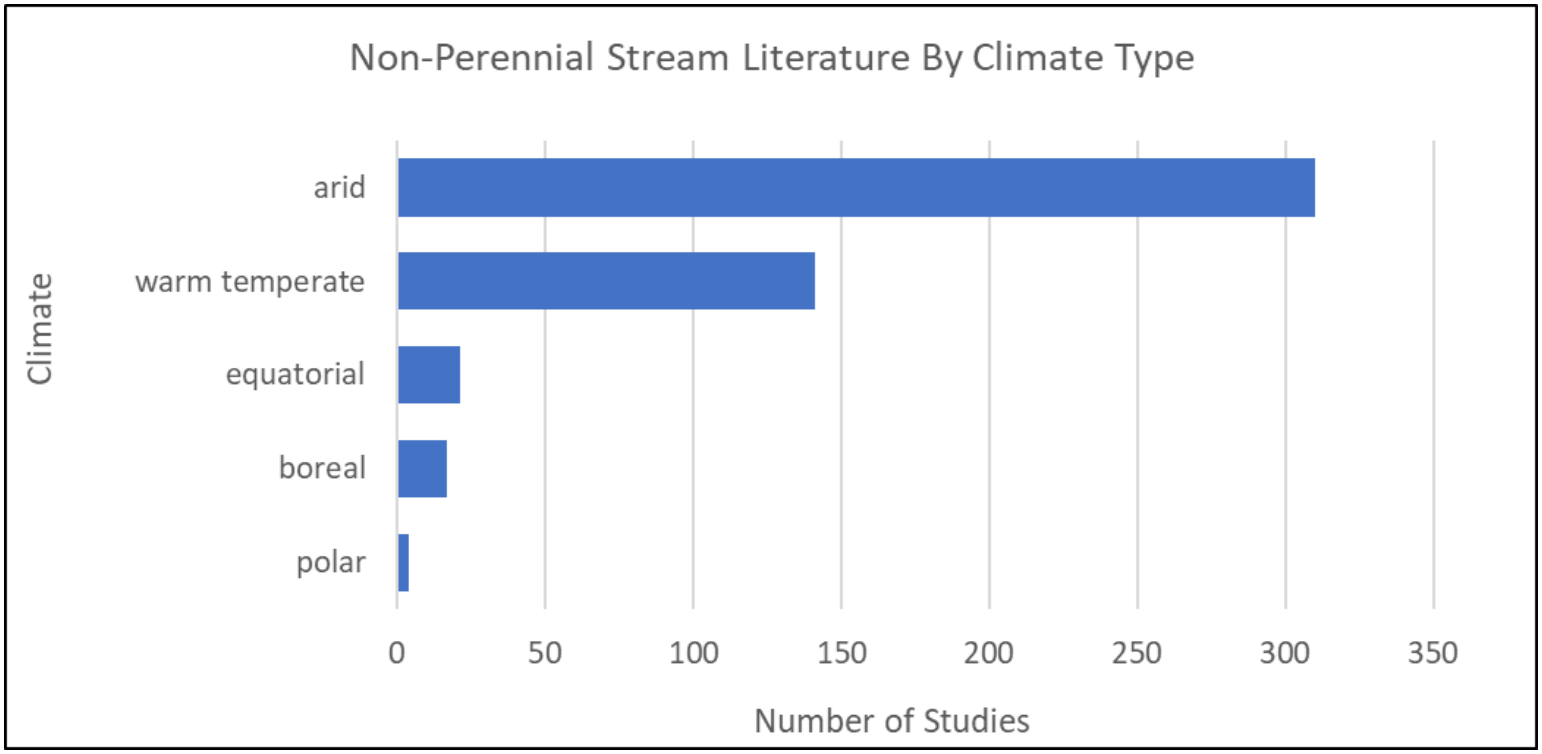


Figure 254. Breakdown of georeferenced non-perennial stream studies across all climate types worldwide.

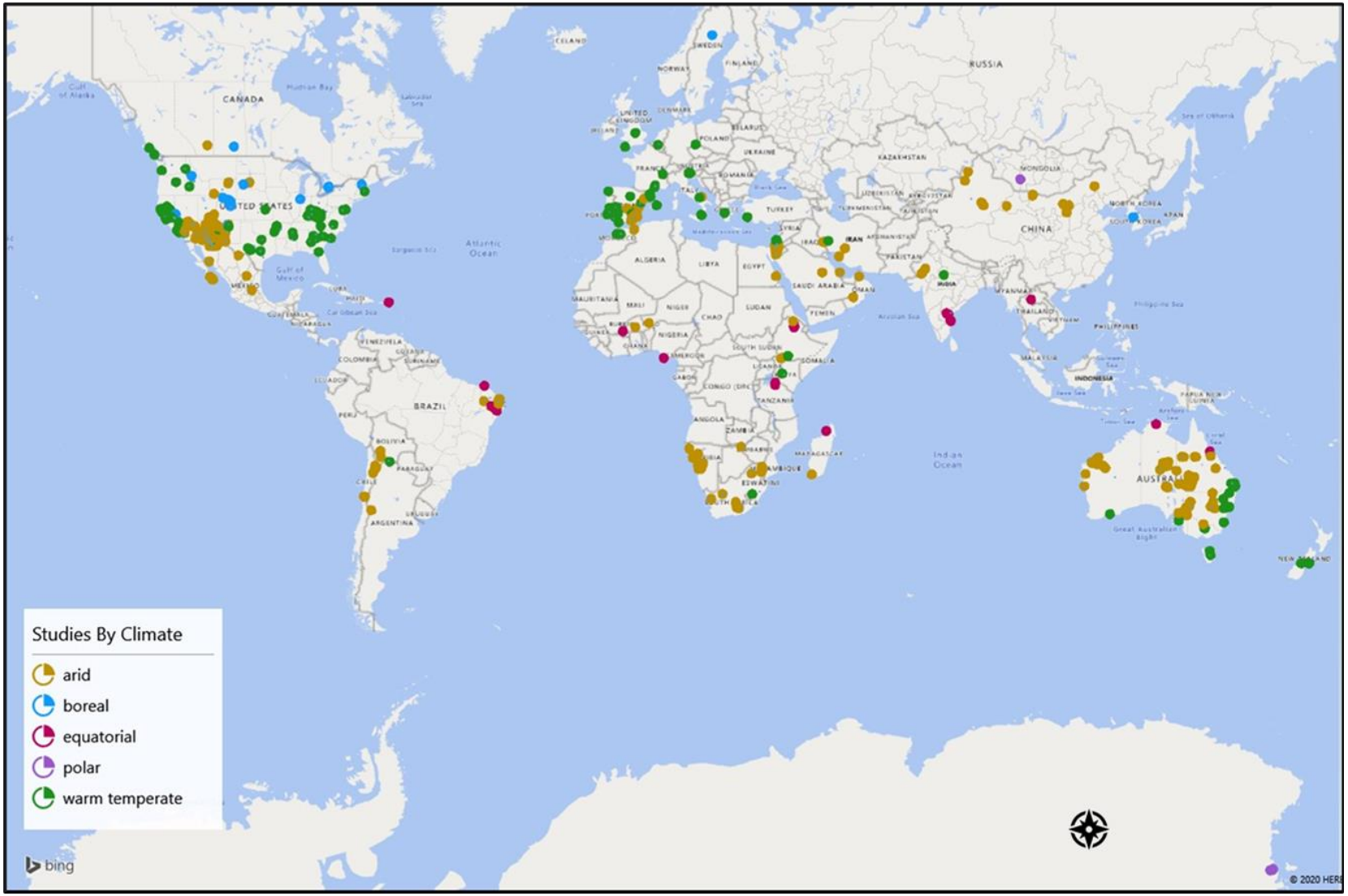


Figure 255. Georeferenced non-perennial stream study locations across all climate types worldwide.

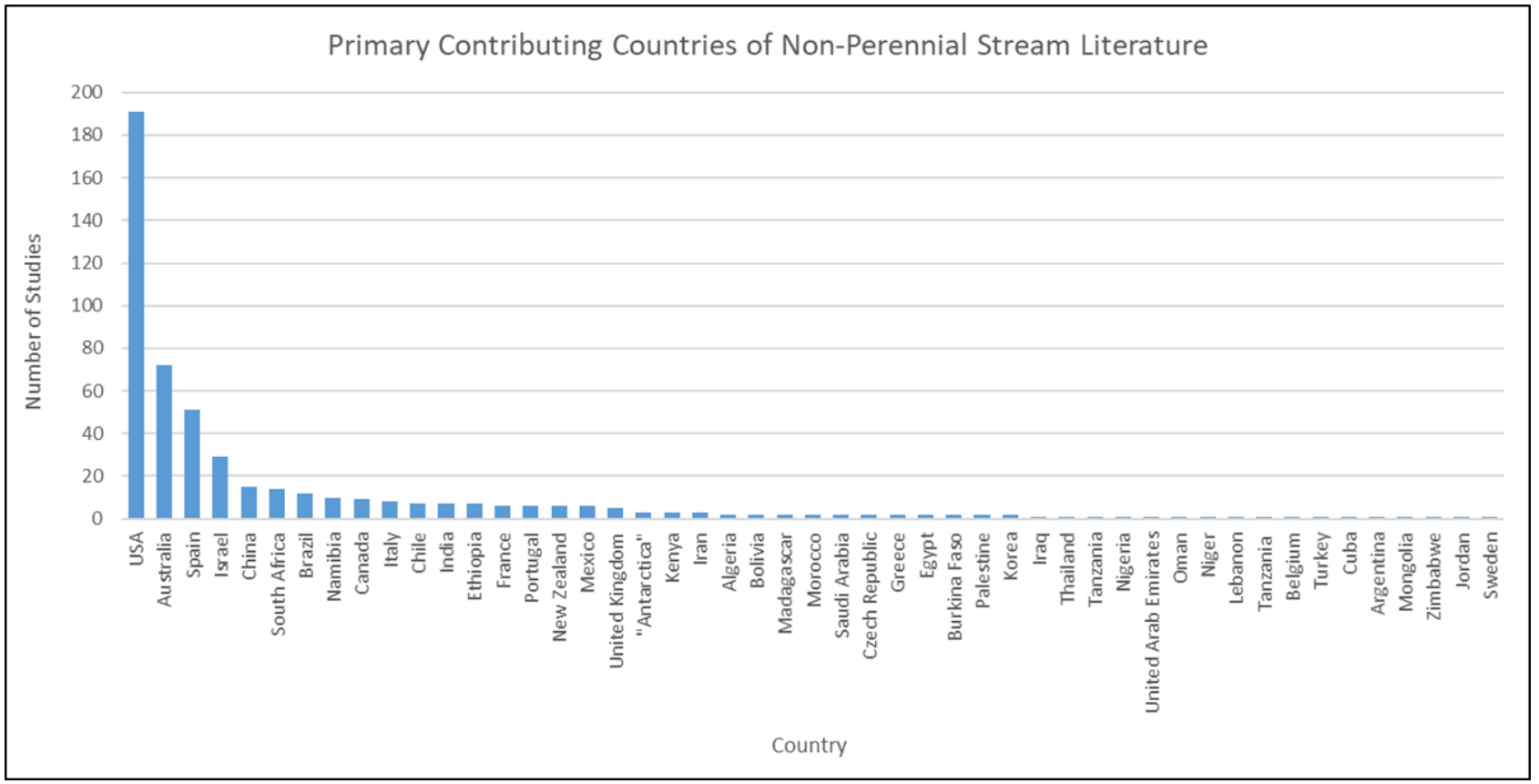


Figure 256. Contributions by country of non-perennial stream literature across all climate types worldwide.

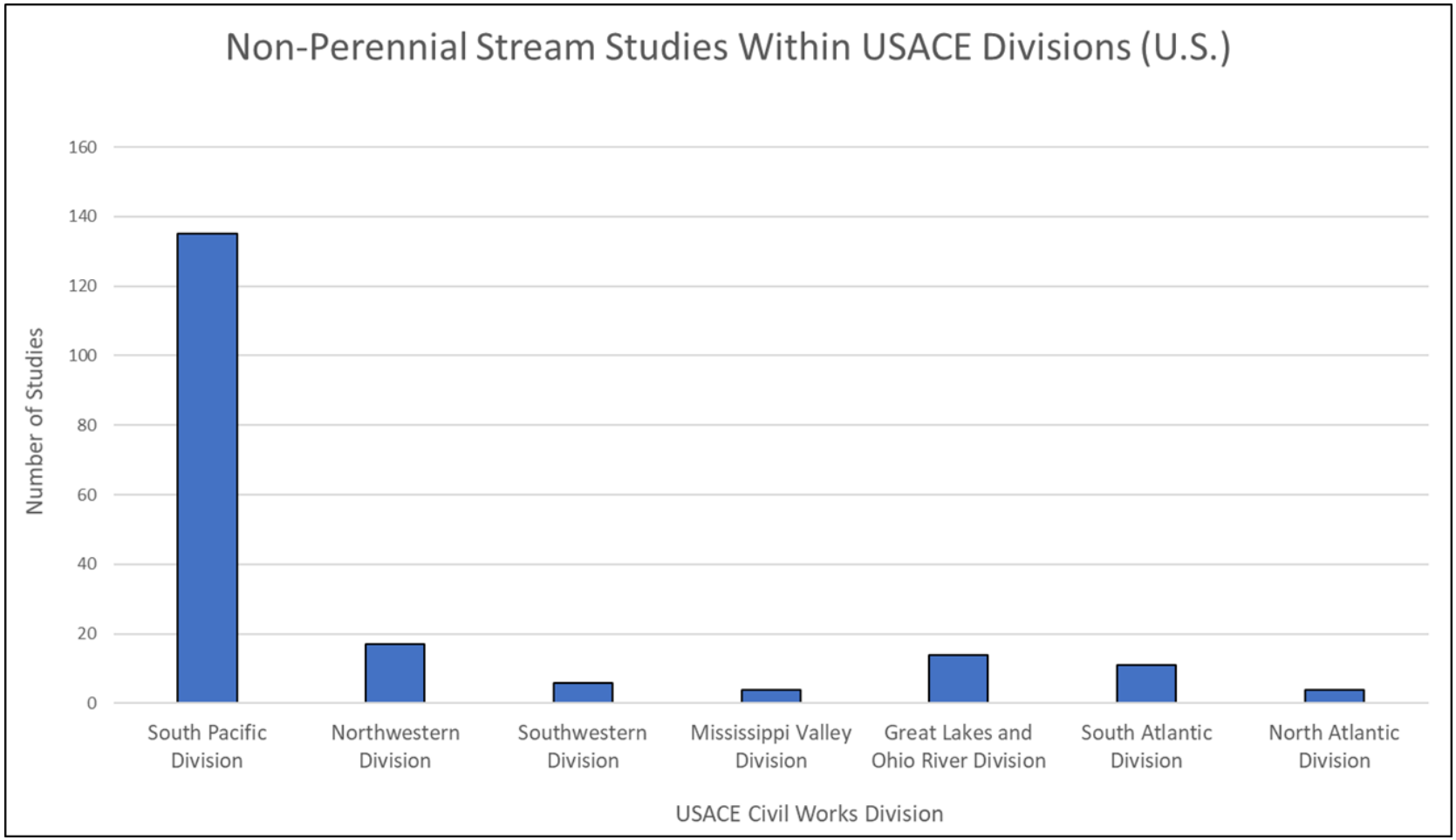


Figure 257. Non-perennial stream study locations by Corps Civil Works Division within the USA.

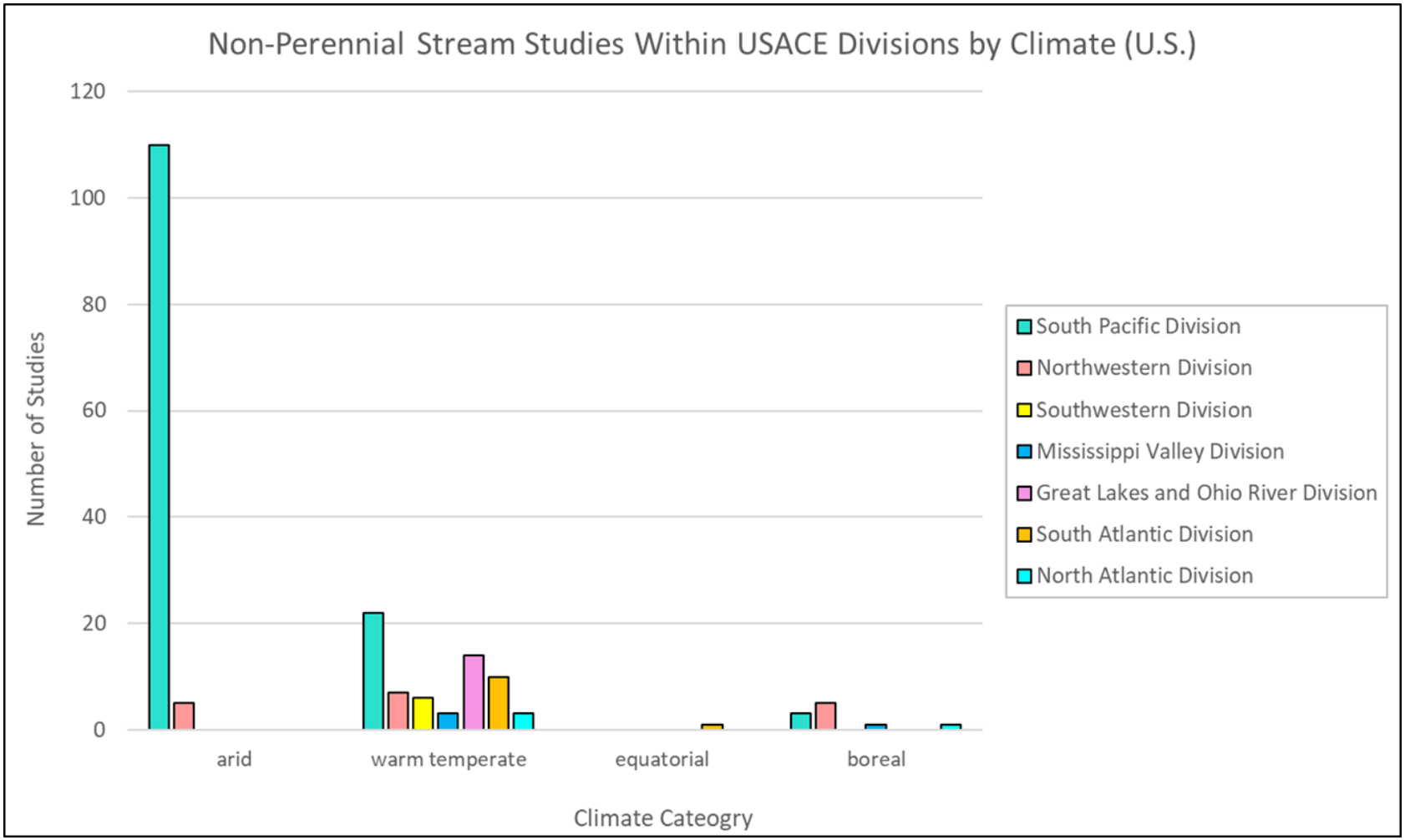


Figure 258. Non-perennial stream study locations by Corps Civil Works Divisions among all climate types, USA.

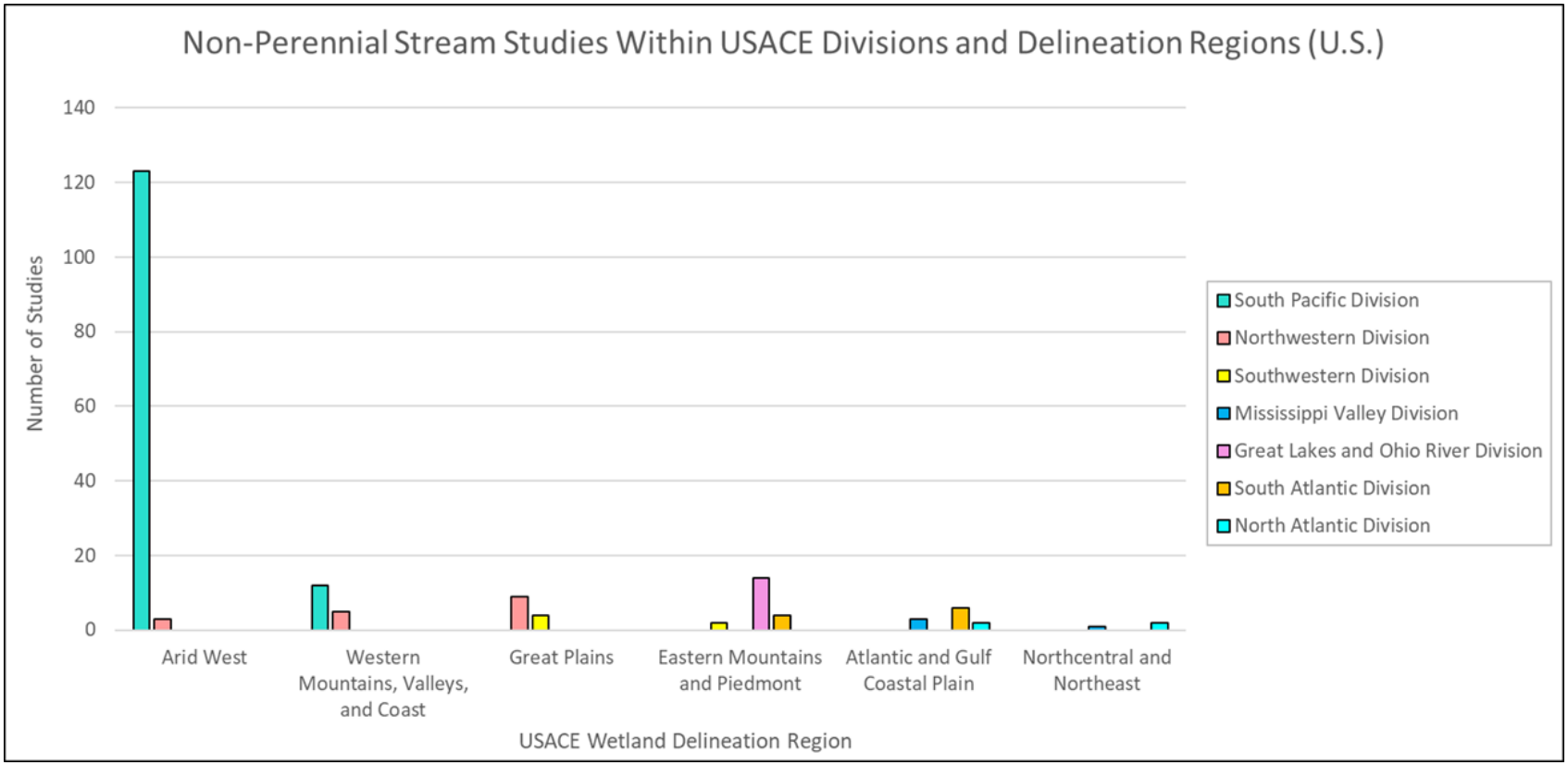


Figure 259. Non-perennial stream study locations comparison by Corps Civil Works Divisions among Corps delineation regions, USA.

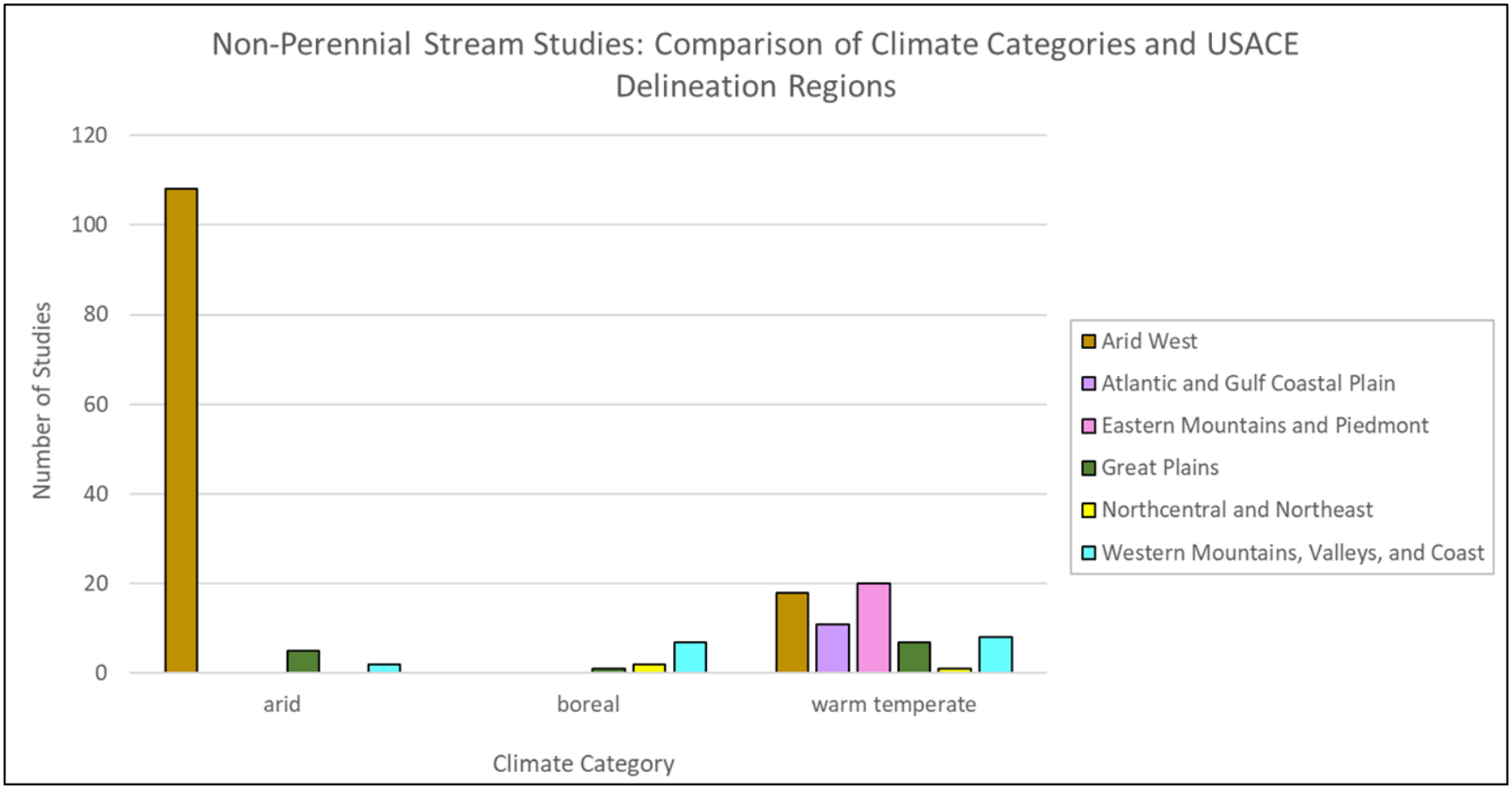


Figure 260. Non-perennial stream study locations comparison by Corps delineation regions and climate types, USA.

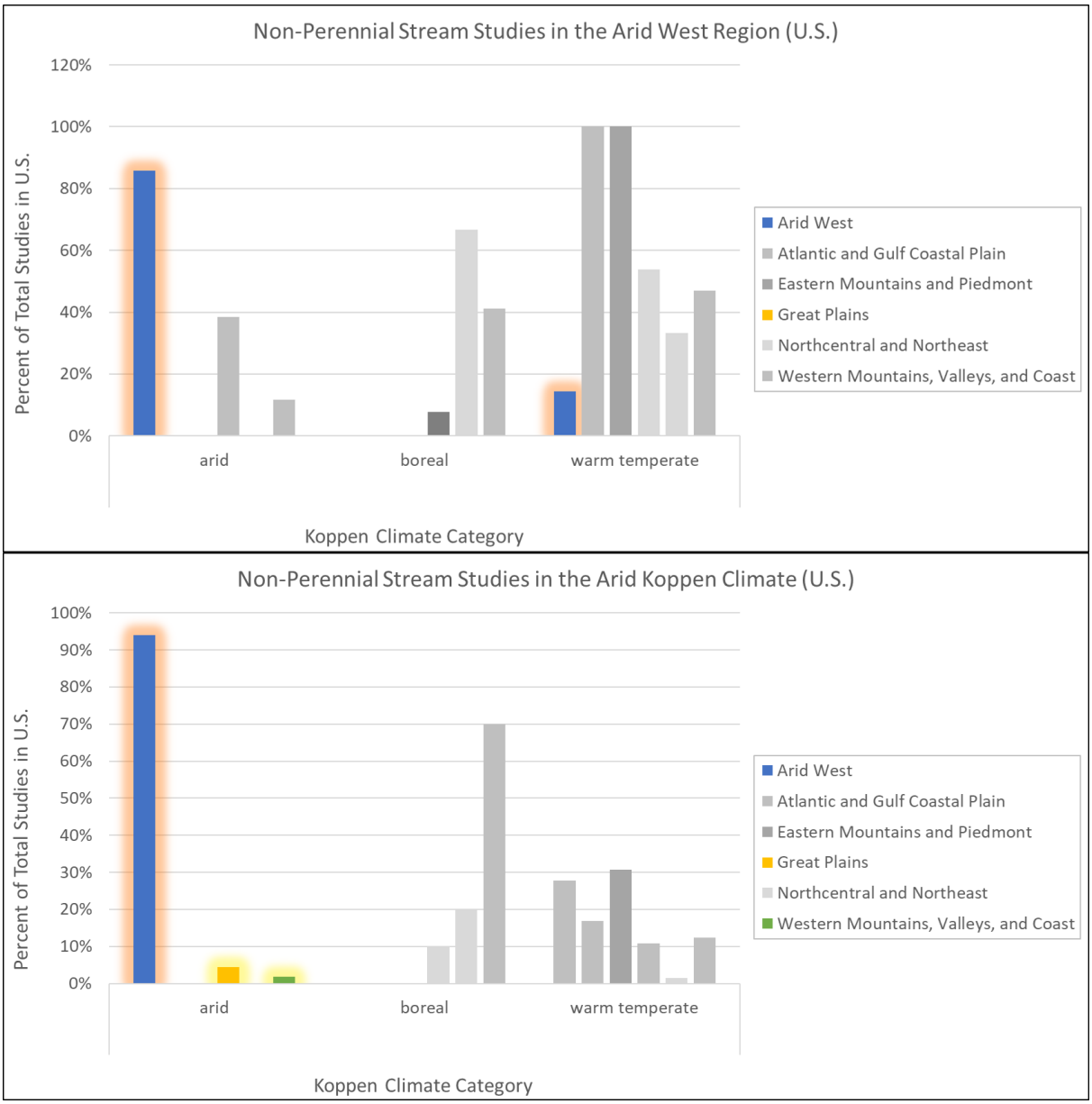


Figure 261. Non-perennial stream study locations comparison of Corps Arid West delineation region and Koppen-Geiger arid climate types, USA.

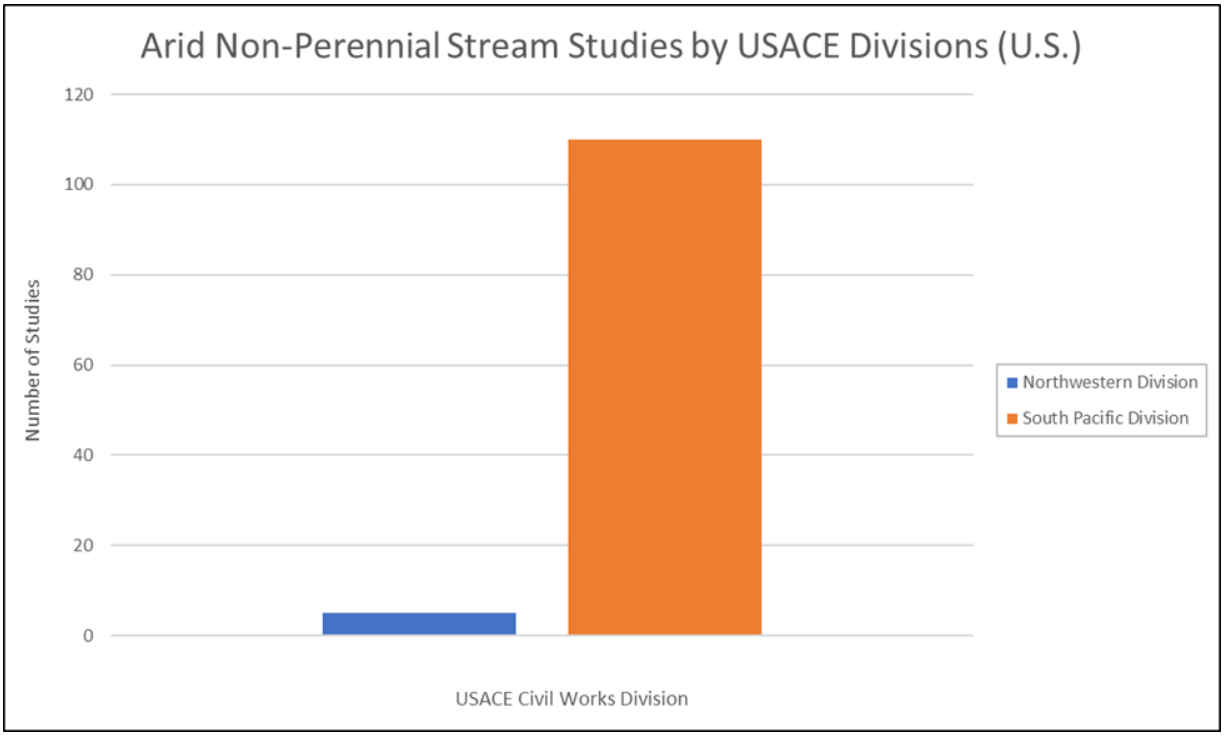


Figure 262. Non-perennial arid stream study locations by Corps Civil Works Divisions, USA.

Appendix F: Supplemental Functions Results of Arid Climate Non-Perennial Literature

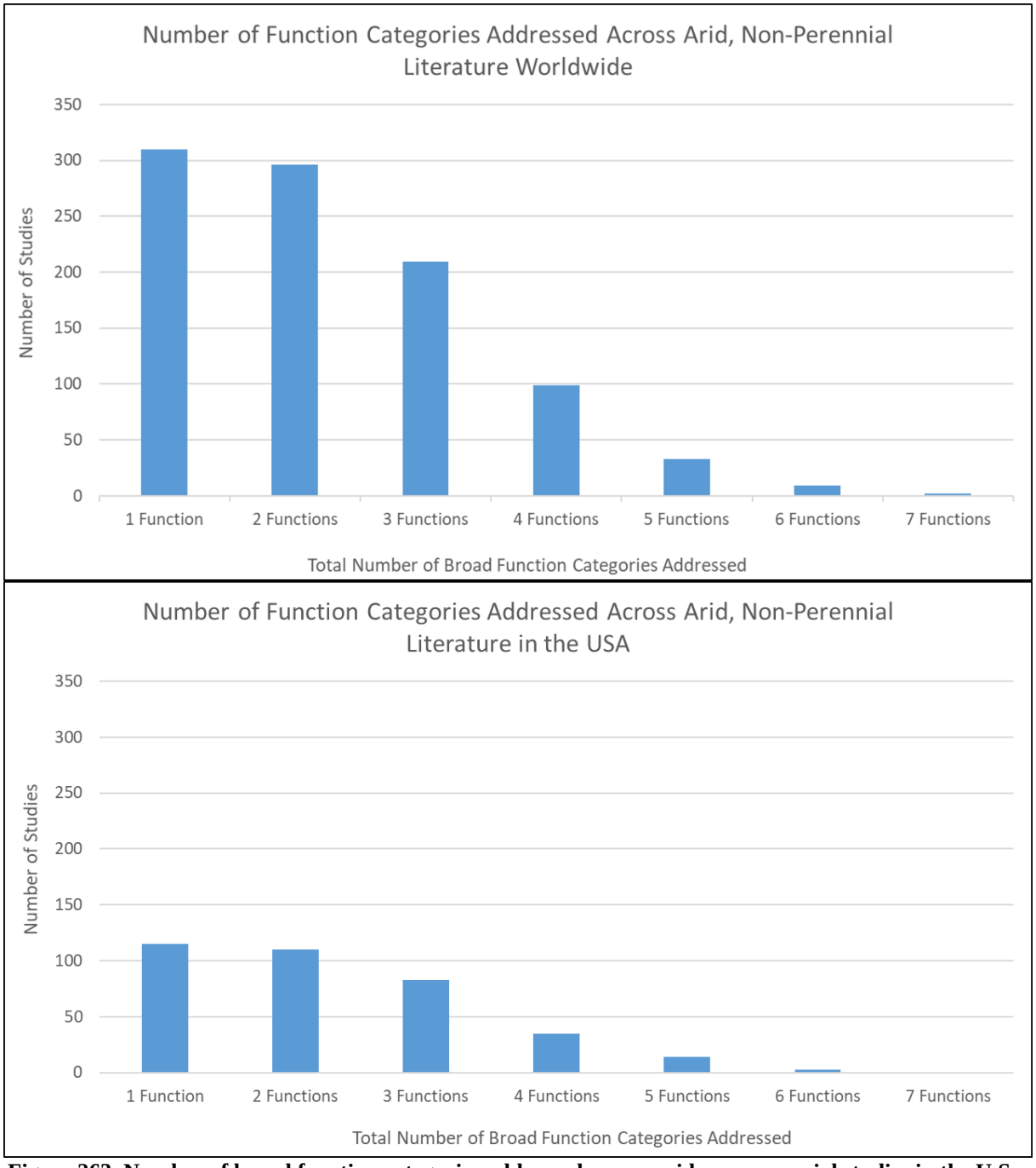
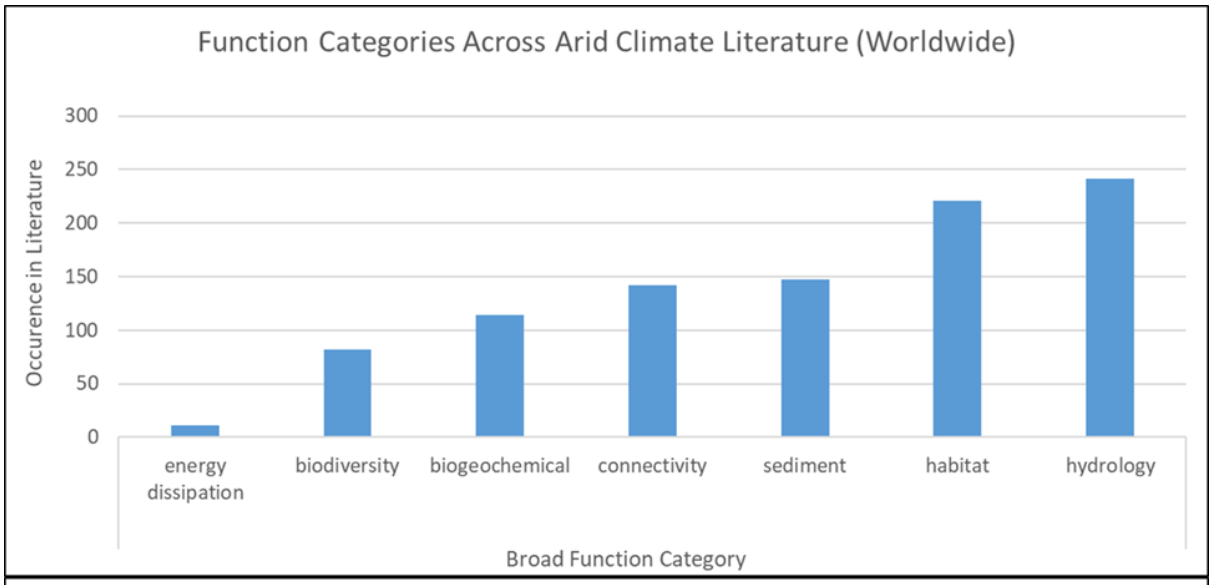


Figure 263. Number of broad function categories addressed across arid non-perennial studies in the U.S. (115) and worldwide (310, including U.S. studies).



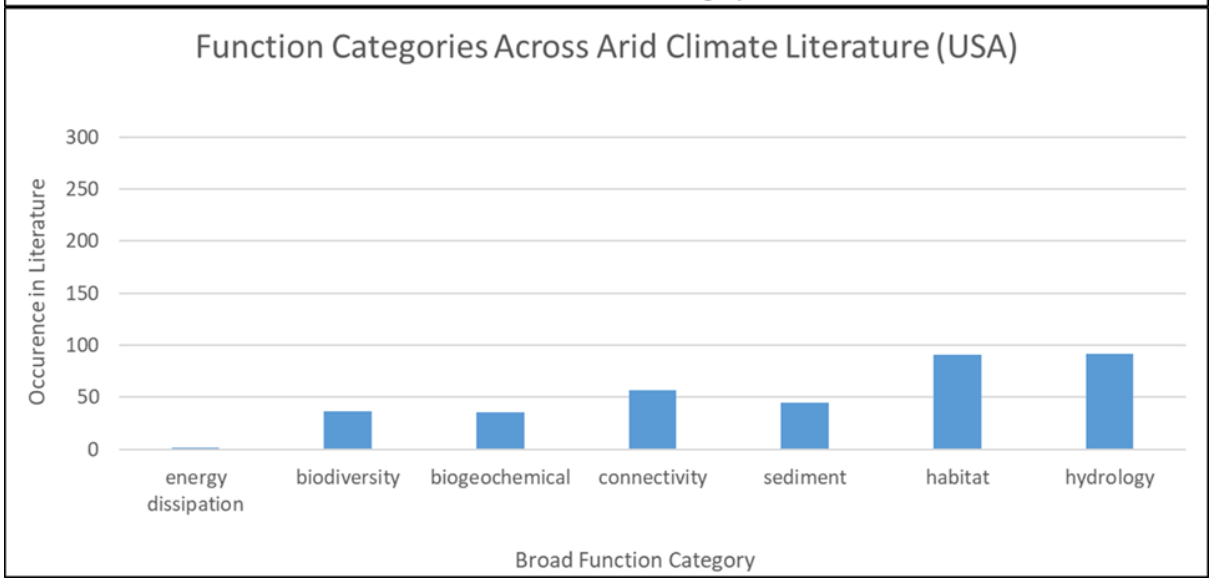


Figure 264. Occurrence of broad function categories addressed across all arid non-perennial studies in the U.S. and worldwide.

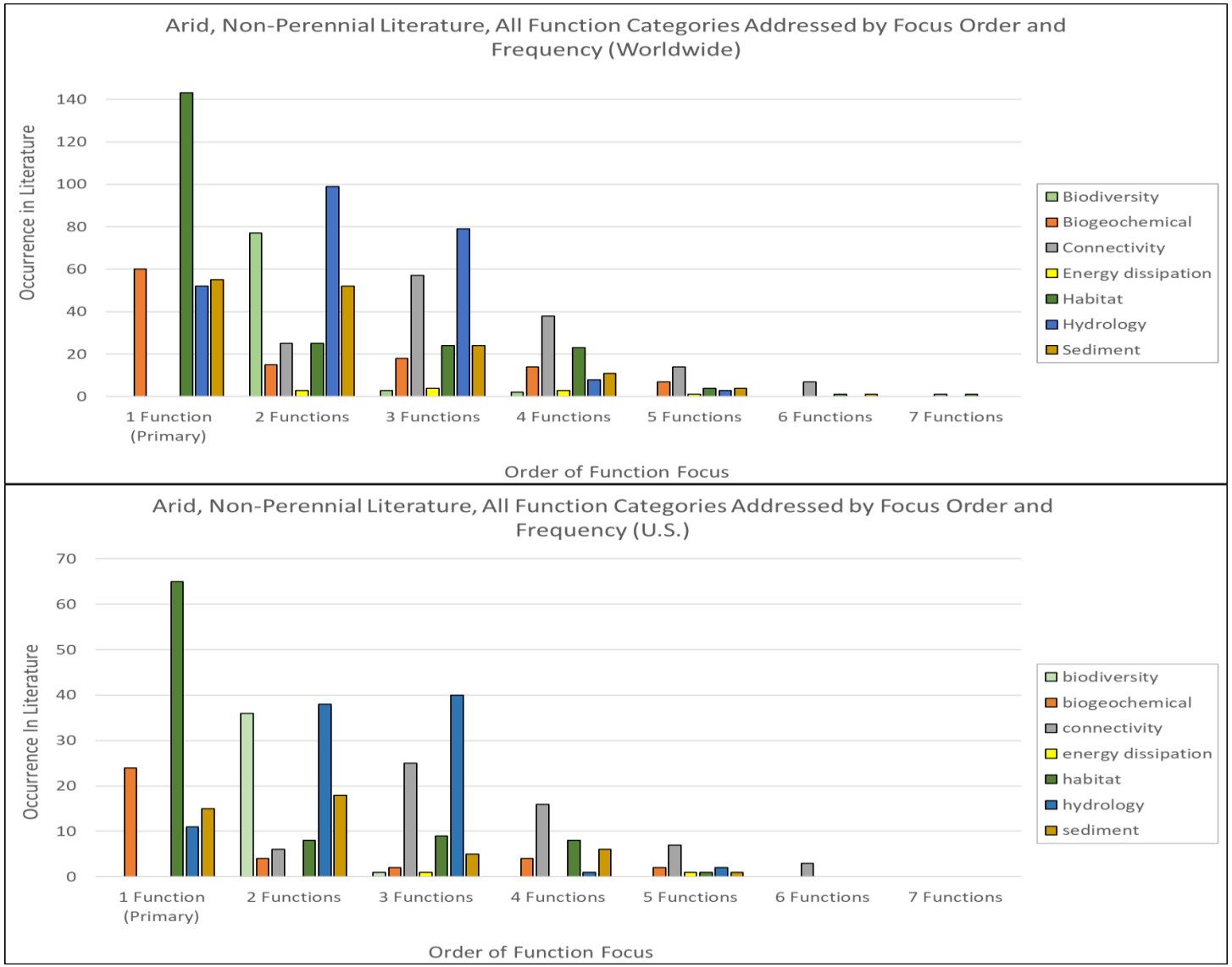


Figure 265. Primary function and other broad function category results across all global and U.S. arid literature.

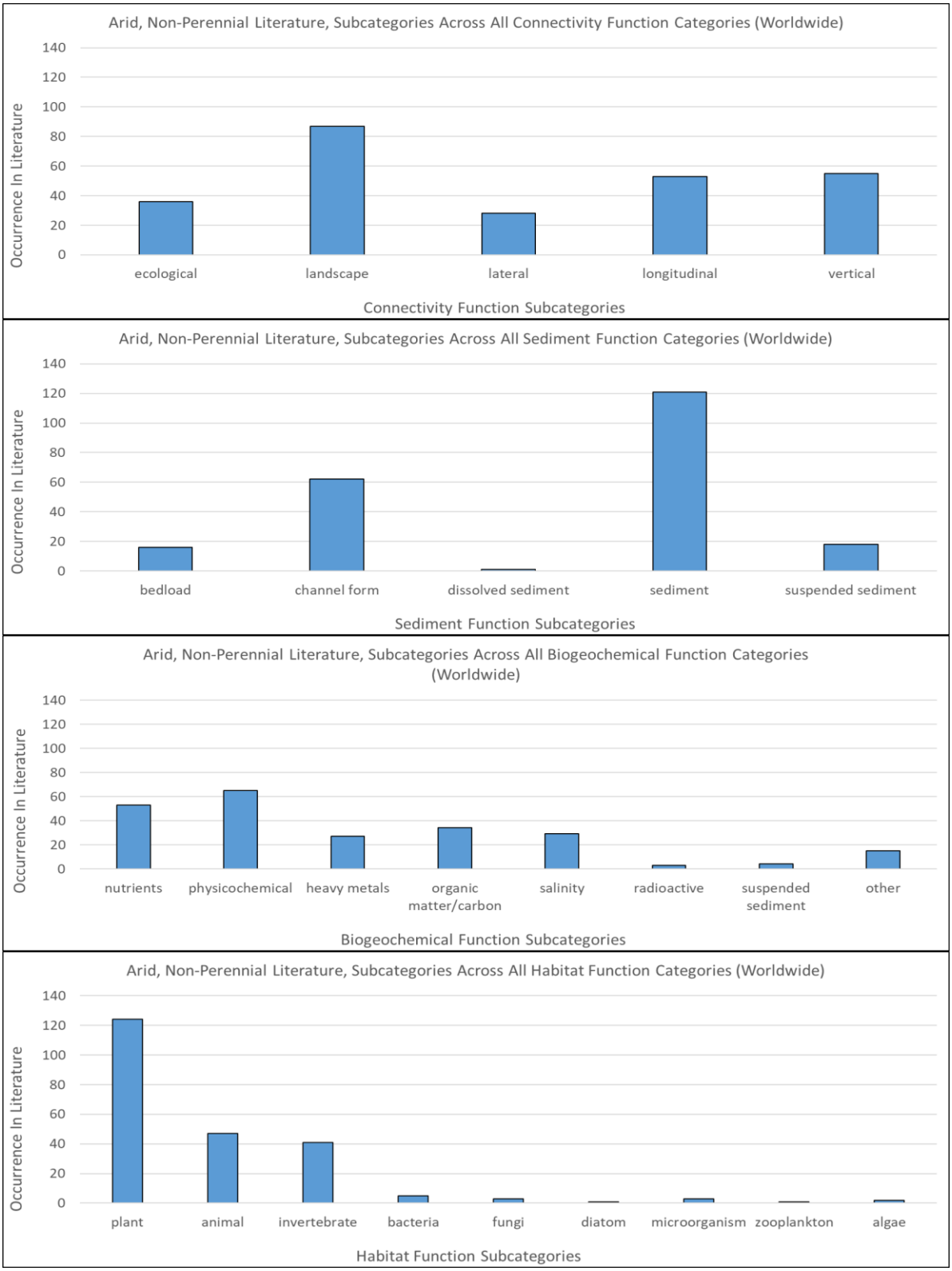


Figure 266. Occurrence of Habitat, Sediment, Biogeochemical, and Connectivity subcategories across arid non-perennial literature worldwide.

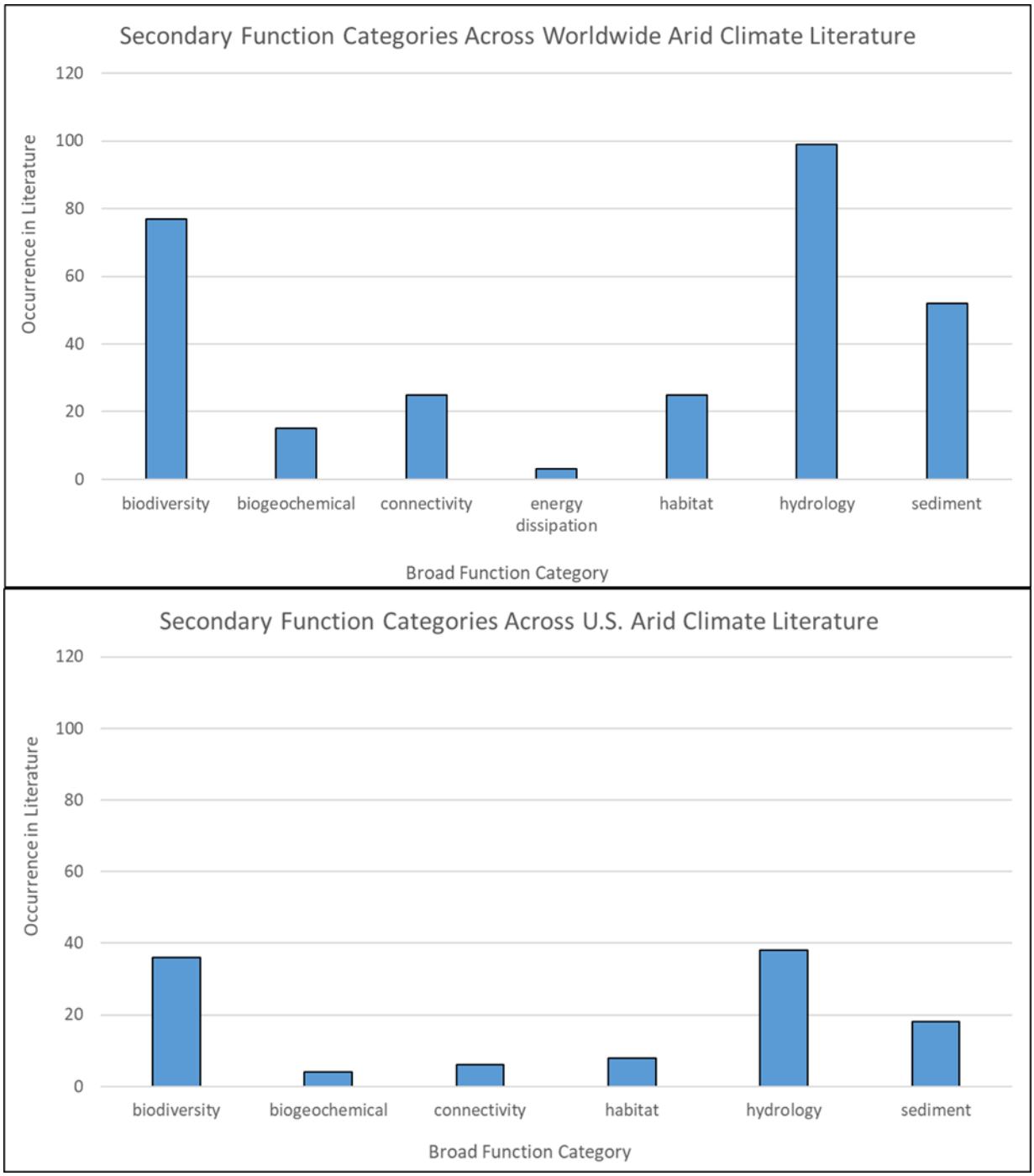


Figure 267. Occurrence of second recorded broad function categories across non-perennial arid literature worldwide and in the U.S.

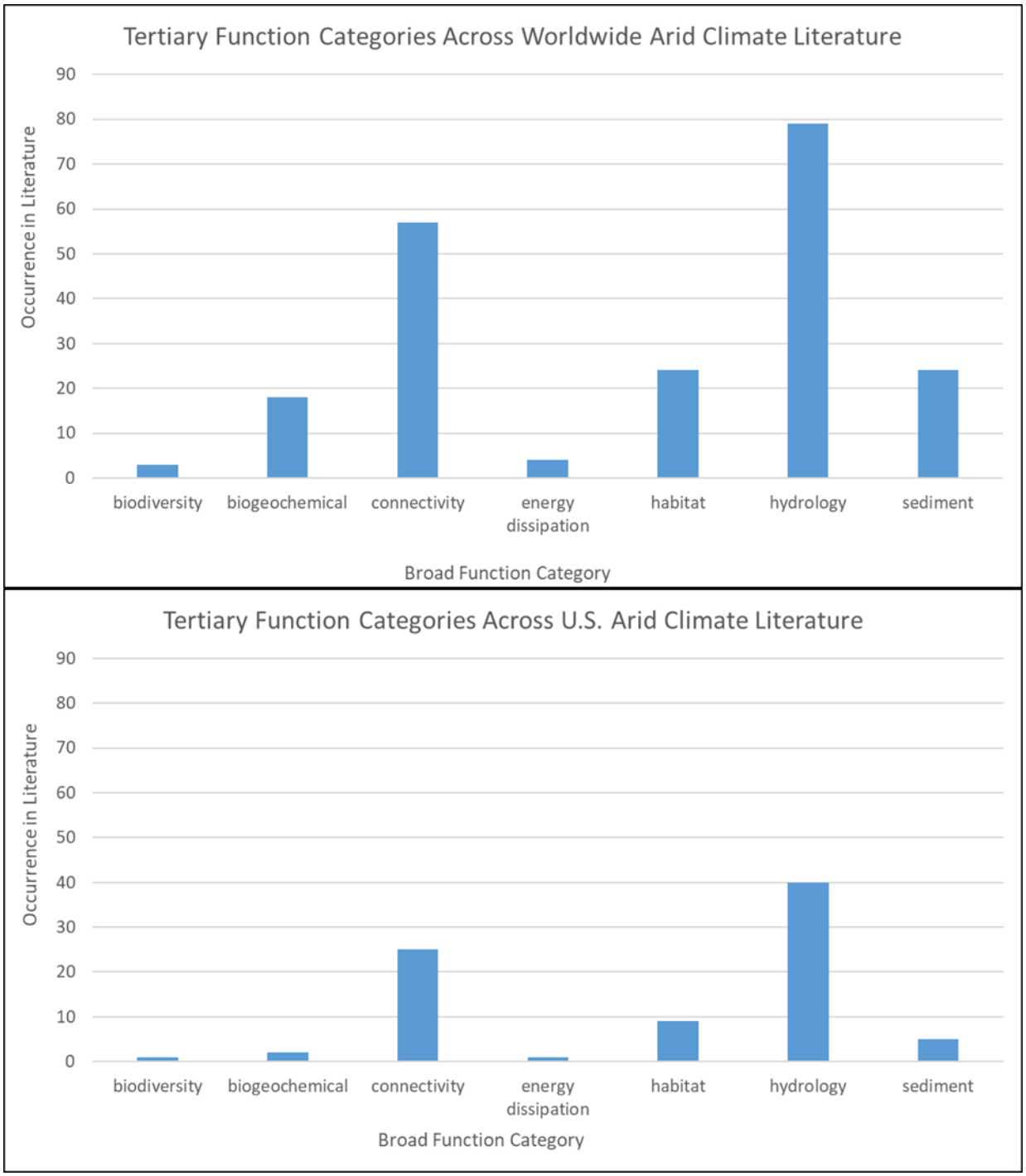


Figure 268. Occurrence of third recorded broad function categories across non-perennial arid literature worldwide and in the U.S.

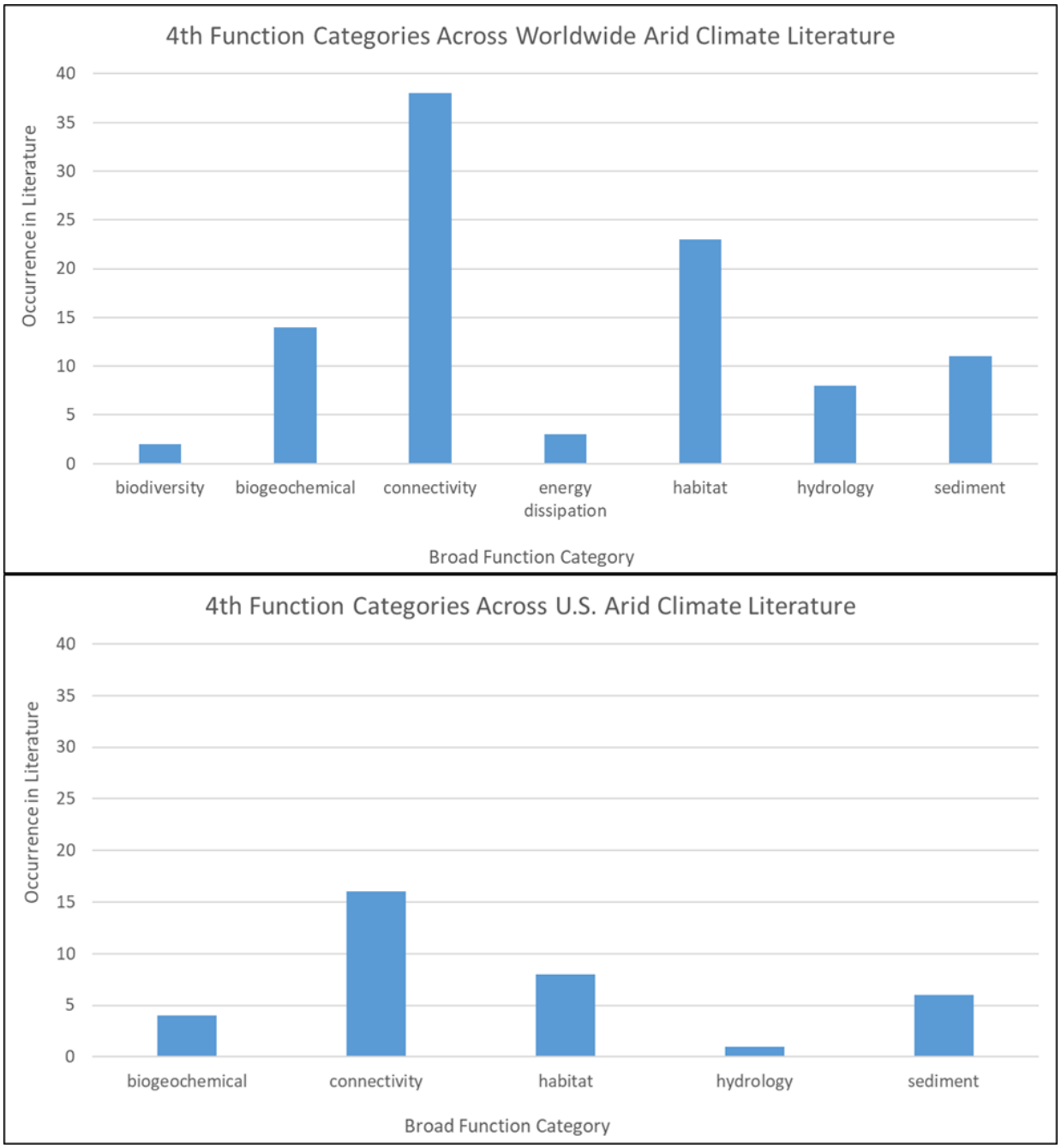


Figure 269. Occurrence of fourth recorded broad function categories across non-perennial arid literature worldwide and in the U.S.

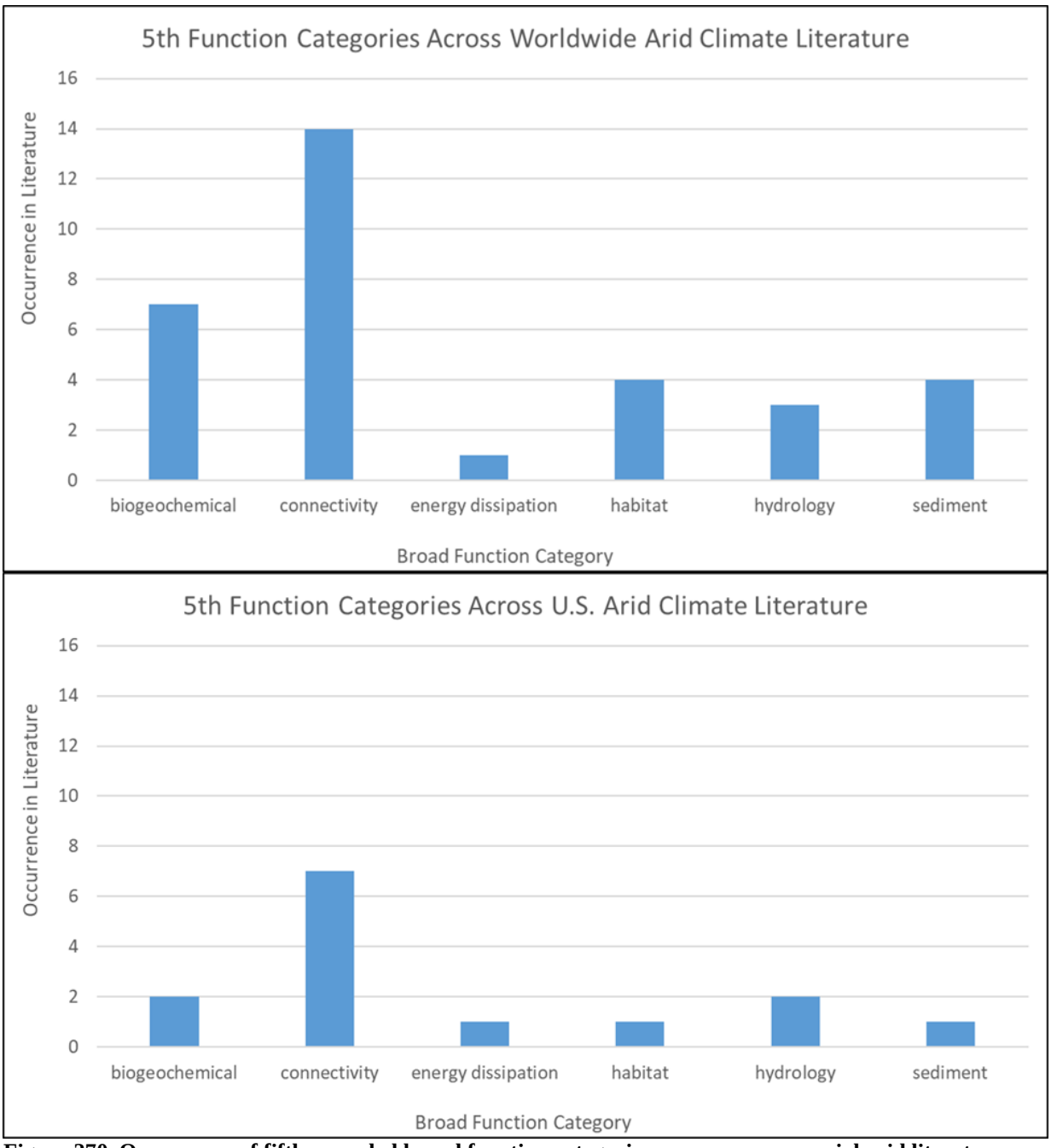


Figure 270. Occurrence of fifth recorded broad function categories across non-perennial arid literature worldwide and in the U.S.

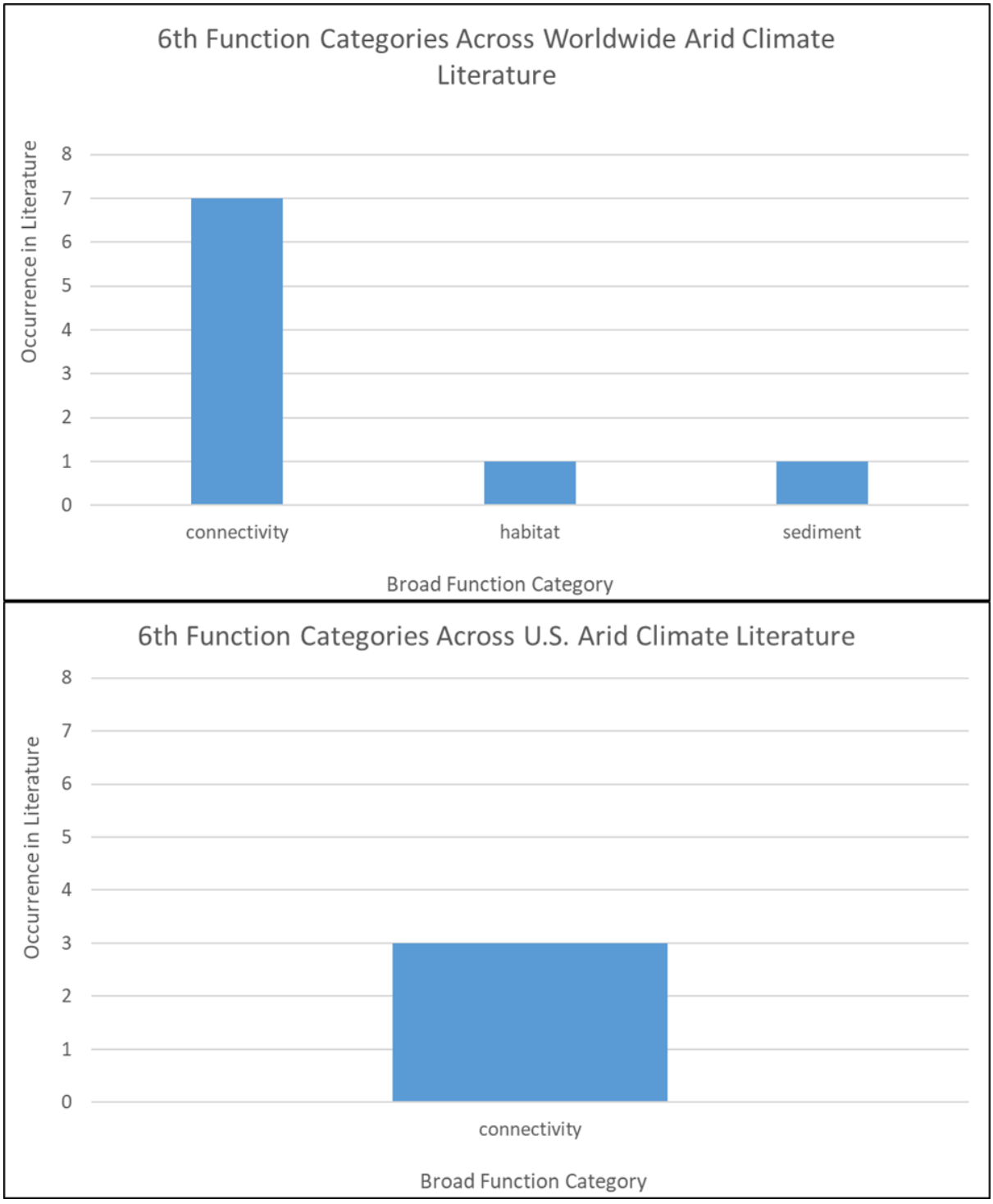


Figure 271. Occurrence of sixth recorded broad function categories across non-perennial arid literature worldwide and in the U.S.

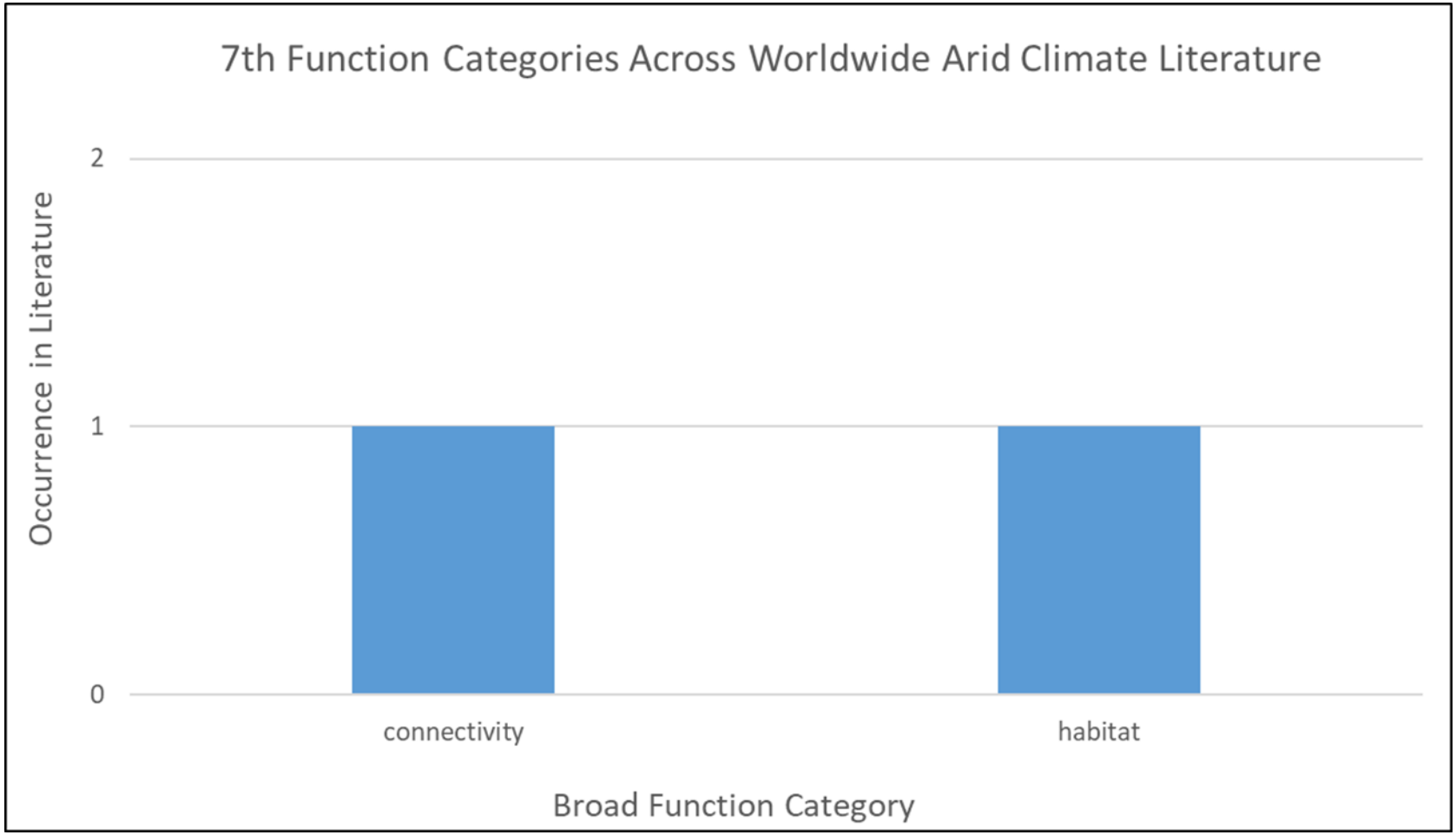


Figure 272. Occurrence of seventh recorded broad function categories across non-perennial arid literature worldwide.

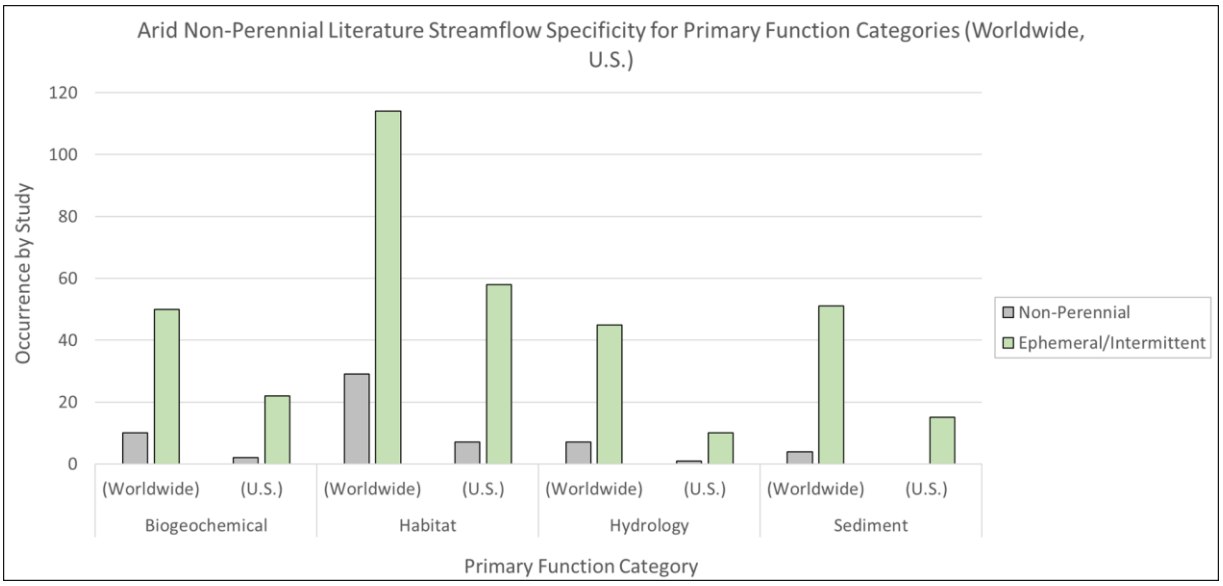


Figure 273. Occurrence of primary recorded broad function categories across non-perennial arid literature summarized streamflow types worldwide, including the U.S.

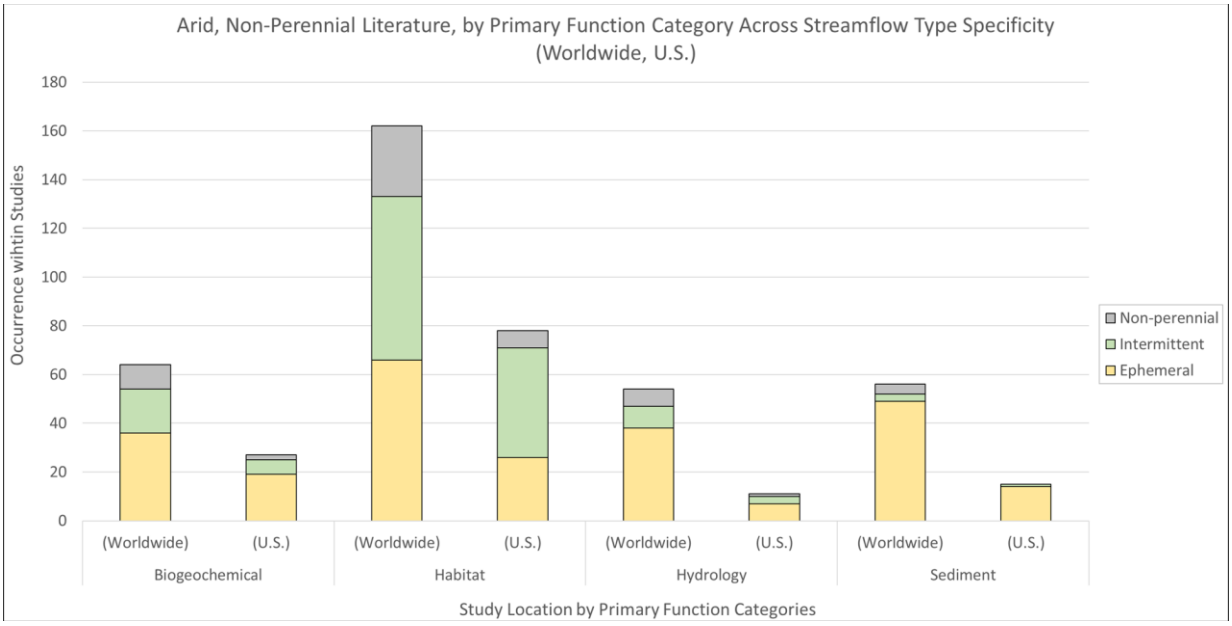


Figure 274. Occurrence of primary recorded broad function categories across non-perennial arid literature streamflow types worldwide, including the U.S.

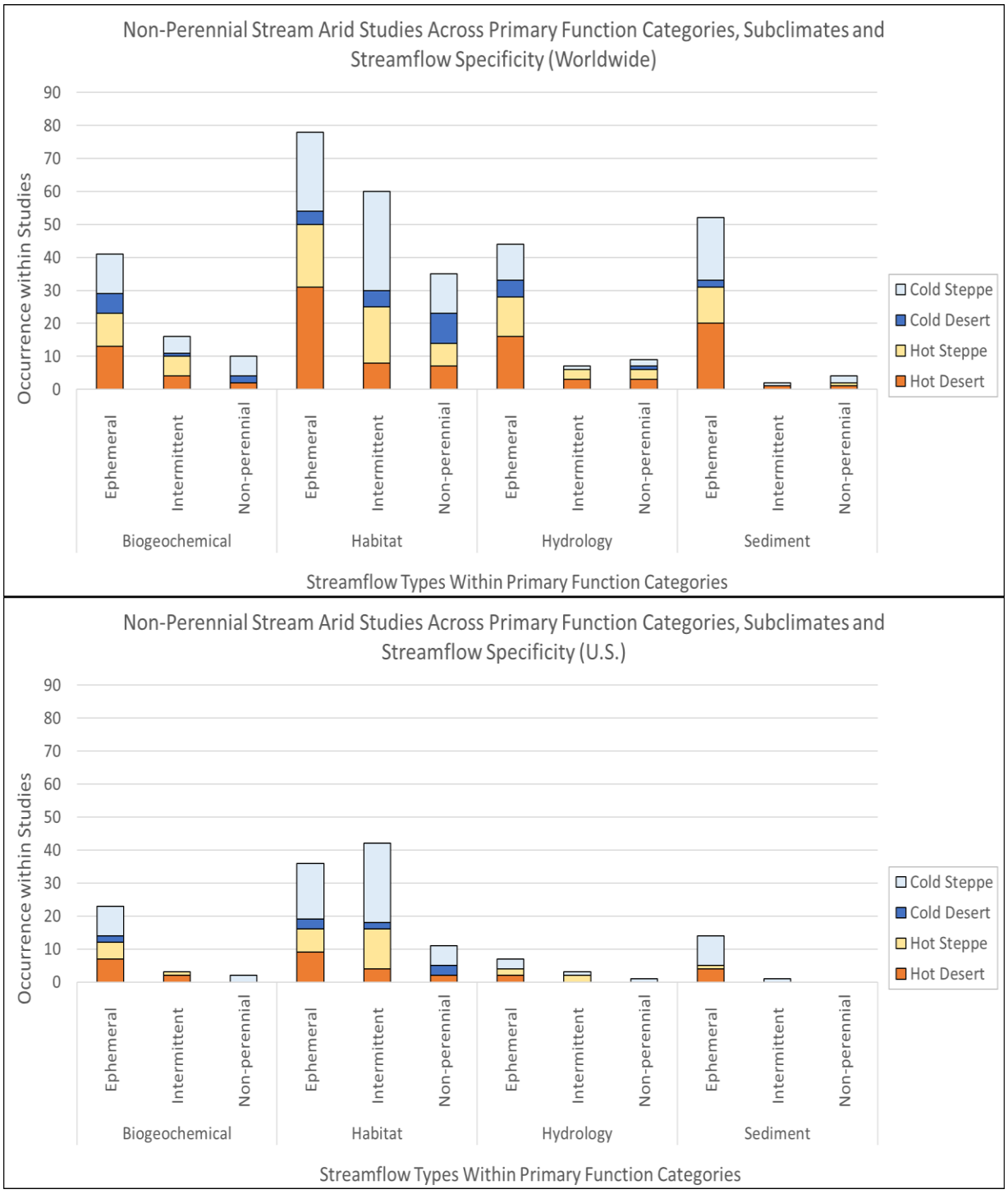


Figure 275. Occurrence of primary recorded broad function categories across non-perennial arid literature streamflow types and subclimates, separately by worldwide and U.S. studies.

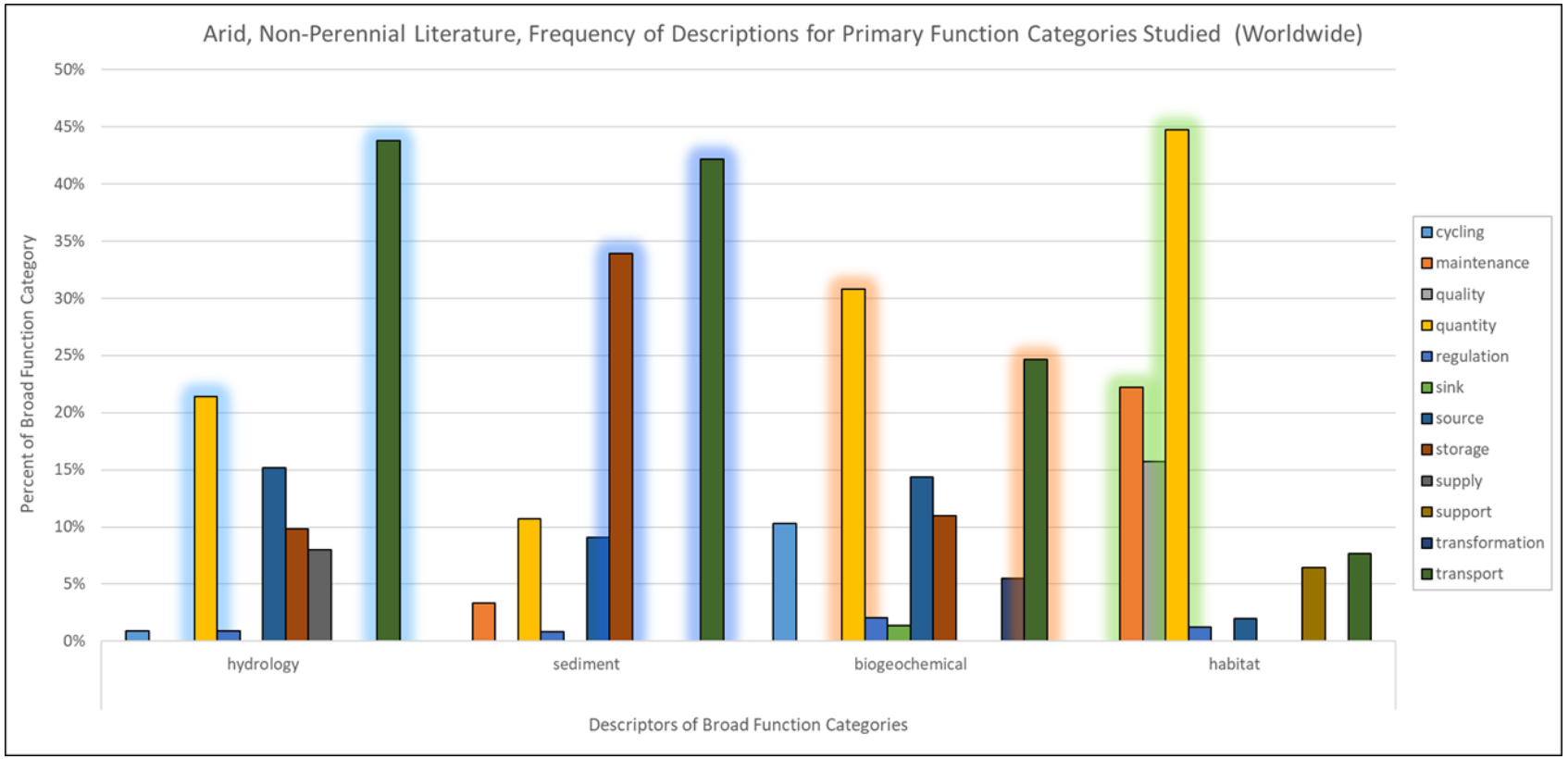


Figure 276. Occurrence of recorded descriptors of primary broad function categories in non-perennial arid literature, worldwide. Top descriptor categories highlighted.

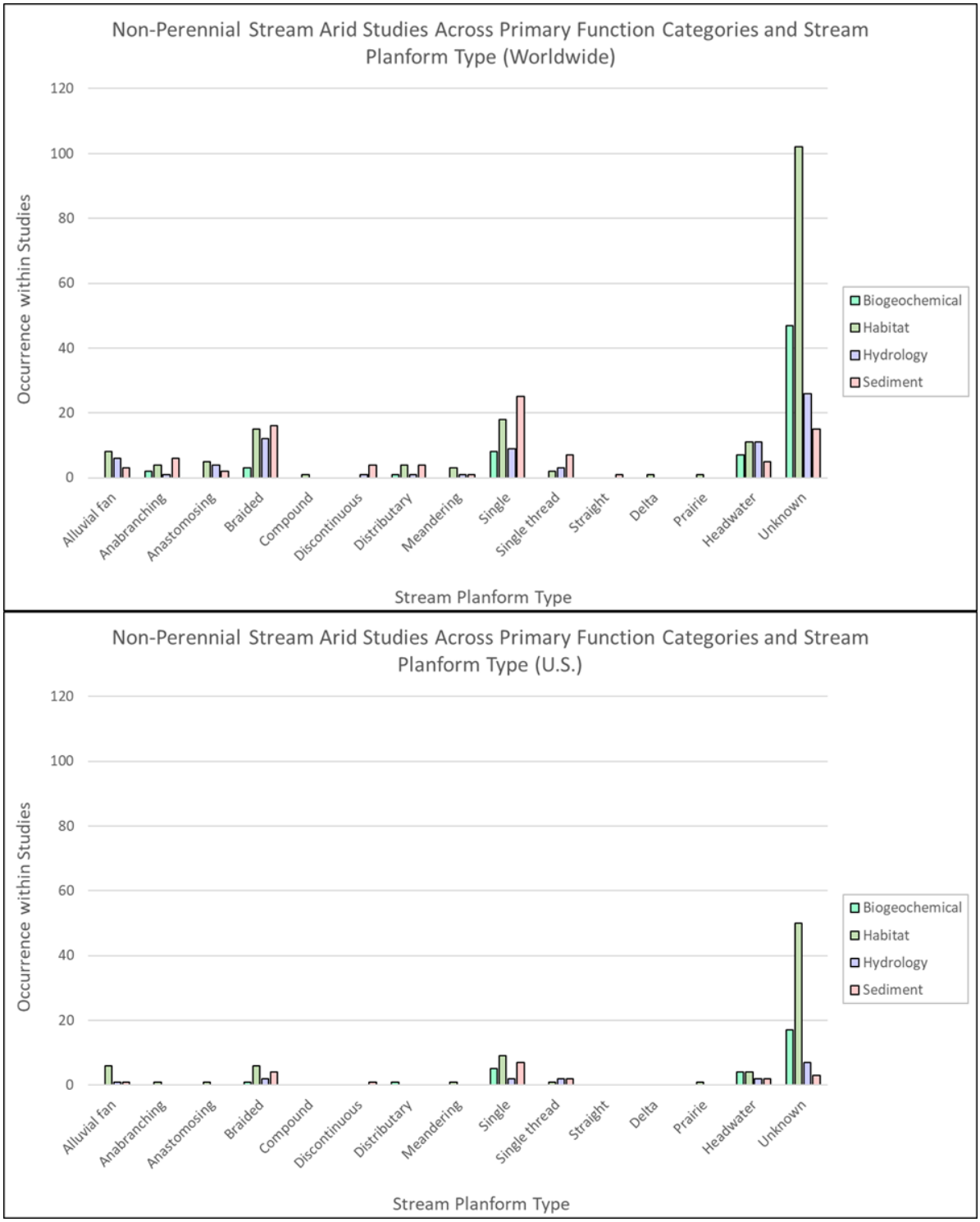


Figure 277. Sampling locations of primary broad function categories within river corridor areas in global and U.S. arid literature.

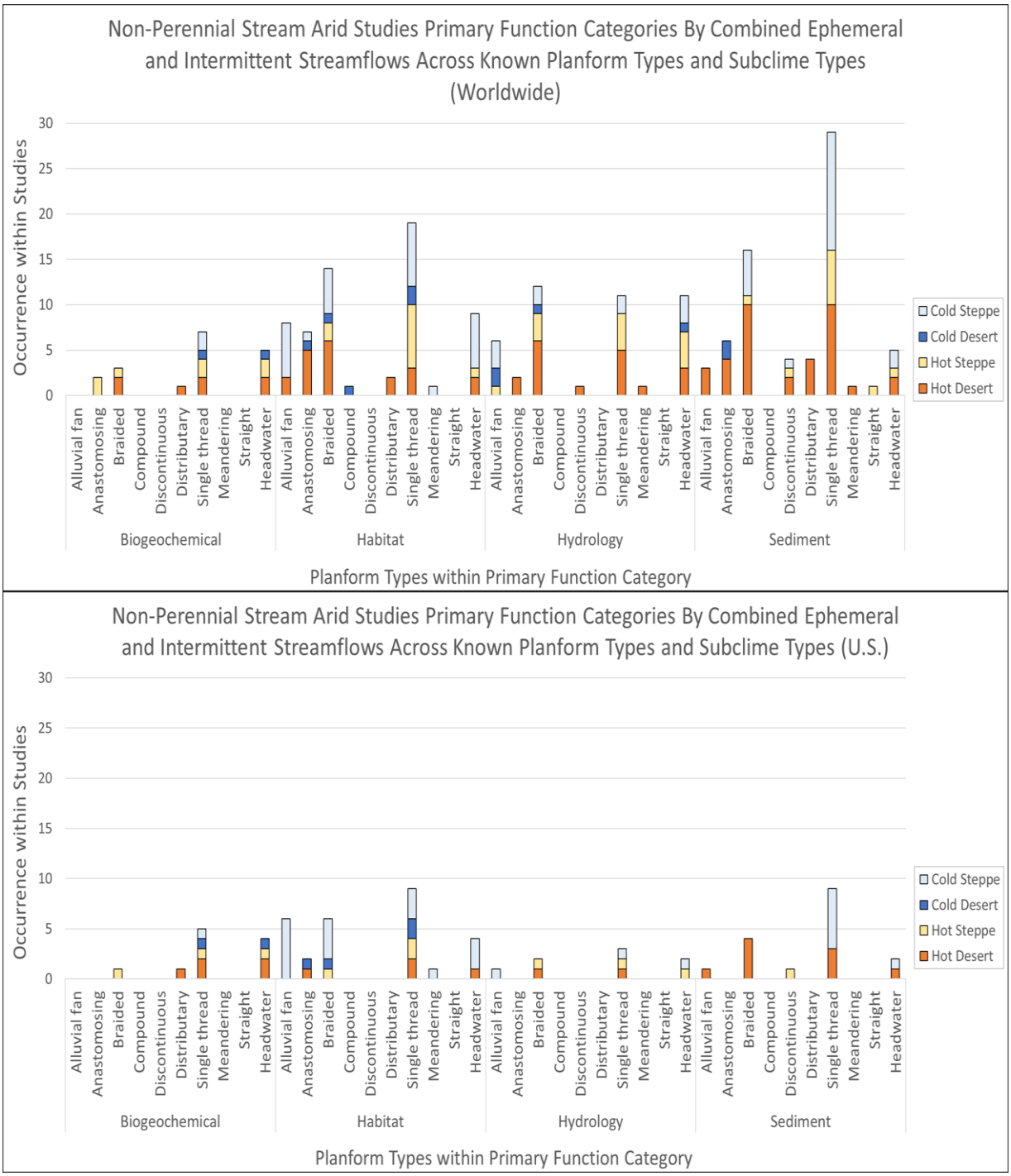


Figure 278. Sampling of primary broad function categories across condensed planform types by subclimes, within global and U.S. arid non-perennial stream literature.

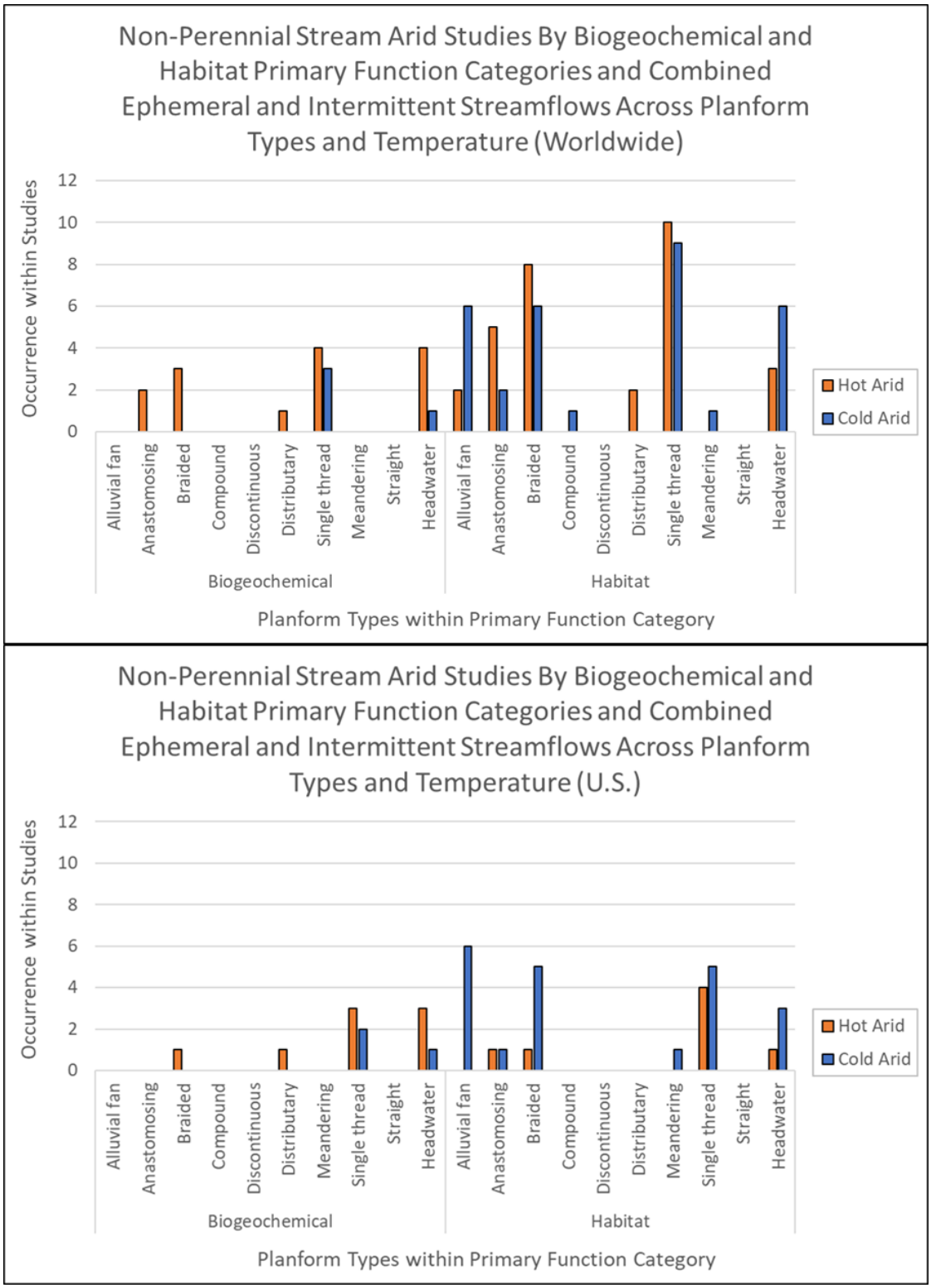


Figure 279. Sampling of Biogeochemical and Habitat primary broad function categories across condensed planform types and temperatures, within global and U.S. arid non-perennial stream literature.

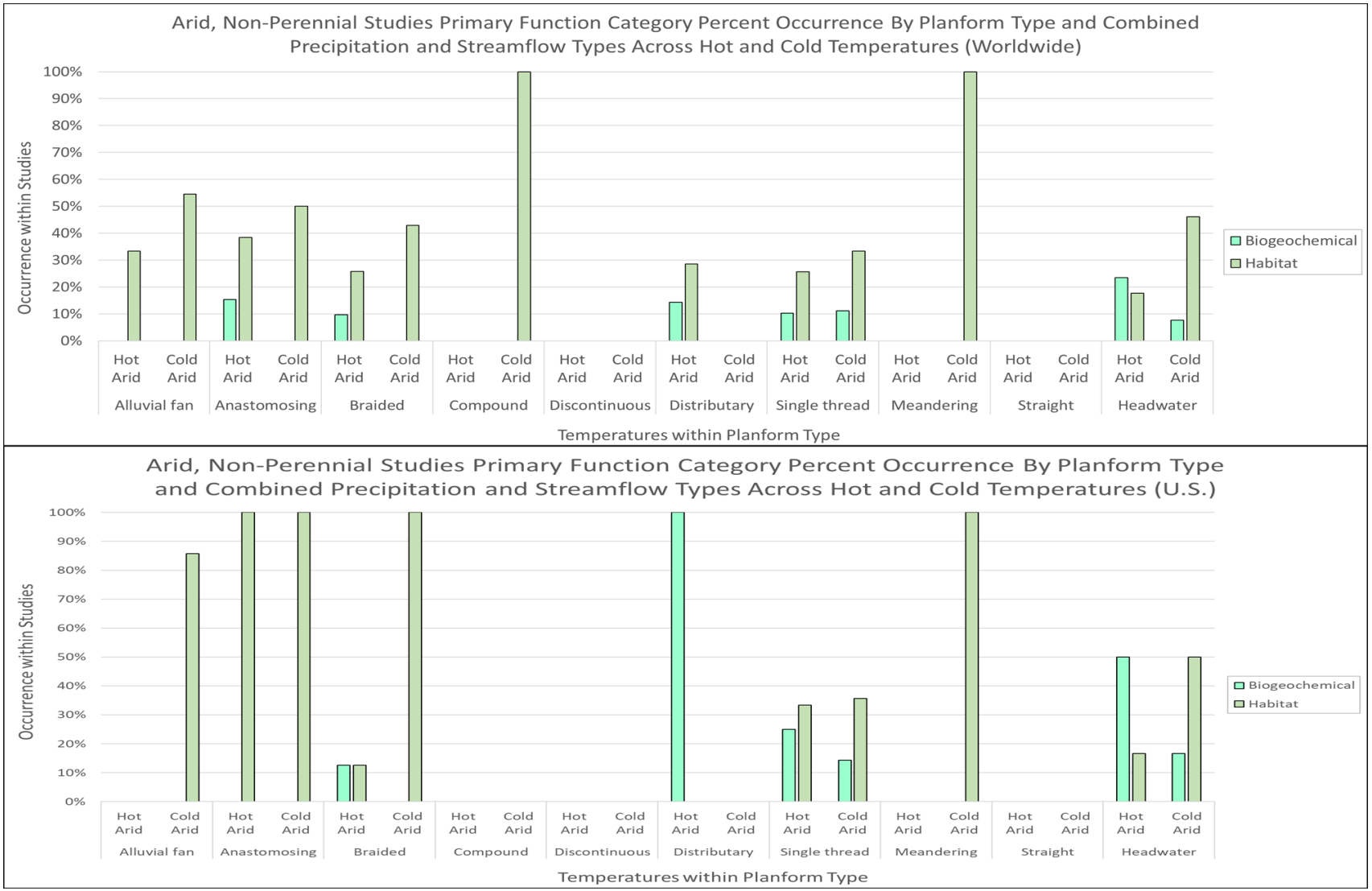


Figure 280. Sampling of planform types across Biogeochemical and Habitat primary broad function categories by temperatures, within global and U.S. arid non-perennial stream literature.

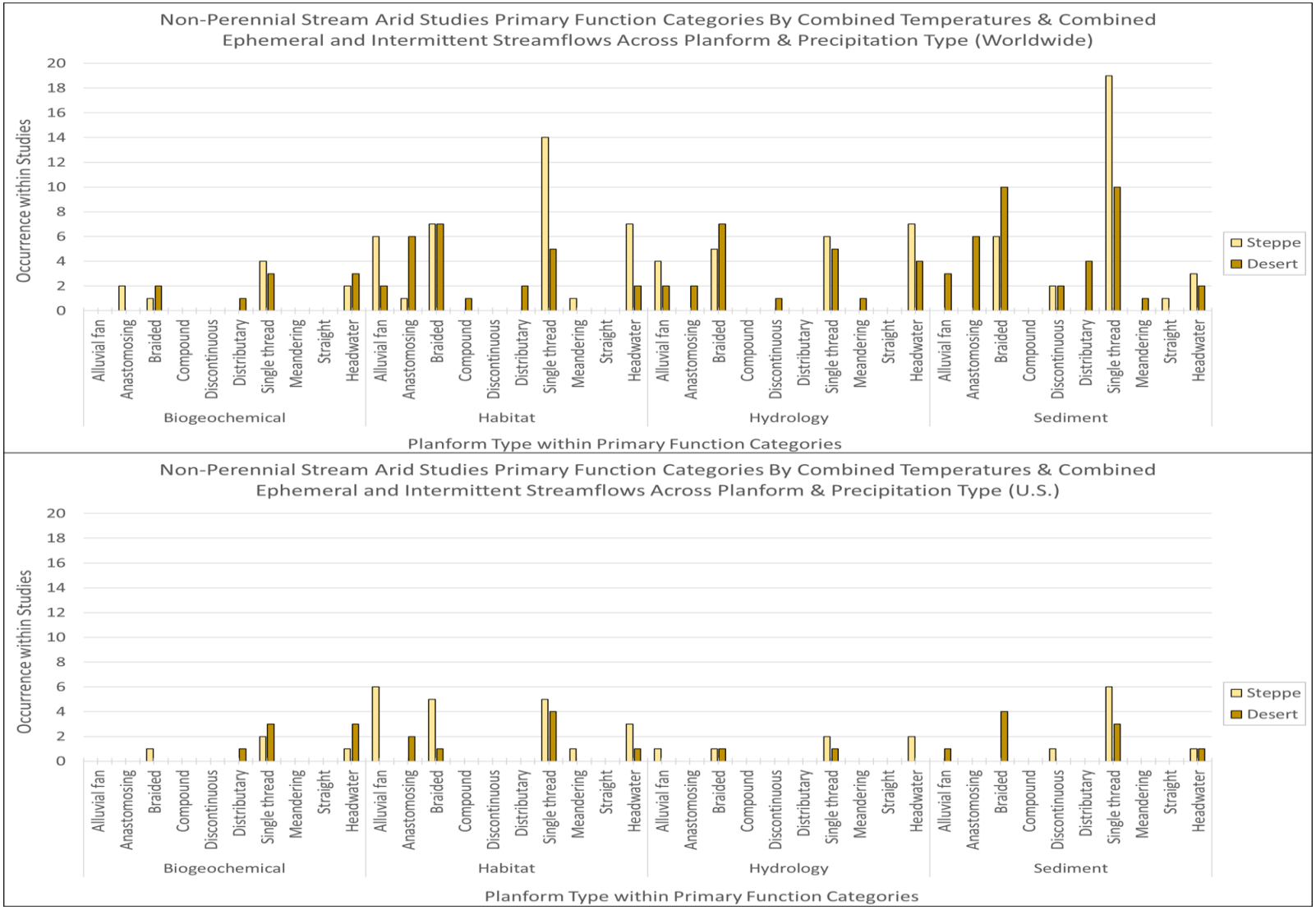


Figure 281. Sampling of primary broad function categories across condensed planform types and precipitation types, within global and U.S. arid non-perennial stream literature.

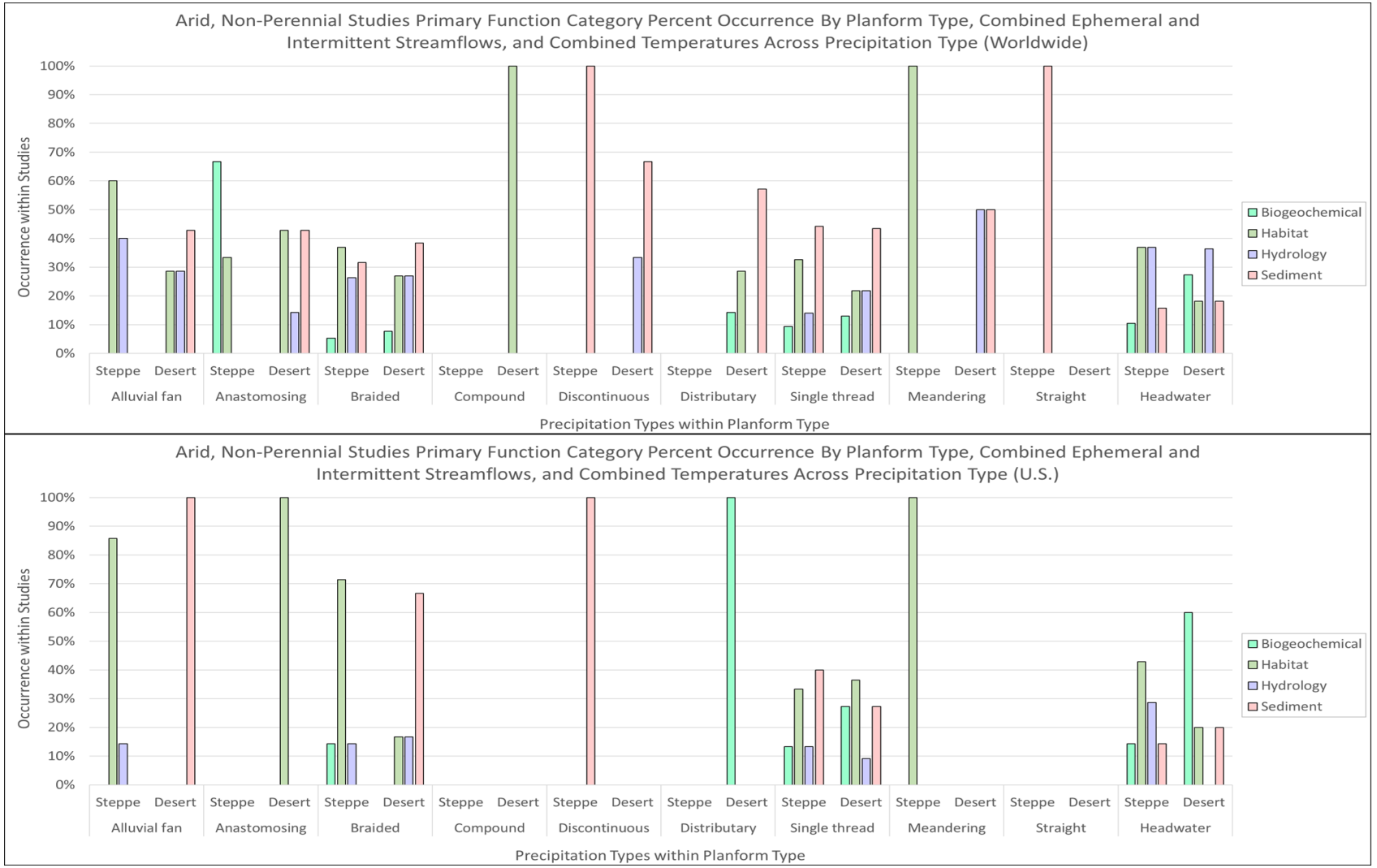


Figure 282. Sampling of primary broad function categories across condensed planform types by precipitation types, within global and U.S. arid non-perennial stream literature.

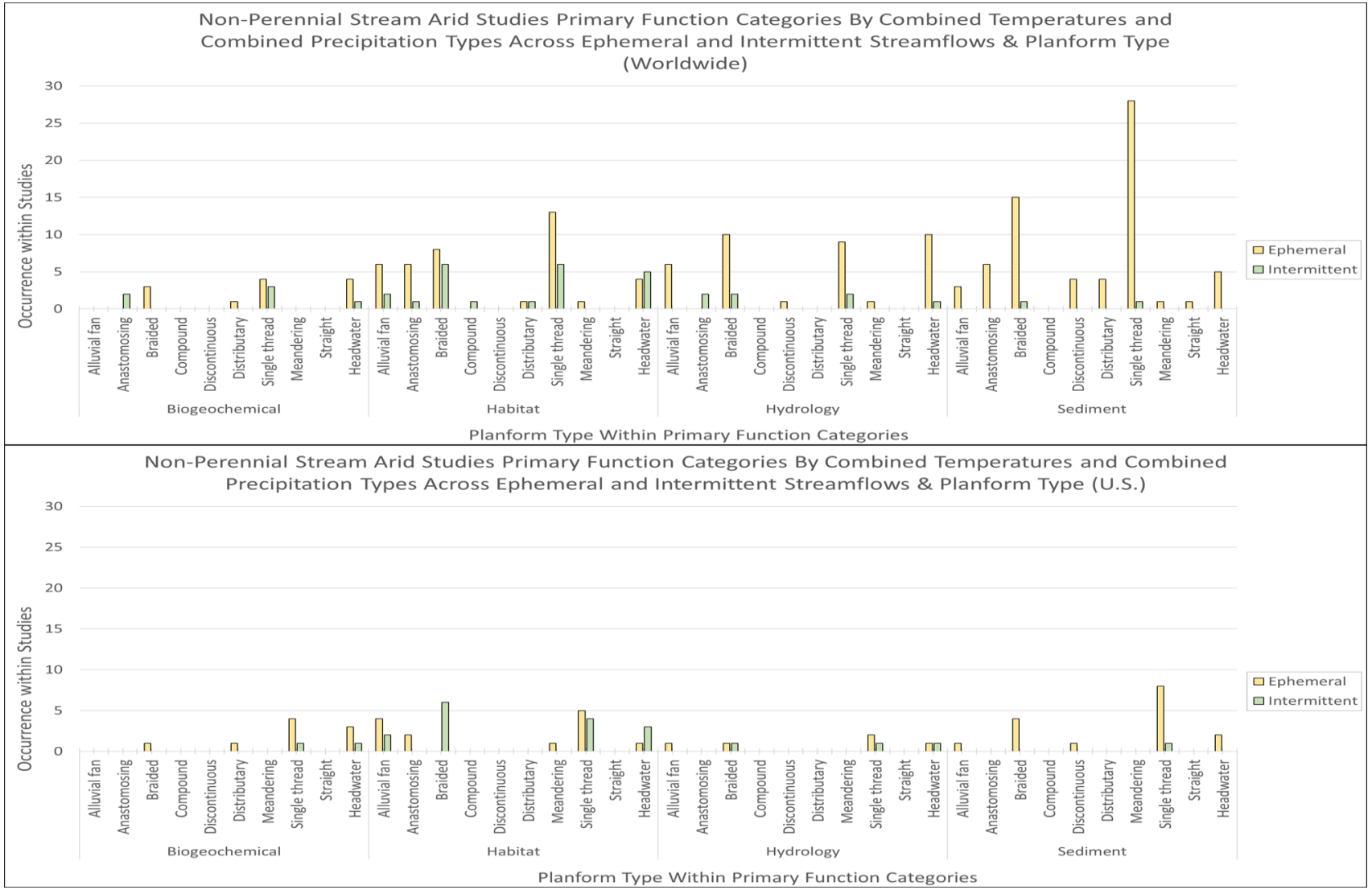


Figure 283. Sampling of primary broad function categories across condensed planform types by ephemeral and intermittent streamflow types, within global and U.S. arid non-perennial stream literature.



Figure 284. Sampling by condensed planform types across primary broad function categories and ephemeral and intermittent streamflow types, within global and U.S. arid non-perennial stream literature.



Figure 285. Sampling by condensed planform types across primary broad function categories, ephemeral and intermittent streamflow types, and precipitation types, within global and U.S. arid non-perennial stream literature.



Figure 286. Sampling of each primary broad function category across condensed sampling location types and subclime types by known streamflow types, within U.S. arid non-perennial stream literature.

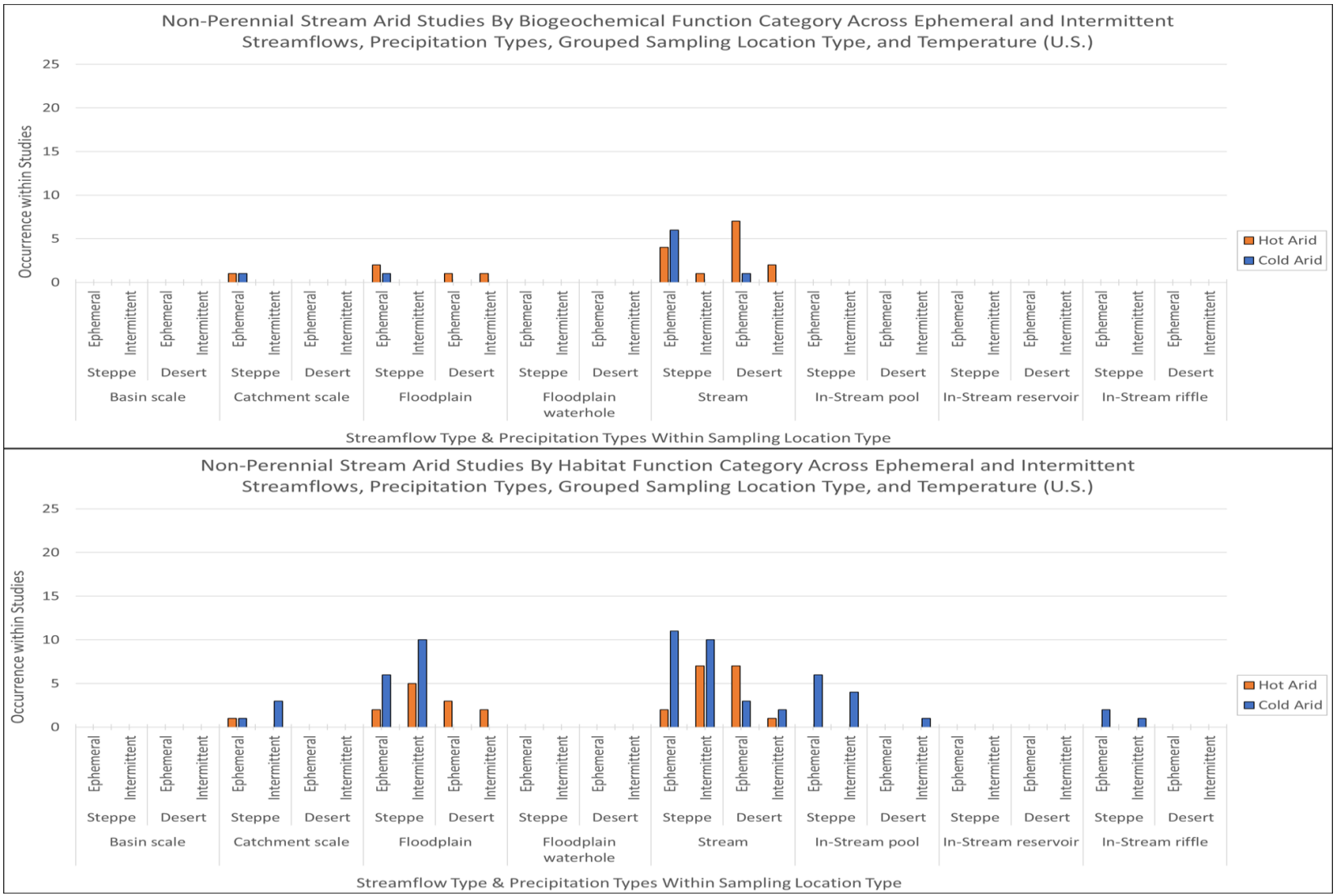


Figure 287. Sampling of Biogeochemical and Habitat function categories across condensed sampling location types and temperatures, by precipitation and known streamflow types, within U.S. arid non-perennial stream literature.

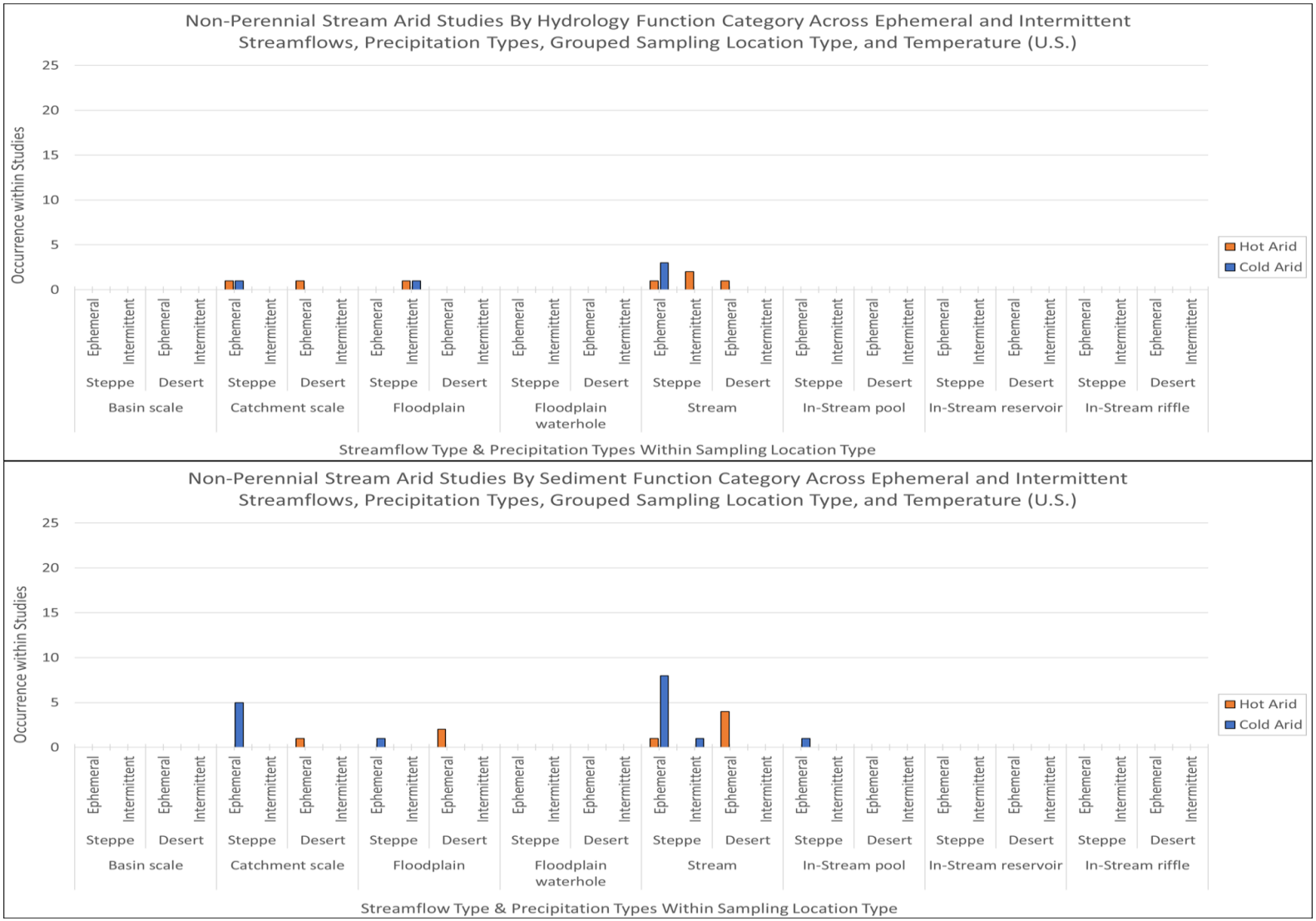


Figure 288. Sampling of Hydrology and Sediment function categories across condensed sampling location types and temperatures, by precipitation and known streamflow types, within U.S. arid non-perennial stream literature.

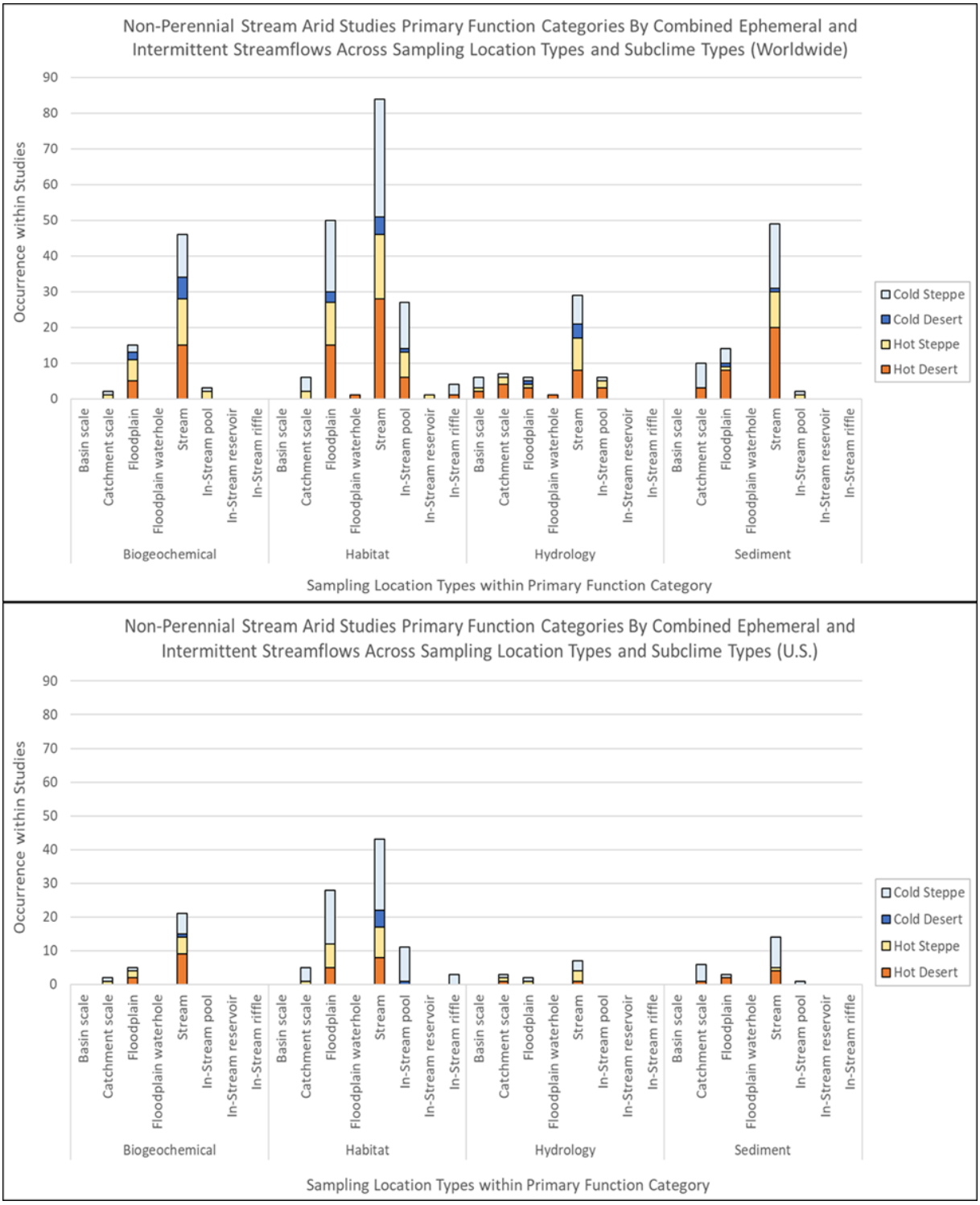


Figure 289. Sampling of primary broad function categories across condensed sampling location types by subclimes, within global and U.S. arid non-perennial stream literature.

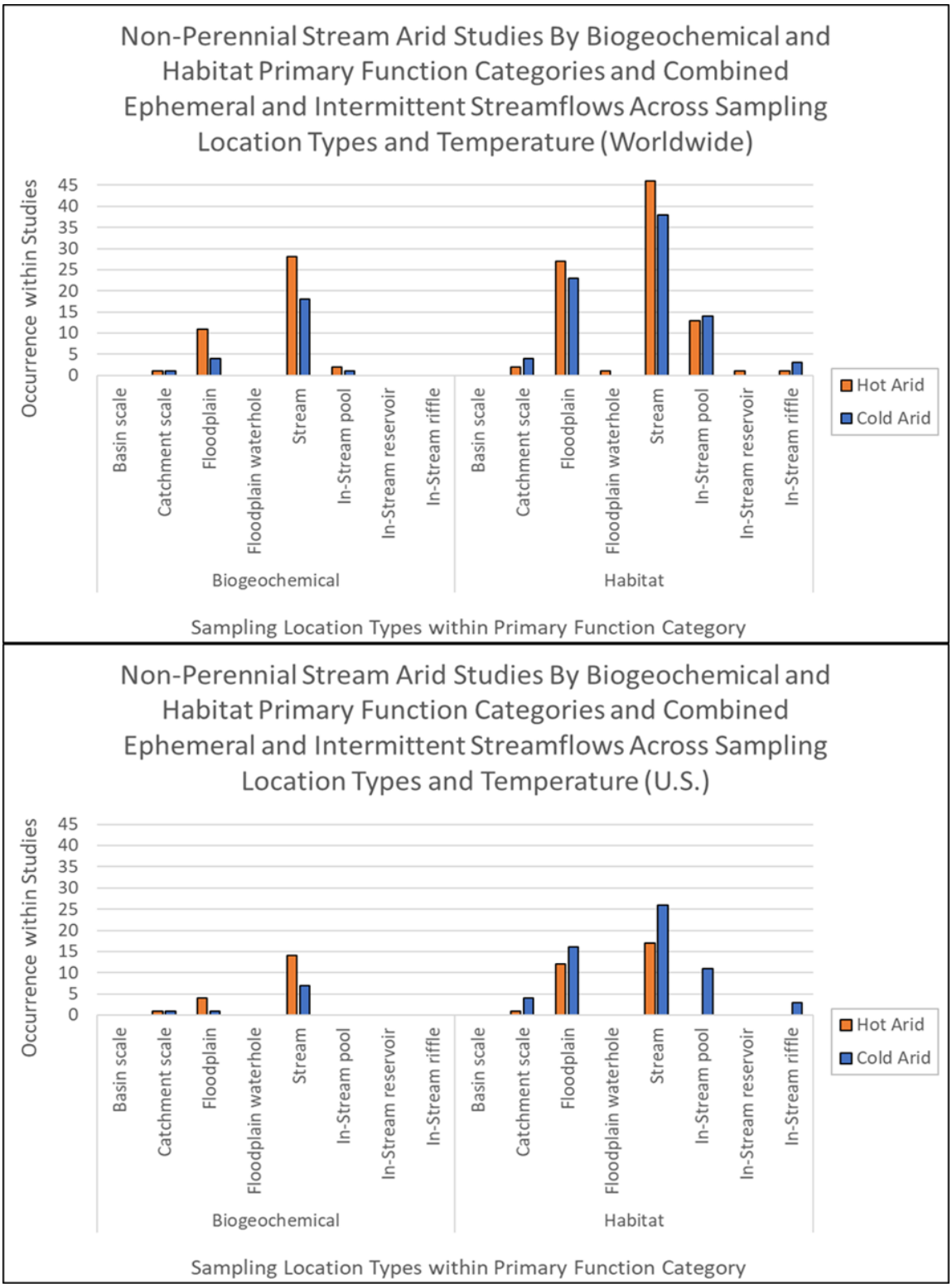


Figure 290. Sampling of Biogeochemical and Habitat primary broad function categories across condensed sampling location types and temperatures, within global and U.S. arid non-perennial stream literature.

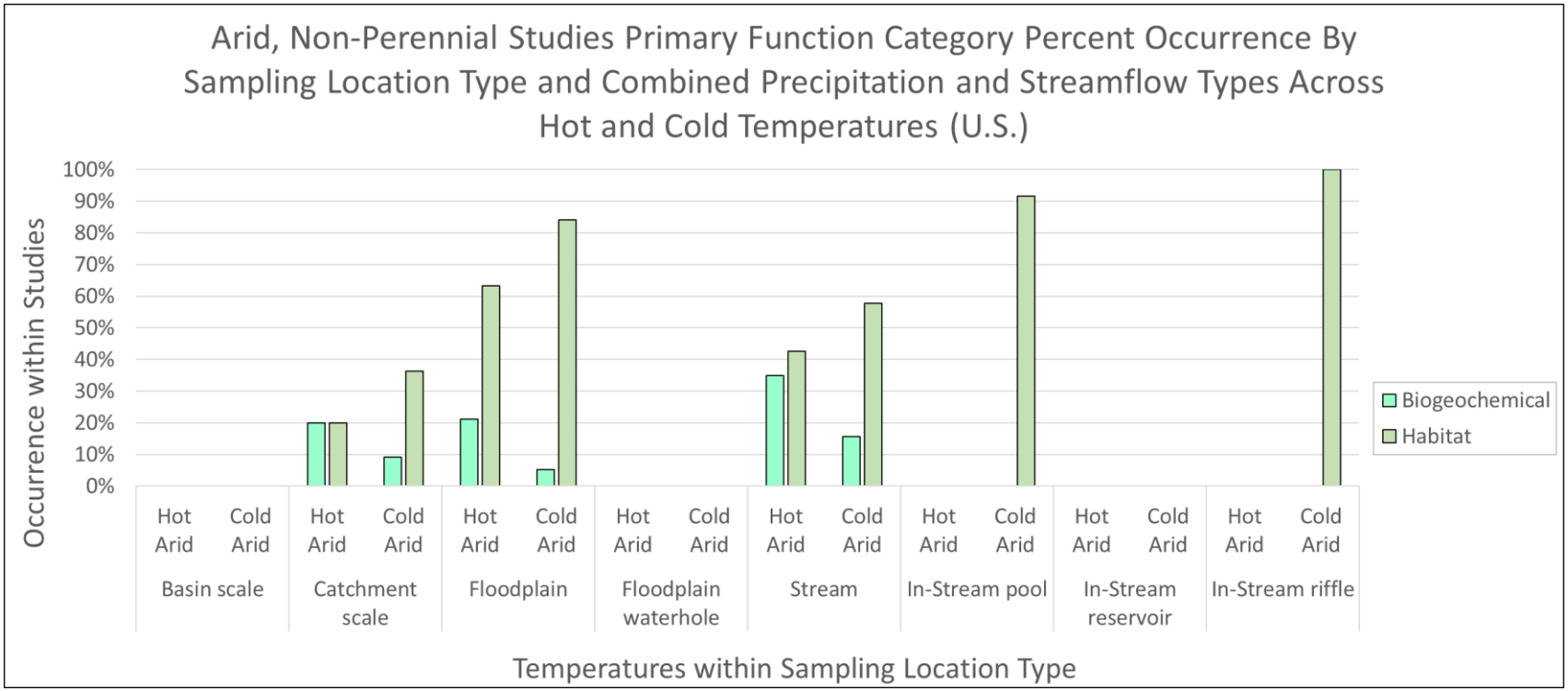


Figure 291. Sampling of sampling location types across Biogeochemical and Habitat primary broad function categories by temperatures, within U.S. arid non-perennial stream literature.

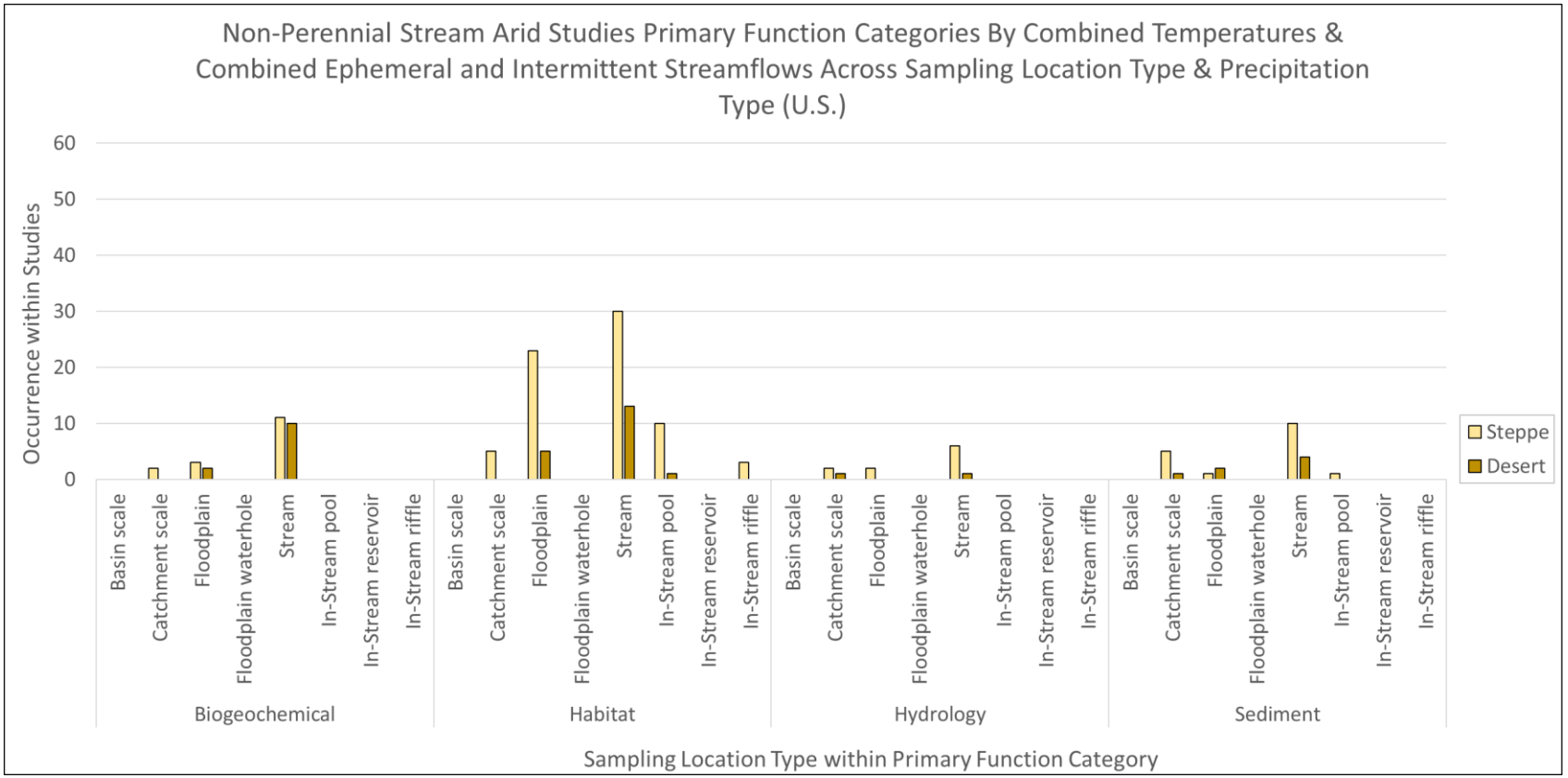


Figure 292. Sampling of primary broad function categories across condensed sampling location types and precipitation types, within U.S. arid non-perennial stream literature.

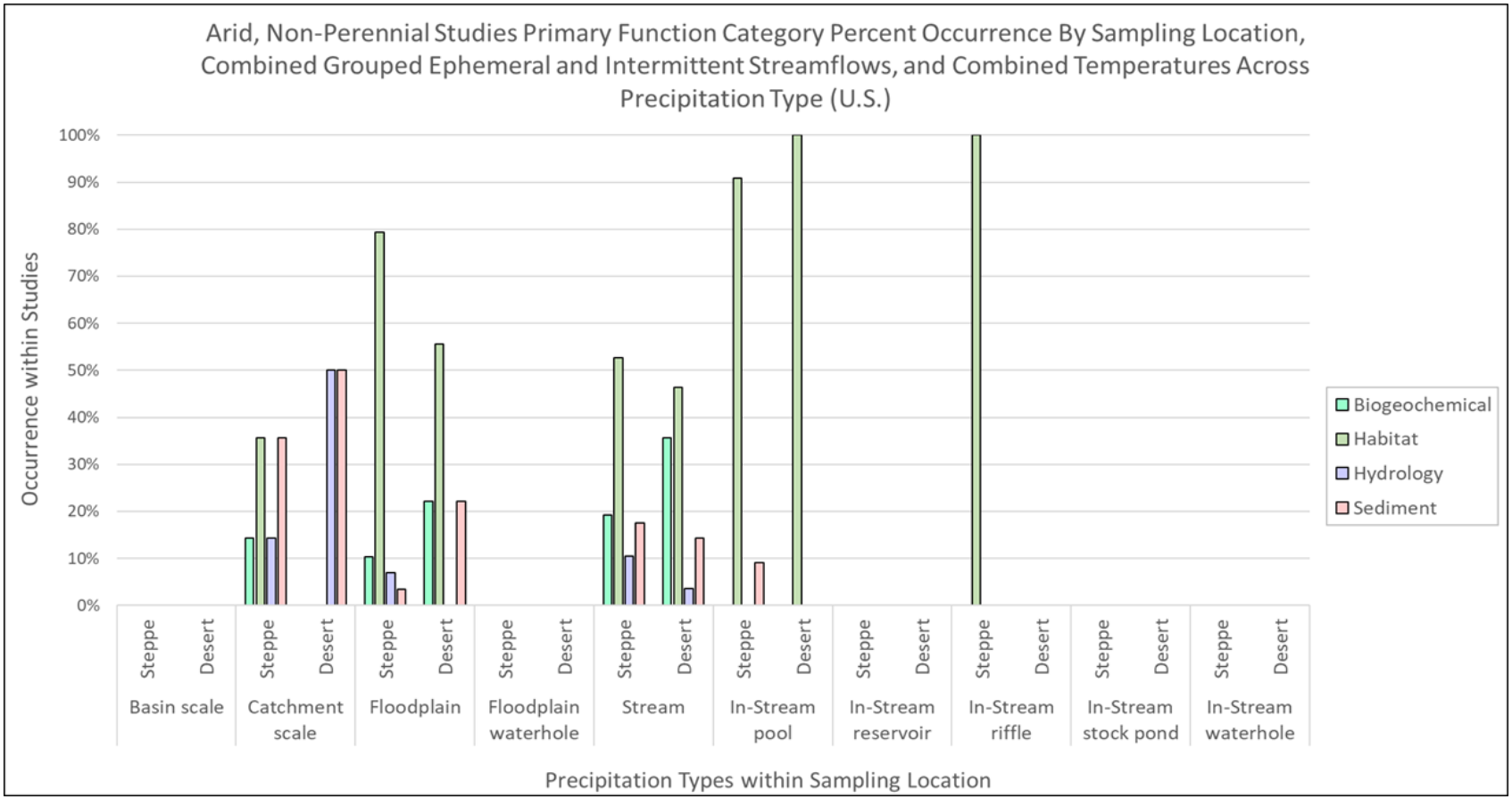


Figure 293. Sampling of condensed sampling location types across primary broad function categories by precipitation types, within U.S. arid non-perennial stream literature.

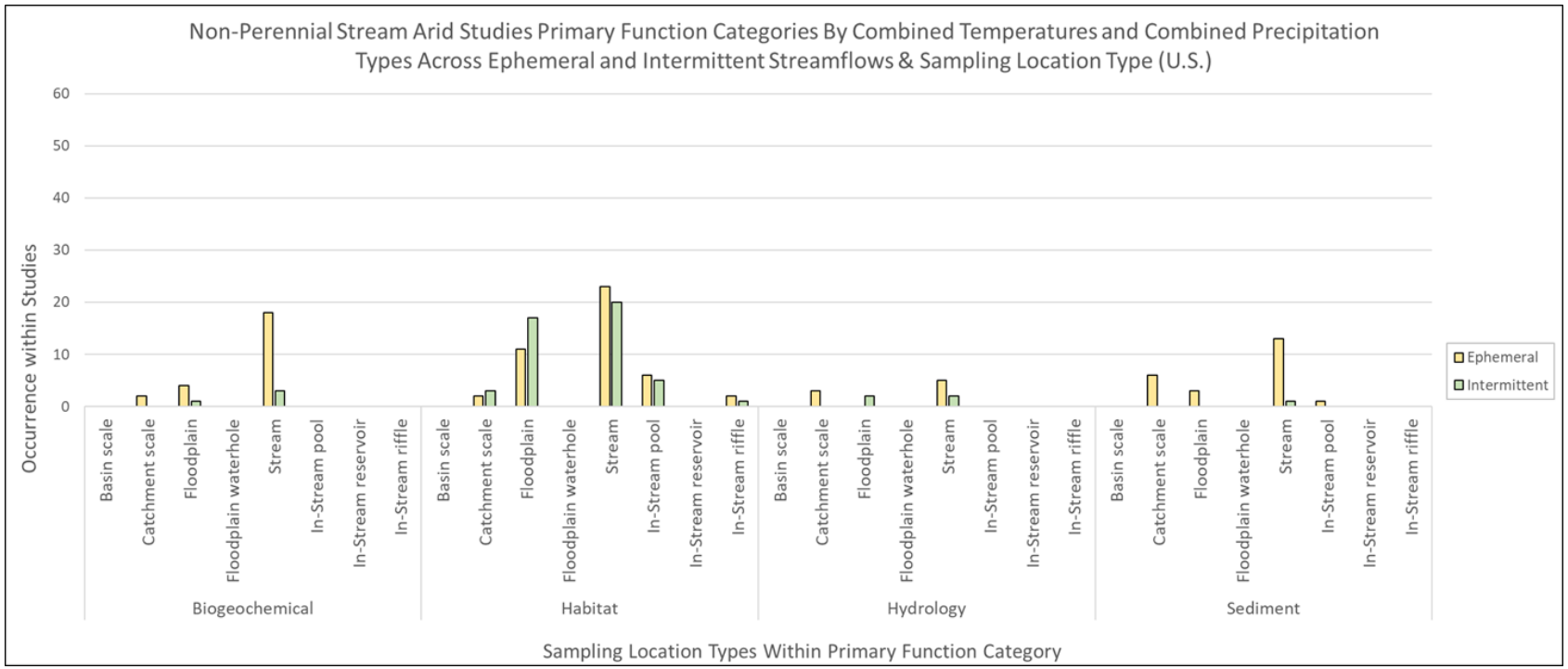


Figure 294. Sampling of primary broad function categories across condensed sampling location types by known streamflow types, within U.S. arid non-perennial stream literature.

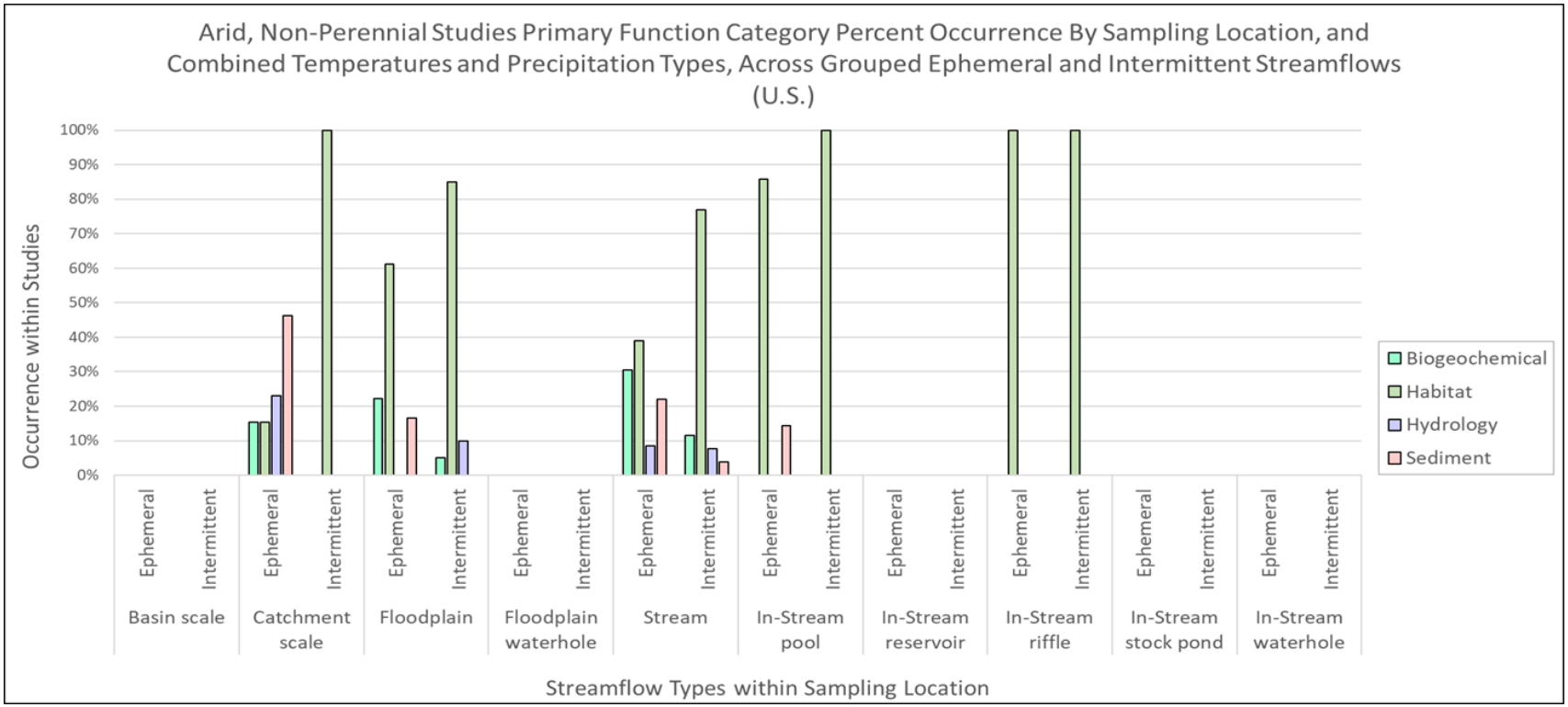


Figure 295. Sampling by condensed sampling location types across primary broad function categories by known streamflow types, within U.S. arid non-perennial stream literature.

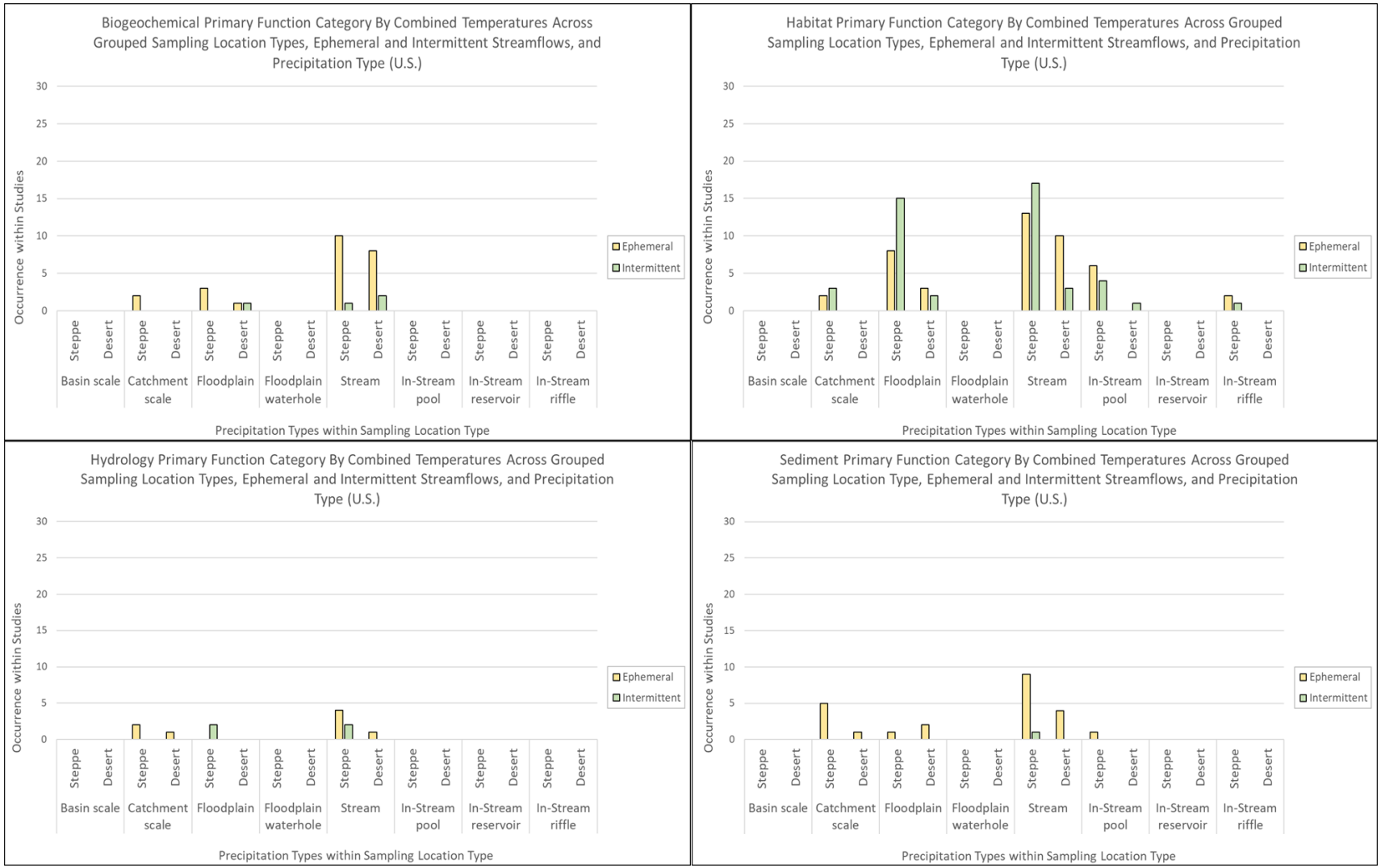


Figure 296. Sampling of each primary broad function category across condensed sampling location types and known streamflow types, by precipitation types, within U.S. arid non-perennial stream literature.

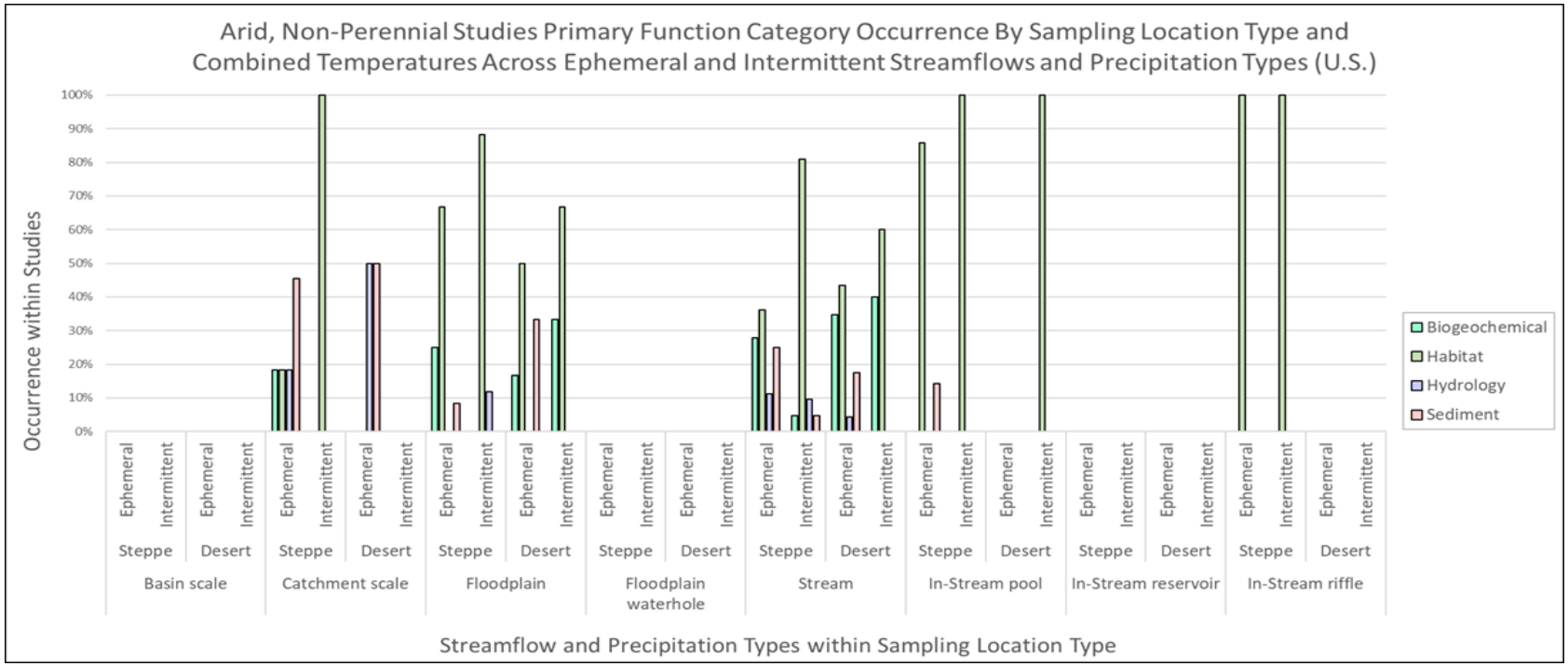


Figure 297. Sampling of condensed sampling location types across primary broad function categories and precipitation types, by known streamflow types, and precipitation types, within U.S. arid non-perennial stream literature.

Table 43. Overall occurrence trends of the primary function categories among planform types, Koppen-Geiger subclimes, and streamflow regimes within U.S. arid non-perennial stream literature. The relative representation between the function categories is noted as slight (>), moderate (>>), or significant (>>>). Data layer trends that mirror overall study trends are denoted as "*".

U.S.								
Overall		**Cold Steppe**	**>>**	**Hot Desert**	**>**	**Hot Steppe**	**>>**	**Cold Desert**
By Function	Biogeochemical	*	>	*	>	*	>>	*
	Habitat	Cold Steppe	>>>	Hot Steppe	>	Hot Desert	>>	Cold Desert
	Hydrology	Cold Steppe	>	Hot Steppe	>	Hot Desert	>	Cold Desert
	Sediment	*	>>	*	>>	*	>	*
By Ephemeral flow	Biogeochemical	*	>	*	>	*	>>	*
	Habitat	*	>>	*	>	*	>>	*
	Hydrology	*	>	*	>	*		NA
	Sediment	*	>>	*	>>	*		NA
By Intermittent flow	Biogeochemical	Hot Desert	>	Hot Steppe	>	Cold Steppe		NA
	Habitat	Cold Steppe	>>	Hot Steppe	>>>	Hot Desert	>	Cold Desert
	Hydrology	Hot Steppe	>	Cold Steppe		NA		NA
	Sediment	Cold Steppe		NA		NA		NA
Planform type		*	>	*	>>	*	>	*
By Function	Biogeochemical	Hot Desert	>>	Hot Steppe	>	Cold Desert	>>	Cold Steppe
	Habitat	Cold Steppe	>>>	Hot Desert	=	Cold Desert	>	Hot Steppe
	Hydrology	Cold Steppe	=	Hot Steppe	>	Hot Desert		NA
	Sediment	Hot Desert	>	Cold Steppe	>>>	Hot Steppe		NA
By Ephemeral flow	Biogeochemical	Hot Desert	>>	Hot Steppe	=	Cold Desert	>>	Cold Steppe
	Habitat	Cold Steppe	>>	Hot Desert	=	Cold Desert		NA
	Hydrology	Cold Steppe	>	Hot Desert		NA		NA
	Sediment	Hot Desert	>	Cold Steppe	>>>	Hot Steppe		NA
By Intermittent flow	Biogeochemical	Hot Desert	=	Hot Steppe		NA		NA
	Habitat	Cold Steppe		Hot Steppe		Hot Desert	=	Cold Desert
	Hydrology	Hot Steppe		NA		NA		NA
	Sediment	*		NA		NA		NA

Table 44. Overall occurrence trends of the primary function categories among planform types, hot and cold temperatures, and streamflow regimes within U.S. arid non-perennial stream literature. The relative representation between the function categories is noted as slight (>), moderate (>>), or significant (>>>). Data layer trends that mirror overall study trends are denoted as "*".

U.S.				
Overall		**Cold arid**	**>**	**Hot arid**
By Function	Biogeochemical	Hot arid	>	Cold arid
	Habitat	*	>>	*
	Hydrology	Hot arid	>	Cold arid
	Sediment	*	>>	*
By Ephemeral flow	Biogeochemical	Hot arid	>	Cold arid
	Habitat	*	>	*
	Hydrology	Hot arid	>	Cold arid
	Sediment	*	>>	*
By Intermittent flow	Biogeochemical	Hot arid	>>	Cold arid
	Habitat	*	>>	*
	Hydrology	Hot arid	>	Cold arid
	Sediment	*	>	*
Planform type		*	>>>	*
By Function	Biogeochemical	Hot arid	>>>	Cold arid
	Habitat	*	>>>	*
	Hydrology	Hot arid	>	Cold arid
	Sediment	Hot arid	>	Cold arid
By Ephemeral flow	Biogeochemical	Hot arid	>>	Cold arid
	Habitat	*	>>>	*
	Hydrology	*	>	*
	Sediment	Hot arid	>	Cold arid
By Intermittent flow	Biogeochemical	Hot arid		NA
	Habitat	*	>>	*
	Hydrology	Hot arid		NA
	Sediment	*		NA

Table 45. Overall occurrence trends of the primary function categories among planform types and Koppen-Geiger subclimes within U.S. arid non-perennial stream literature. The relative representation between the function categories is noted as slight (>), moderate (>>), or significant (>>>). Data layer trends that mirror overall study trends are denoted as "*".

U.S.							
Overall	**Cold Steppe**	**>>**	**Hot Desert**	**>**	**Hot Steppe**	**>>**	**Cold Desert**
Biogeochemical	*	>	*	>	*	>>	*
Habitat	Cold Steppe	>>>	Hot Steppe	>	Hot Desert	>>	Cold Desert
Hydrology	Cold Steppe	>	Hot Steppe	>	Hot Desert	>	Cold Desert
Sediment	*	>>	*	>>	*	>	*
Planform type	*	>	*	>>	*	>	*
Biogeochemical	Hot Desert	>>	Hot Steppe	>	Cold Desert	>>	Cold Steppe
Habitat	Cold Steppe	>>>	Hot Desert	=	Cold Desert	>	Hot Steppe
Hydrology	Cold Steppe	=	Hot Steppe	>	Hot Desert		NA
Sediment	Hot Desert	>	Cold Steppe	>>>	Hot Steppe		NA

Table 46. Overall occurrence trends of the primary function categories among planform types and hot and cold temperatures within U.S. arid non-perennial stream literature. The relative representation between the function categories is noted as slight (>), moderate (>>), or significant (>>>). Data layer trends that mirror overall study trends are denoted as "*".

U.S.			
Overall	**Cold arid**	**>**	**Hot arid**
Biogeochemical	Hot arid	>	Cold arid
Habitat	*	>>	*
Hydrology	Hot arid	>	Cold arid
Sediment	*	>>	*
Planform type	*	>>>	*
Biogeochemical	Hot arid	>>>	Cold arid
Habitat	*	>>>	*
Hydrology	Hot arid	>	Cold arid
Sediment	Hot arid	>	Cold arid

Table 47. Overall occurrence trends of the primary function categories among planform types and arid precipitation types within U.S. arid non-perennial stream literature. The relative representation between the function categories is noted as slight (>), moderate (>>), or significant (>>>). Data layer trends that mirror overall study trends are denoted as "*".

U.S.			
Overall	**Steppe**	**>>**	**Desert**
Biogeochemical	*	>	*
Habitat	*	>>	*
Hydrology	*	>>>	*
Sediment	*	>>	*
Planform type	*	>	*
Biogeochemical	Desert	>	Steppe
Habitat	*	>>	*
Hydrology	*	>>>	*
Sediment	Desert	>	Steppe

Table 48. Overall occurrence trends of the primary function categories among planform types and streamflow regimes within U.S. arid non-perennial stream literature. The relative representation between the function categories is noted as slight (>), moderate (>>), or significant (>>>). Data layer trends that mirror overall study trends are denoted as "*".

U.S.			
Overall	**Ephemeral**	**>**	**Intermittent**
Biogeochemical	*	>>>	*
Habitat	Intermittent	>>	Ephemeral
Hydrology	*	>>	*
Sediment	*	>>>	*
Planform type	*	>>	*
Biogeochemical	*	>>>	*
Habitat	Intermittent	>	Ephemeral
Hydrology	*	>	*
Sediment	*	>>>	*

Table 49. Overall occurrence trends of the primary function categories among planform types, arid precipitation types, and streamflow regimes within U.S. arid non-perennial stream literature. The relative representation between the function categories is noted as slight (>), moderate (>>), or significant (>>>). Data layer trends that mirror overall study trends are denoted as "*".

U.S.				
Overall		Steppe	>>	Desert
By Function	Biogeochemical	*	>	*
	Habitat	*	>>	*
	Hydrology	*	>>>	*
	Sediment	*	>>	*
By Ephemeral flow	Biogeochemical	*	>	*
	Habitat	*	>>	*
	Hydrology	*	>>	*
	Sediment	*	>>	*
By Intermittent flow	Biogeochemical	*	>	*
	Habitat	*	>>>	*
	Hydrology	*	>>>	*
	Sediment	*	>>>	*
Planform type		*	>	*
By Function	Biogeochemical	Desert	>	Steppe
	Habitat	*	>>	*
	Hydrology	*	>>>	*
	Sediment	Desert	>	Steppe
By Ephemeral flow	Biogeochemical	Desert	>>	Steppe
	Habitat	*	>	*
	Hydrology	*	>	*
	Sediment	Desert	>	Steppe
By Intermittent flow	Biogeochemical	*	=	*
	Habitat	*	>>>	*
	Hydrology	*		NA
	Sediment	*		NA

Table 50. Overall occurrence trends of the primary function categories among sampling location types, Koppen-Geiger subclimes, and streamflow regimes within U.S. arid non-perennial stream literature. The relative representation between the function categories is noted as slight (>), moderate (>>), or significant (>>>). Data layer trends that mirror overall study trends are denoted as "*".

U.S.								
Overall		**Cold Steppe**	**>>**	**Hot Desert**	**>**	**Hot Steppe**	**>>**	**Cold Desert**
By Function	Biogeochemical	*	>	*	>	*	>>	*
	Habitat	**Cold Steppe**	>>>	**Hot Steppe**	>	**Hot Desert**	>>	**Cold Desert**
	Hydrology	**Cold Steppe**	>	**Hot Steppe**	>	**Hot Desert**	>	**Cold Desert**
	Sediment	*	>>	*	>>	*	>	*
By Ephemeral flow	Biogeochemical	*	>	*	>	*	>>	*
	Habitat	*	>>	*	>	*	>>	*
	Hydrology	*	>	*	>	*		NA
	Sediment	*	>>	*	>>	*		NA
By Intermittent flow	Biogeochemical	**Hot Desert**	>	**Hot Steppe**	>	**Cold Steppe**		**NA**
	Habitat	**Cold Steppe**	>>	**Hot Steppe**	>>>	**Hot Desert**	>	**Cold Desert**
	Hydrology	**Hot Steppe**	>	**Cold Steppe**		NA		NA
	Sediment	**Cold Steppe**		NA		NA		NA
Sampling location		*	>>	*	>	*	>>>	*
By Function	Biogeochemical	**Hot Desert**	>	**Cold Steppe**	=	**Hot Steppe**	>>>	**Cold Desert**
	Habitat	**Cold Steppe**	>>>	**Hot Steppe**	>	**Hot Desert**	>>	**Cold Desert**
	Hydrology	**Cold Steppe**	=	**Hot Steppe**	>>	**Hot Desert**		NA
	Sediment	*	>>	*	>>>	*		NA
By Ephemeral flow	Biogeochemical	*	=	*	>	*	>>>	*
	Habitat	*	>>	*	>>	*	>	*
	Hydrology	*	>>	*	=	*		NA
	Sediment	*	>>	*	>>>	*		NA
By Intermittent flow	Biogeochemical	**Hot Desert**	>>>	**Hot Steppe**		NA		NA
	Habitat	**Cold Steppe**	>>	**Hot Steppe**	>>>	**Hot Desert**	=	**Cold Desert**
	Hydrology	**Hot Steppe**	>>>	**Cold Steppe**		NA		NA
	Sediment	*		NA		NA		NA

Table 51. Overall occurrence trends of the primary function categories among sampling location types, hot and cold temperatures, and streamflow regimes within U.S. arid non-perennial stream literature. The relative representation between the function categories is noted as slight (>), moderate (>>), or significant (>>>). Data layer trends that mirror overall study trends are denoted as "*".

U.S.				
Overall		**Cold arid**	**>**	**Hot arid**
By Function	Biogeochemical	Hot arid	>	Cold arid
	Habitat	*	>>	*
	Hydrology	Hot arid	>	Cold arid
	Sediment	*	>>	*
By Ephemeral flow	Biogeochemical	Hot arid	>	Cold arid
	Habitat	*	>	*
	Hydrology	Hot arid	>	Cold arid
	Sediment	*	>>	*
By Intermittent flow	Biogeochemical	Hot arid	>>	Cold arid
	Habitat	*	>>	*
	Hydrology	Hot arid	>	Cold arid
	Sediment	*	>	*
Sampling location		*	>	*
By Function	Biogeochemical	Hot arid	>>	Cold arid
	Habitat	*	>>	*
	Hydrology	Hot arid	>	Cold arid
	Sediment	*	>>	*
By Ephemeral flow	Biogeochemical	Hot arid	>>	Cold arid
	Habitat	*	>>	*
	Hydrology	*	=	*
	Sediment	*	>>	*
By Intermittent flow	Biogeochemical	Hot arid		NA
	Habitat	*	>>	*
	Hydrology	Hot arid	>>>	Cold arid
	Sediment	*		NA

Table 52. Overall occurrence trends of the primary function categories among sampling location types and Koppen-Geiger subclimes within U.S. arid non-perennial stream literature. The relative representation between the function categories is noted as slight (>), moderate (>>), or significant (>>>). Data layer trends that mirror overall study trends are denoted as "*".

U.S.							
Overall	**Cold Steppe**	>>	**Hot Desert**	>	**Hot Steppe**	>>	**Cold Desert**
Biogeochemical	*	>	*	>	*	>>	*
Habitat	Cold Steppe	>>>	Hot Steppe	>	Hot Desert	>>	Cold Desert
Hydrology	Cold Steppe	>	Hot Steppe	>	Hot Desert	>	Cold Desert
Sediment	*	>>	*	>>	*	>	*
Sampling location	*	>>	*	>	*	>>>	*
Biogeochemical	Hot Desert	>	Cold Steppe	=	Hot Steppe	>>>	Cold Desert
Habitat	Cold Steppe	>>>	Hot Steppe	>	Hot Desert	>>	Cold Desert
Hydrology	Cold Steppe	=	Hot Steppe	>>	Hot Desert		NA
Sediment	*	>>	*	>>>	*		NA

Table 53. Overall occurrence trends of the primary function categories among sampling location types and hot and cold temperatures within U.S. arid non-perennial stream literature. The relative representation between the function categories is noted as slight (>), moderate (>>), or significant (>>>). Data layer trends that mirror overall study trends are denoted as "*".

U.S.			
Overall	**Cold arid**	**>**	**Hot arid**
Biogeochemical	Hot arid	>	Cold arid
Habitat	*	>>	*
Hydrology	Hot arid	>	Cold arid
Sediment	*	>>	*
Sampling location	*	>	*
Biogeochemical	Hot arid	>>	Cold arid
Habitat	*	>>	*
Hydrology	Hot arid	>	Cold arid
Sediment	*	>>	*

Table 54. Overall occurrence trends of the primary function categories among sampling location types and arid precipitation types within U.S. arid non-perennial stream literature. The relative representation between the function categories is noted as slight (>), moderate (>>), or significant (>>>). Data layer trends that mirror overall study trends are denoted as "*".

U.S.			
Overall	**Steppe**	**>>**	**Desert**
Biogeochemical	*	>	*
Habitat	*	>>	*
Hydrology	*	>>>	*
Sediment	*	>>	*
Sampling location	*	>>>	*
Biogeochemical	*	>	*
Habitat	*	>>>	*
Hydrology	*	>>>	*
Sediment	*	>>	*

Table 55. Overall occurrence trends of the primary function categories among sampling location types and streamflow regimes within U.S. arid non-perennial stream literature. The relative representation between the function categories is noted as slight (>), moderate (>>), or significant (>>>). Data layer trends that mirror overall study trends are denoted as "*".

U.S.			
Overall	**Ephemeral**	**>**	**Intermittent**
Biogeochemical	*	>>>	*
Habitat	Intermittent	>>	Ephemeral
Hydrology	*	>>	*
Sediment	*	>>>	*
Sampling location	*	>>	*
Biogeochemical	*	>>>	*
Habitat	Intermittent	>	Ephemeral
Hydrology	*	>>	*
Sediment	*	>>>	*

Table 56. Overall occurrence trends of the primary function categories among sampling location types, arid precipitation types, and streamflow regimes within U.S. arid non-perennial stream literature. The relative representation between the function categories is noted as slight (>), moderate (>>), or significant (>>>). Data layer trends that mirror overall study trends are denoted as "*".

U.S.				
Overall		Steppe	>>	Desert
By Function	Biogeochemical	*	>	*
	Habitat	*	>>	*
	Hydrology	*	>>>	*
	Sediment	*	>>	*
By Ephemeral flow	Biogeochemical	*	>	*
	Habitat	*	>>	*
	Hydrology	*	>>	*
	Sediment	*	>>	*
By Intermittent flow	Biogeochemical	*	>	*
	Habitat	*	>>>	*
	Hydrology	*	>>>	*
	Sediment	*	>>>	*
Sampling location		*	>>>	*
By Function	Biogeochemical	*	>	*
	Habitat	*	>>>	*
	Hydrology	*	>>>	*
	Sediment	*	>>	*
By Ephemeral flow	Biogeochemical	*	>>	*
	Habitat	*	>>	*
	Hydrology	*	>>>	*
	Sediment	*	>>	*
By Intermittent flow	Biogeochemical	Desert	>>>	Steppe
	Habitat	*	>>>	*
	Hydrology	*		NA
	Sediment	*		NA

Appendix G: Extent of Data Provided Within Analyzed Literature

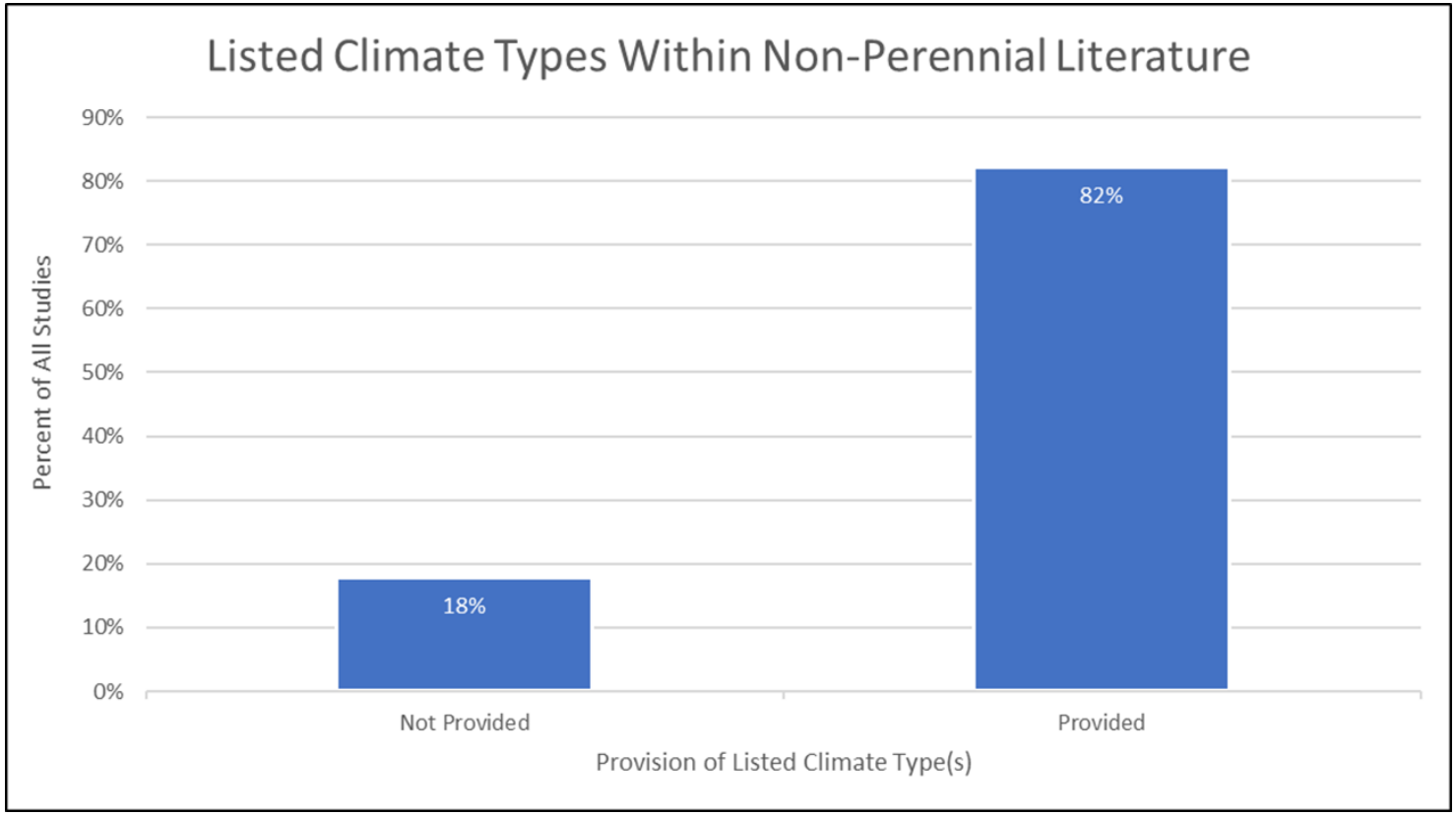


Figure 298. The provision of listed climate type(s) within non-perennial stream literature analyzed worldwide.

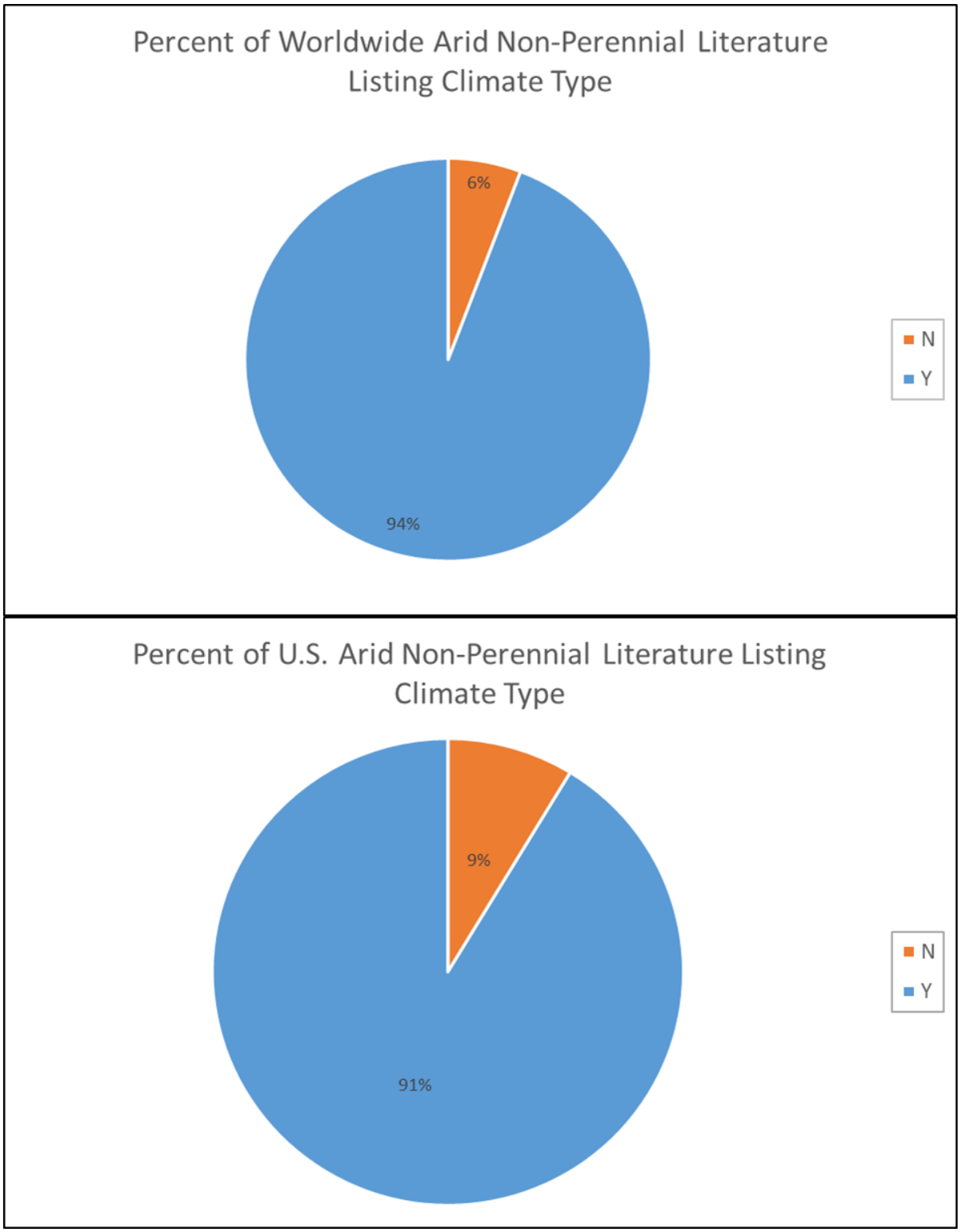


Figure 299. The provision of listed climate type(s) within arid non-perennial stream literature analyzed worldwide and in the U.S.

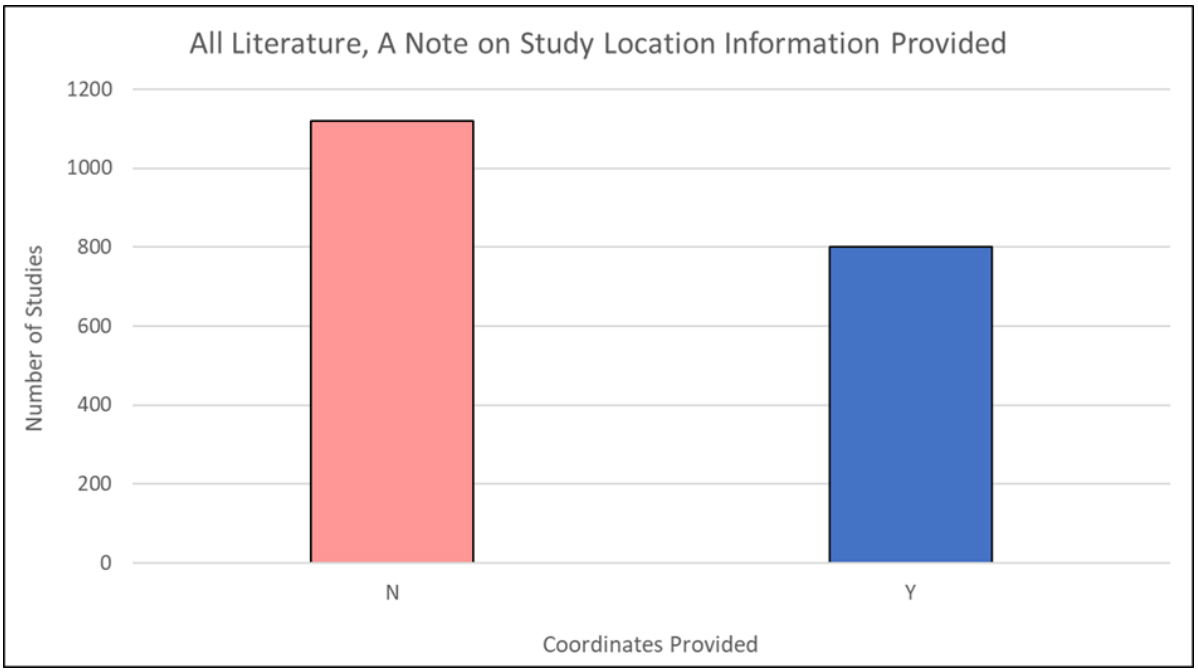


Figure 300. The provision of study location coordinates within literature analyzed worldwide.

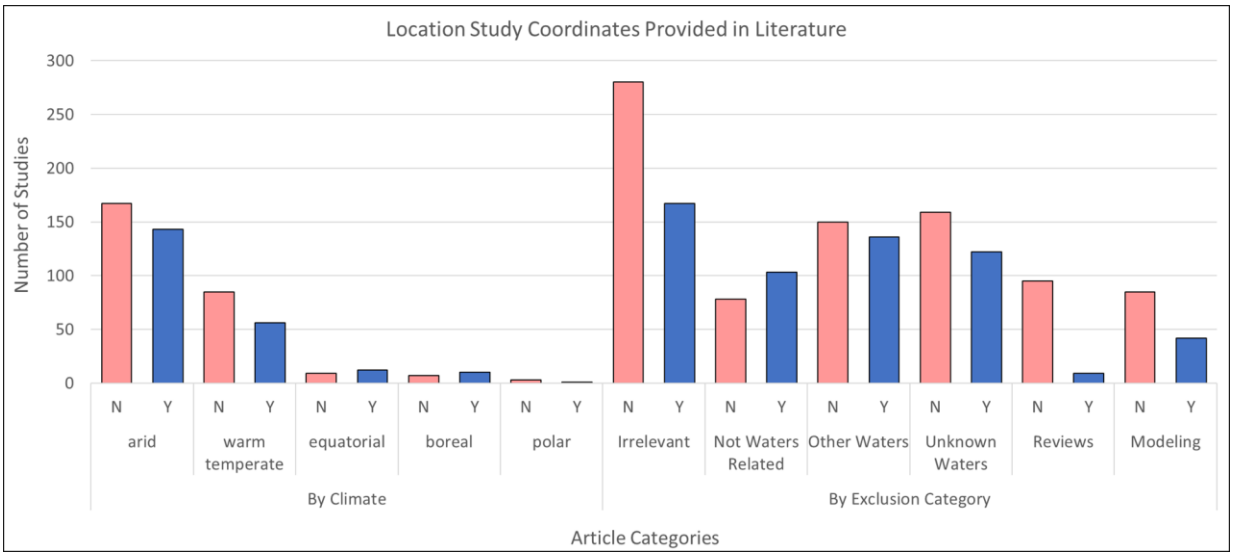


Figure 301. The provision of study coordinates among tiers of analyzed literature worldwide.

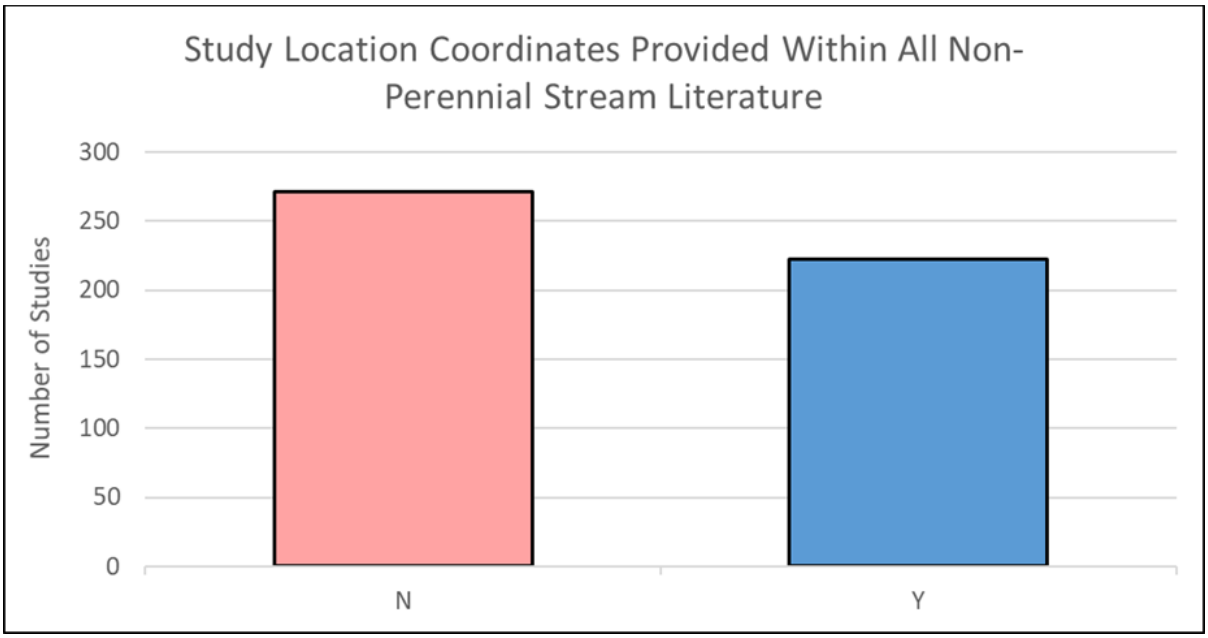


Figure 302. The provision of study coordinates among non-perennial stream literature analyzed worldwide.

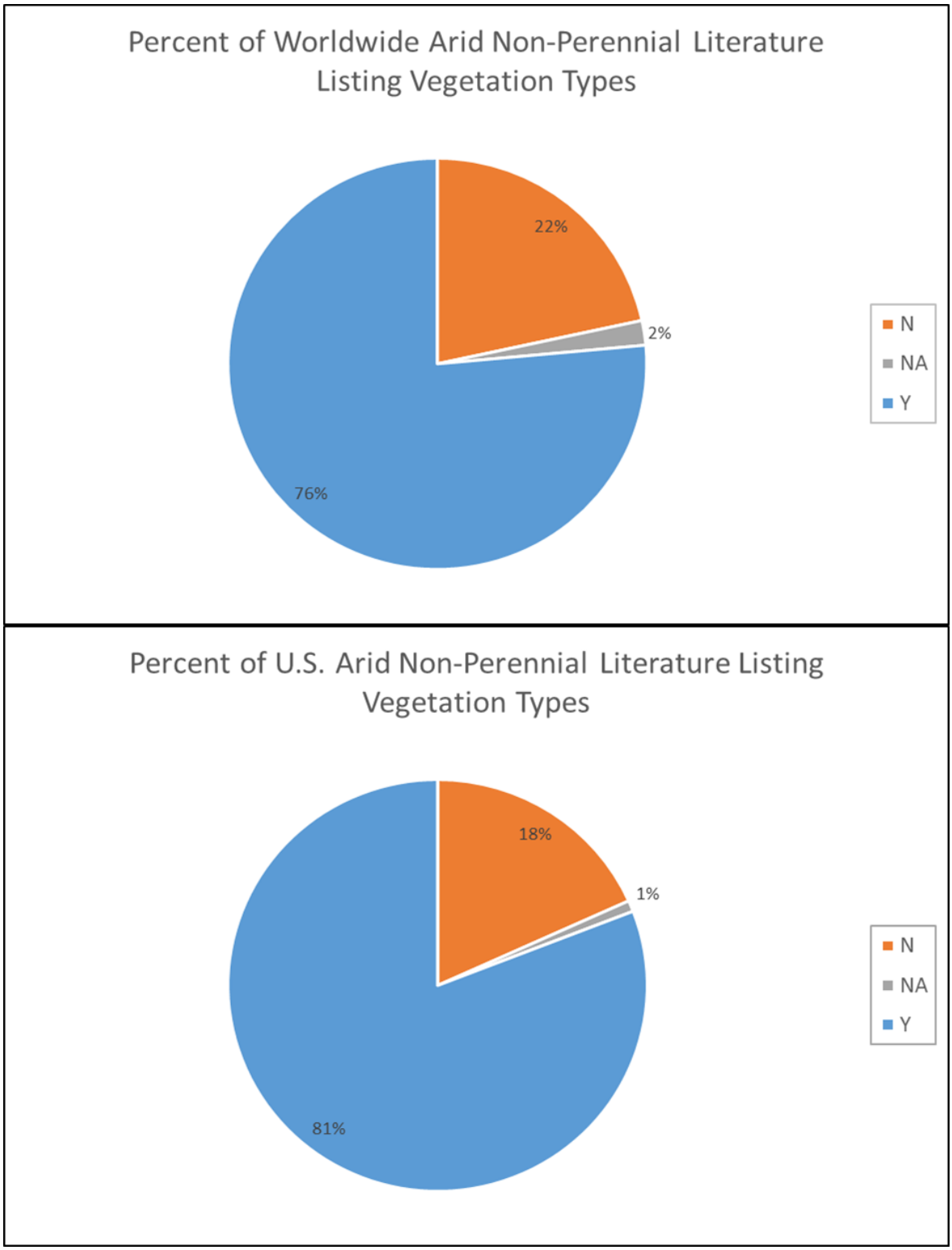


Figure 303. The provision of listed vegetation type(s) within arid non-perennial stream literature worldwide and in the U.S.

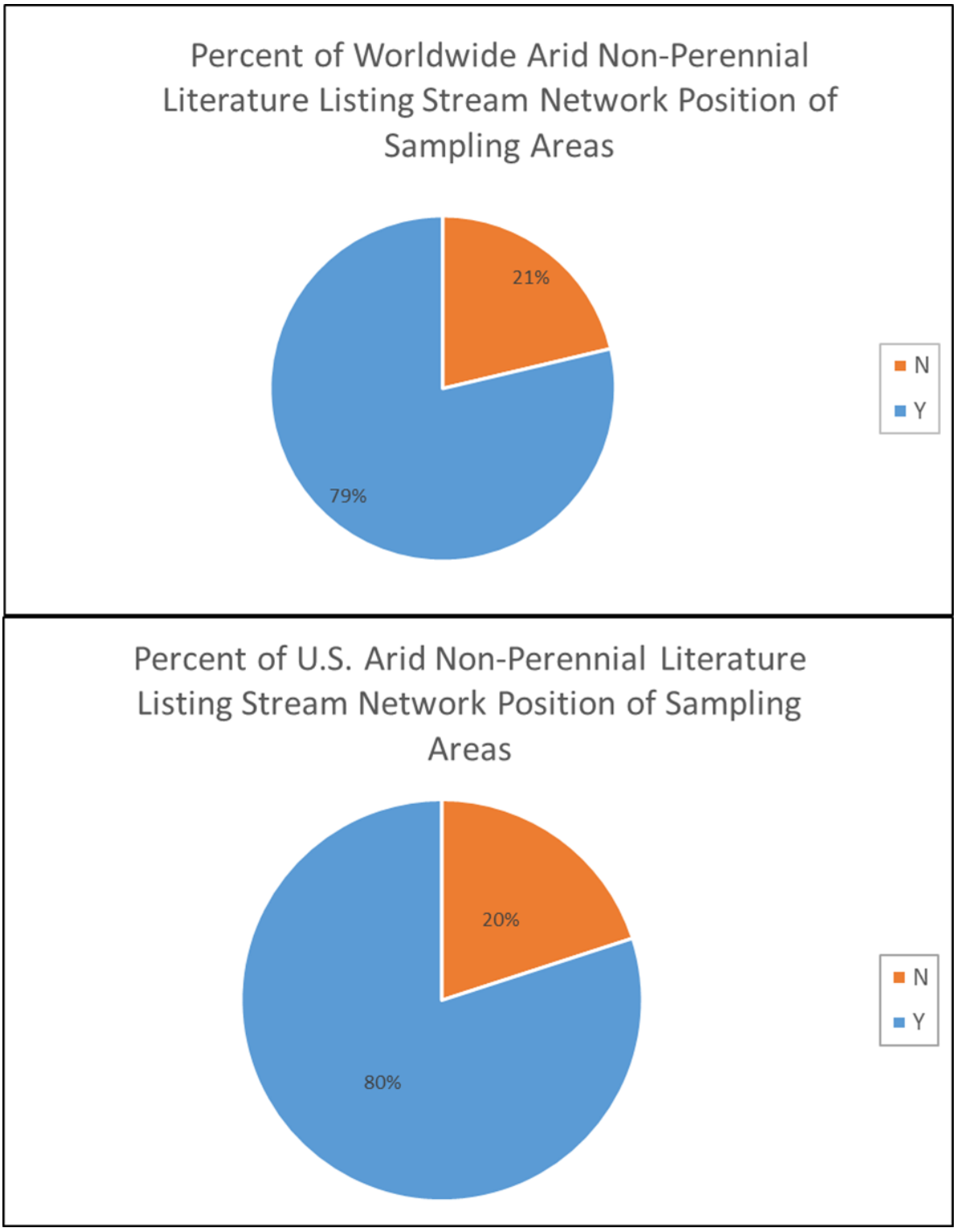


Figure 304. The provision of sampling area(s) stream network position(s) within arid non-perennial stream literature worldwide and in the U.S.

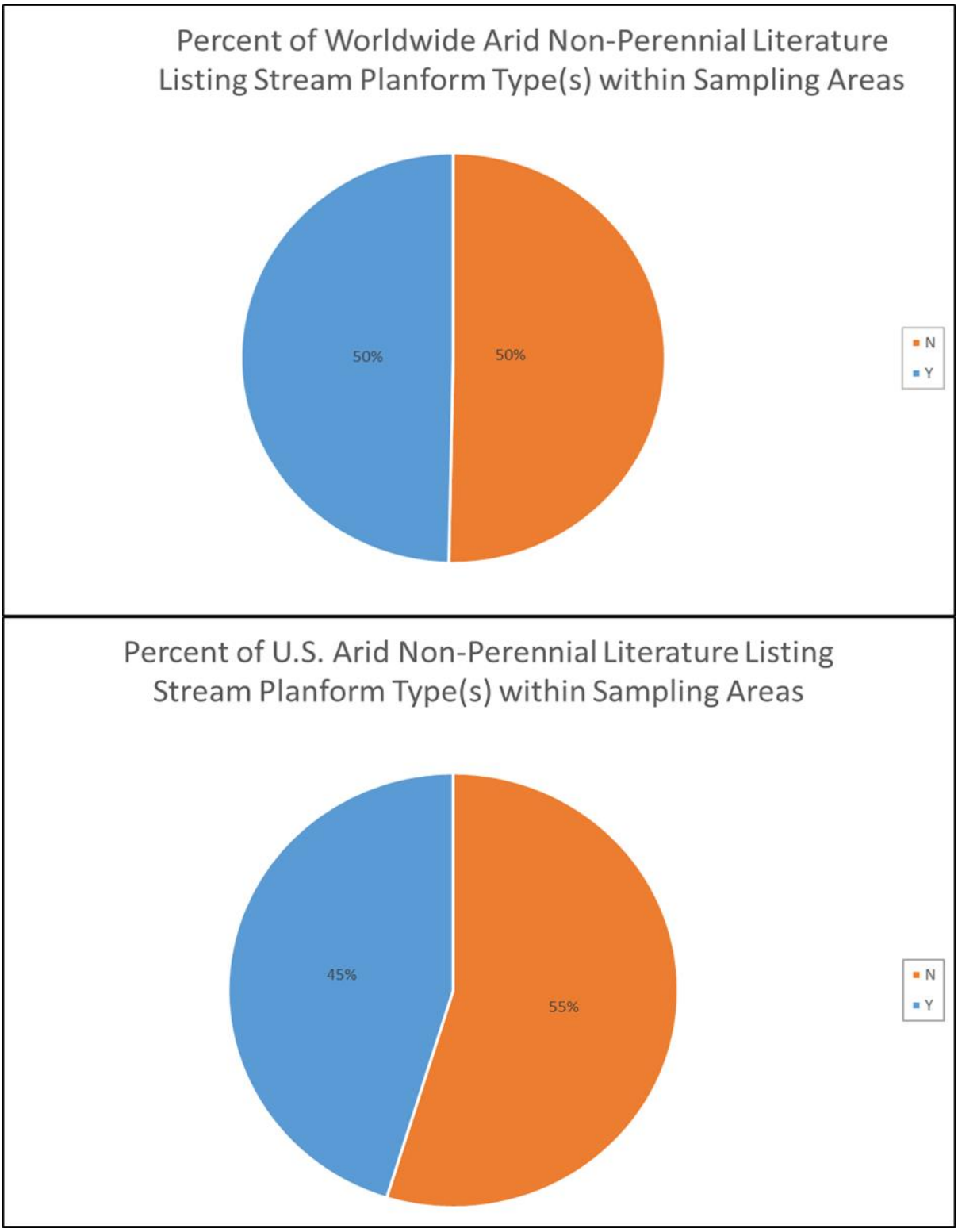


Figure 305. The provision of stream planform type(s) within arid non-perennial stream literature worldwide and in the U.S.

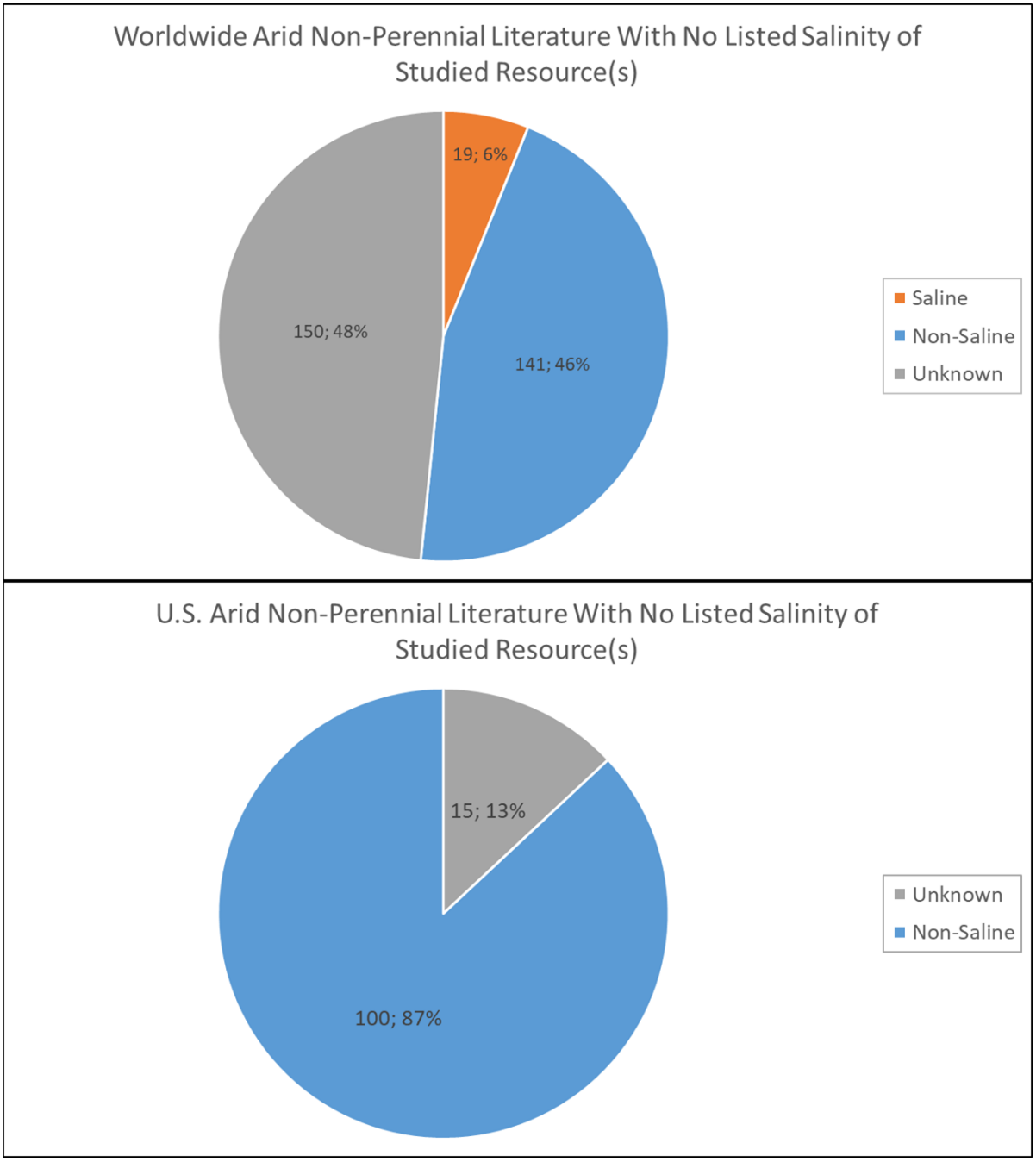


Figure 306. The provision of salinity information of sampling sites within arid non-perennial stream literature worldwide and in the U.S.

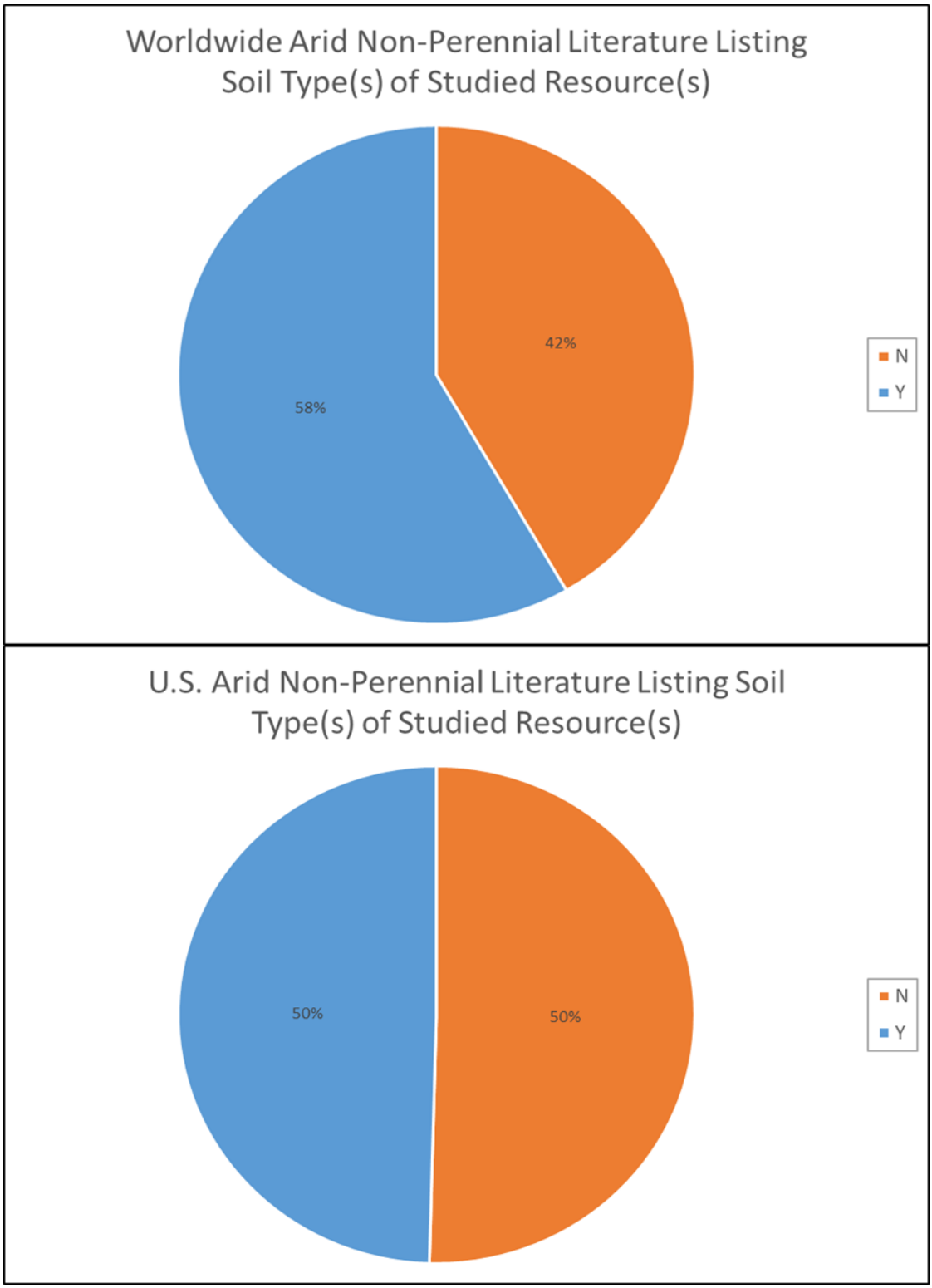


Figure 307. The provision of soils information of sampling sites within arid non-perennial stream literature worldwide and in the U.S.

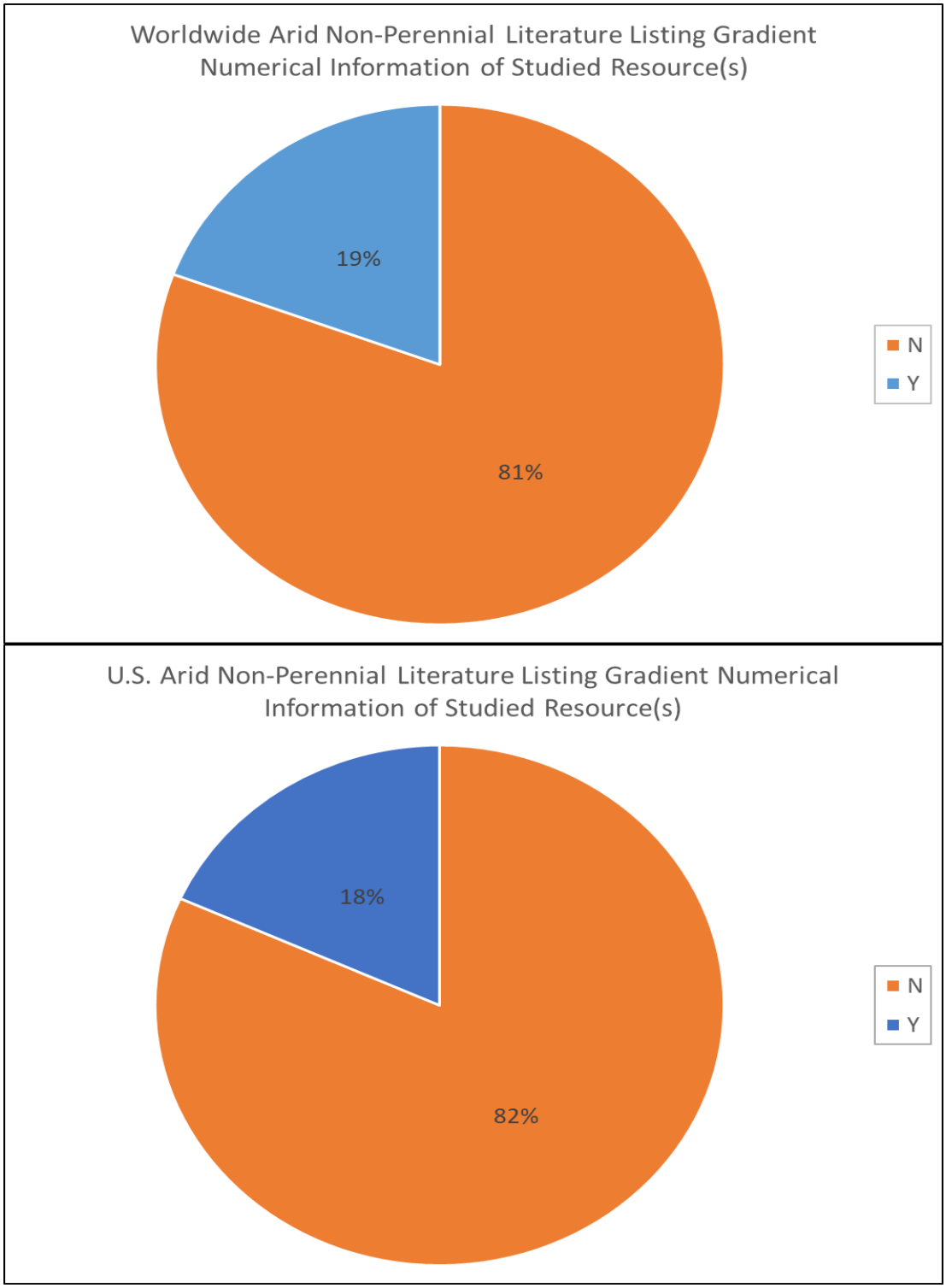


Figure 308. The provision of gradient information of sampling sites within arid non-perennial stream literature worldwide.

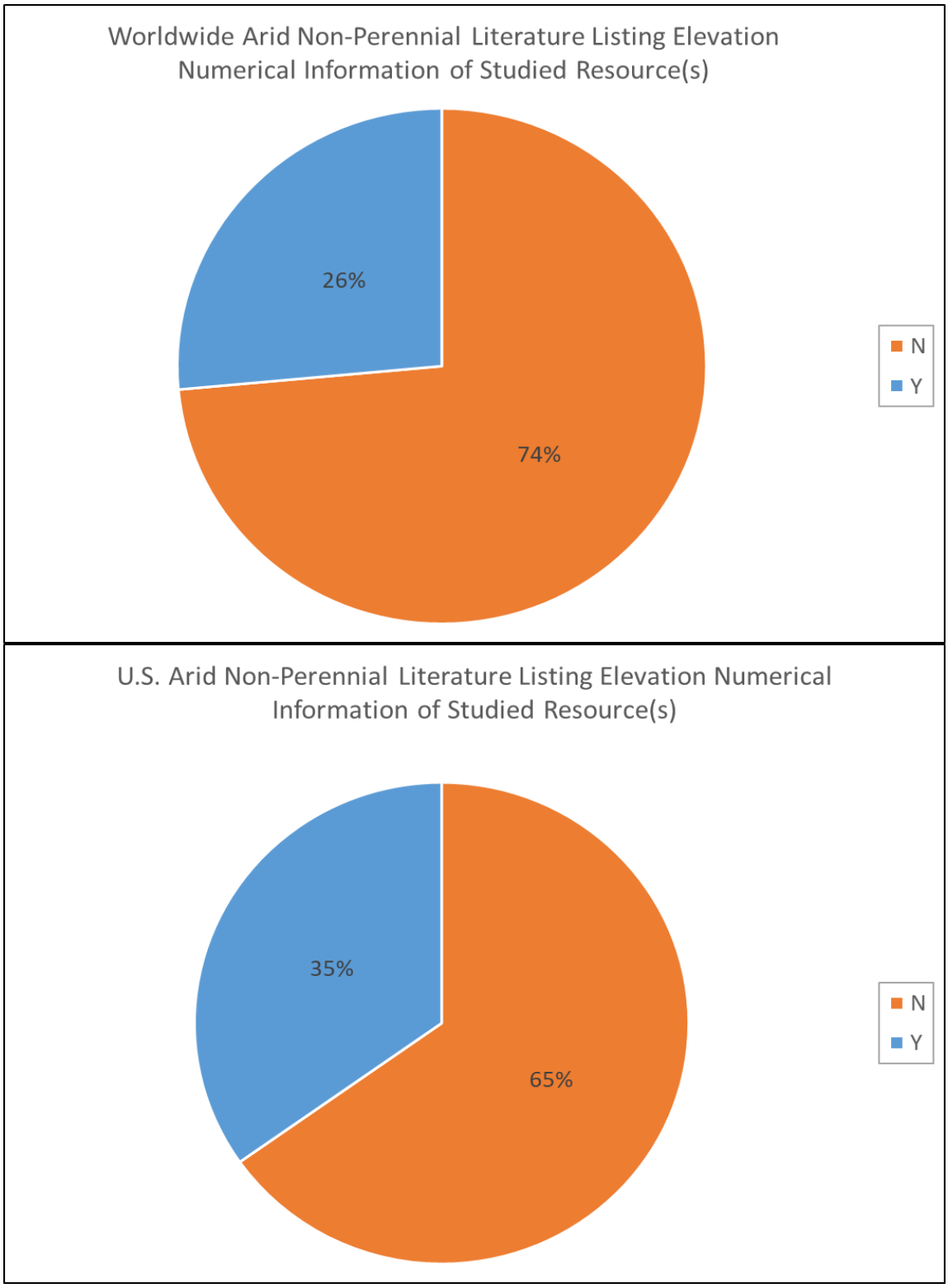


Figure 309. The provision of elevation information of sampling sites within arid non-perennial stream literature worldwide.

Appendix H: References of Arid Non-Perennial Stream Literature Set

Abdalla, F. E. S., I.; Bamousa, A. O.; Mansour, A.; Mohamed, A.; Tahoon, M. (2014). Flash Floods and Groundwater Recharge Potentials in Arid Land Alluvial Basins, Southern Red Sea Coast, Egypt. International Journal of Geosciences, 5(9), 971-982.

Abdulaziz, A. M. H., Jose M.; Faid, Abdalla. (2012). Hydrogeological characterization of Gold Valley: an investigation of precipitation recharge in an intermountain basin in the Death Valley region, California, USA. [Caracterisation hydrogeologique de la Gold Valley; une etude de la recharge par les precipitations dans un bassin intra montagneux de la region de la Vallee de la Mort, Californie, USA]. Hydrogeology Journal, 20(4), 701-718. doi:http://dx.doi.org/10.1007/s10040-012-0840-8

Abed, R. M. M. K., Tatiana; Gajdos, Peter; Certik, Milan. (2015). Bacterial diversity and fatty acid composition of hypersaline cyanobacterial mats from an inland desert wadi. Journal of Arid Environments, 115, 81-89. doi:http://dx.doi.org/10.1016/j.jaridenv.2015.01.010

Abellán, P. S.-F., David; Velasco, Josefa; Millán, Andrés. (2007). Effectiveness of protected area networks in representing freshwater biodiversity: the case of a Mediterranean river basin (south-eastern Spain). Aquatic Conservation: Marine and Freshwater Ecosystems, 17(4), 361-374. doi:10.1002/aqc.778

Acuña, V. D., Clifford N. (2007). Impact of monsoonal rains on spatial scaling patterns in water chemistry of a semiarid river network. Journal of Geophysical Research: Biogeosciences, 112(G4), 1-11. doi:10.1029/2007JG000493

Acworth, R. I. R., G. C.; Cuthbert, M. O.; Jensen, E.; Leggett, K. (2016). Long-term spatio-temporal precipitation variability in arid-zone Australia and implications for groundwater recharge. Hydrogeology Journal, 24(4), 905-921. doi:10.1007/s10040-015-1358-7

Adams, E. A. M., Stephen A.; Springer, Abraham E.; Blasch, Kyle W.; Bills, Donald J. (2006). Electrical resistance sensors record spring flow timing, Grand Canyon, Arizona. Ground Water, 44(5), 630-641. doi:http://dx.doi.org/10.1111/j.1745-6584.2006.00223.x

Aerts, R. V. O., K.; Haile, M.; Hermy, M.; Deckers, J.; Muys, B. (2006). Species composition and diversity of small Afromontane forest fragments in northern Ethiopia. Plant Ecology, 187(1), 127-142. doi:10.1007/s11258-006-9137-0

Al-Qudah, O. M. W., John C.; Woocay, Arturo. (2015). Chemistry and evolution of desert ephemeral stream runoff. Journal of Arid Environments, 122, 169-179. doi:10.1016/j.jaridenv.2015.06.010

Al-Rowaily, S. L. E.-B., M. I.; Al-Dujain, F. A. R. (2012). Changes in vegetation composition and diversity in relation to morphometry, soil and grazing on a hyper-arid watershed in the central Saudi Arabia. Catena, 97, 41-49. doi:10.1016/j.catena.2012.05.004

Allen, D. C. M., Kevin E.; Elser, Stephen R.; Sabo, John L. (2014). Water as a trophic currency in dryland food webs. Frontiers in Ecology and the Environment, 12(3), 156-160.

Allsopp, N. G., L.; Knight, R.; Monakisi, C.; Hoffman, M. T. (2007). The impact of heavy grazing on an ephemeral river system in the succulent karoo, South Africa. Journal of Arid Environments, 71(1), 82-96. doi:http://dx.doi.org/10.1016/j.jaridenv.2007.03.001

Alpers, C. N. W., Donald O. (1990). Hydrogeochemistry and stable isotopes of ground and surface waters from two adjacent closed basins, Atacama Desert, northern Chile. Applied Geochemistry, 5(5–6), 719-734. doi:https://doi.org/10.1016/0883-2927(90)90067-F

Alvarado-Castro, J. A. J., María Luisa. (2011). Reproductive behavior of Homalonychus selenopoides (Araneae: Homalonychidae). Journal of Arachnology, 39(1), 118-127. doi:10.1636/Hi10-35.1

Alvarez-Cobelas, M. S.-A., R.; Sánchez-Carrillo, S.; Angeler, D. G. (2010). Nutrient contents and export from streams in semiarid catchments of central Spain. Journal of Arid Environments, 74(8), 933-945. doi:https://doi.org/10.1016/j.jaridenv.2010.01.002

Amos, K. J. C., J. C.; Hughes, A. O.; Chapman, J.; Takken, I.; Lymburner, L. (2008). A catchment-scale assessment of anabranching in the 143000 km(2) Fitzroy River catchment, north-eastern Australia. Earth Surface Processes and Landforms, 33(8), 1222-1241. doi:10.1002/esp.1609

Arce, M. I. S.-M., Maria del Mar; Gomez, Rosa. (2015). Nitrogen processing following experimental sediment rewetting in isolated pools in an agricultural stream of a semiarid region. Ecological Engineering, 77, 233-241. doi:http://dx.doi.org/10.1016/j.ecoleng.2015.01.035

Arce, M. I. v. S., Daniel; Gomez, Rosa. (2014). Variation in nitrate uptake and denitrification rates across a salinity gradient in Mediterranean semiarid streams. Aquatic Sciences, 76(2), 295-311. doi:10.1007/s00027-014-0336-9

Arthington, A. H. O., Julian D.; Balcombe, Stephen R.; Thoms, Martin C. (2010). Multi-scale environmental factors explain fish losses and refuge quality in drying waterholes of Cooper Creek, an Australian arid-zone river. Marine & Freshwater Research, 61(8), 842-856. doi:http://dx.doi.org/10.1071/MF09096

Arzani, N. (2007). Playa-Lake Level Fluctuation and Recent Sediments of a Terminal Fan-Playa Fringe, Abarkoh Basin, Central Iran. Journal of Sciences, Islamic Republic of Iran, 18(1), 19-33.

Bagstad, K. J. S., J. C.; Lite, S. J. (2005). Response of herbaceous riparian plants to rain and flooding on the San Pedro River, Arizona, USA. Wetlands, 25(1), 210-223. doi:10.1672/0277-5212(2005)025[0210:rohrpt]2.0.co;2

Balcombe, B., S. E.; McKenzie-Smith, F. J.; Davies, P. M. (2005). Variability of fish diets between dry and flood periods in an arid zone floodplain river. Journal of Fish Biology, 67(6), 1552-1567. doi:http://dx.doi.org/10.1111/j.1095-8649.2005.00858.x

Banville, M. J. B., H. L.; Earl, S. R.; Warren, P. S. (2017). Decadal declines in bird abundance and diversity in urban riparian zones. Landscape and Urban Planning, 159, 48-61. doi:10.1016/j.landurbplan.2016.09.026

Barela, I. A. F., J. K. (2016). Habitat and Forage Selection by the American Beaver (Castor Canadensis) on a Regulated River in the Chihuahuan Desert. Southwestern Naturalist, 61(4), 286-293. doi:Doi 10.1894/0038-4909-61.4.286

Barthold, F. K. W., Jinkui; Vaché, Kellie B.; Schneider, Katrin; Frede, Hans-Georg; Breuer, Lutz. (2010). Identification of geographic runoff sources in a data sparse region: hydrological processes and the limitations of tracer-based approaches. Hydrological Processes, 24(16), 2313-2327. doi:10.1002/hyp.7678

Bateman, H. L. S., J. C.; Banville, M. J.; Makings, E.; Scott, B. D.; Suchy, A.; Wolkis, D. (2015). Novel water sources restore plant and animal communities along an urban river. Ecohydrology, 8(5), 792-811. doi:http://dx.doi.org/10.1002/eco.1560

Bendavid-Novak, H. S., Asher P. (1997). The response of Acacia tree populations on small alluvial fans to changes in the hydrological regime: Southern Negev Desert, Israel. Catena, 29(3-4), 341-351. doi:10.1016/s0341-8162(96)00066-5

Benito, G. R., R.; Seely, M.; Kulls, C.; Dahan, O.; Enzel, Y.; Todd, S.; Botero, B.; Morin, E.; Grodek, T.; Roberts, C. (2010). Management of Alluvial Aquifers in Two Southern African Ephemeral Rivers: Implications for IWRM. Water Resources Management, 24(4), 641-667. doi:10.1007/s11269-009-9463-9

Bestland, E. G., Amy; Green, Graham; Olifent, Vanessa; Mackay, Duncan; Whalen, Molly. (2017). Groundwater dependent pools in seasonal and permanent streams in the Clare Valley of South Australia. Journal of Hydrology: Regional Studies, 9, 216-235. doi:https://doi.org/10.1016/j.ejrh.2016.12.087

Blinn, D. W. R., D. E. (2009). Caddisfly (Trichoptera) Assemblages Along Major River Drainages in Arizona. Western North American Naturalist, 69(3), 299-308. doi:Doi 10.3398/064.069.0303

Boersma, K. S. B., Michael T.; Henrichs, Brian A.; Lytle, David A. (2014). Invertebrate assemblages of pools in arid-land streams have high functional redundancy and are resistant to severe drying. Freshwater Biology, 59(3), 491-501. doi:http://dx.doi.org/10.1111/fwb.12280

Bogan, M. T. B., K. S. (2012). Aerial dispersal of aquatic invertebrates along and away from arid-land streams. Freshwater Science, 31(4), 1131-1144. doi:10.1899/12-066.1

Bogan, M. T. B., Kate S.; Lytle, David A. (2013). Flow intermittency alters longitudinal patterns of invertebrate diversity and assemblage composition in an arid-land stream network. Freshwater Biology, 58(5), 1016-1028. doi:http://dx.doi.org/10.1111/fwb.12105

Bourke, M. C. (2002). Suspended sediment concentrations and the geomorphic effect of sub-bankfull flow in a central Australian stream. IAHS-AISH Publication, 276, 315-324.

Bradford, D. F. N., A. C.; Nash,; Sada, D. W.; Jaeger, J. R. (2003). Habitat patch occupancy by toads (Bufo punctatus) in a naturally fragmented desert landscape. Ecology, 84(4), 1012-1023.

Brand, L. A. D., M. D.; Fetz, T.; Stromberg, J. C.; Stewart, S.; Garber, G.; Goodrich, D. C.; Brookshire, D. S.; Broadbent, C. D.; Benedict, K. (2013). Projecting Avian Responses to Landscape Management Along the Middle Rio Grande, New Mexico. Southwestern Naturalist, 58(2), 150-162. doi:10.1894/0038-4909-58.2.150

Brand, L. W., Gary C.; Noon, Barry R. (2008). Factors Influencing Species Richness and Community Composition of Breeding Birds in a Desert Riparian Corridor. Condor, 110(2), 199-210. doi:http://dx.doi.org/10.1525/cond.2008.8421

Brooks, P. D. H., Peter A.; Huth, Anne K. (2007). Seasonal variability in the concentration and flux of organic matter and inorganic nitrogen in a semiarid catchment, San Pedro River, Arizona. Journal of Geophysical Research: Biogeosciences, 112(G3), 1-11. doi:10.1029/2006JG000275

Brooks, P. D. L., Michelle M. (2007). Spatial variability in dissolved organic matter and inorganic nitrogen concentrations in a semiarid stream, San Pedro River, Arizona. Journal of Geophysical Research. G. Biogeosciences, 112(G3), 1-11. doi:http://dx.doi.org/10.1029/2006JG000262

Bruno, D. G.-C., C.; Sanchez-Fernandez, D.; Velasco, J.; Nilsson, C. (2016). Impacts of environmental filters on functional redundancy in riparian vegetation. Journal of Applied Ecology, 53(3), 846-855. doi:10.1111/1365-2664.12619

Bruno, D. G.-C., C.; Velasco, J.; Sanchez-Fernandez, D. (2016). Functional redundancy as a tool for bioassessment: A test using riparian vegetation. Science of the Total Environment, 566, 1268-1276. doi:10.1016/j.scitotenv.2016.05.186

Cadol, D. W., M. L. (2017). Geomorphology as a first order control on the connectivity of riparian ecohydrology. Geomorphology, 277, 154-170. doi:10.1016/j.geomorph.2016.06.022
Callegary, J. B. L., J. M.; Paretti, N. V.; Jones, C. A. (2007). Rapid estimation of recharge potential in ephemeral-stream channels using electromagnetic methods, and measurements of channel and vegetation characteristics. Journal of Hydrology, 344(1-2), 17-31. doi:10.1016/j.jhydrol.2007.06.028

Camarasa-Belmonte, A. M. (2016). Flash floods in Mediterranean ephemeral streams in Valencia Region (Spain). Journal of Hydrology, 541, 99-115. doi:10.1016/j.jhydrol.2016.03.019

Camarasa-Belmonte, A. M. S. B., Francesca. (2001). Flood events in Mediterranean ephemeral streams (ramblas) in Valencia region, Spain. Catena, 45(3), 229-249. doi:10.1016/s0341-8162(01)00146-1

Canedo-Arguelles, M. B., Michael T.; Lytle, David A.; Prat, Narcis. (2016). Are Chironomidae (Diptera) good indicators of water scarcity? Dryland streams as a case study. Ecological Indicators, 71, 155-162. doi:http://dx.doi.org/10.1016/j.ecolind.2016.07.002

Canedo-Arguelles, M. B., Kate S.; Bogan, Michael T.; Olden, Julian D.; Phillipsen, Ivan; Schriever, Tiffany A.; Lytle, David A.; Ladle, Richard. (2015). Dispersal strength determines meta-community structure in a dendritic riverine network. Journal of biogeography., 42(4), 778-790.

Cantalice, J. R. B. M., R. O.; Silva, Yjab; Cunha Filho, M.; Araujo, A. M.; Vieira, L. P.; Bezerra, S. A.; Barros, G., Jr.; Singh, Vijay P. (2015). Hydraulic roughness due to submerged, emergent and flexible natural vegetation in a semiarid alluvial channel. Journal of Arid Environments, 114, 1-7. doi:http://dx.doi.org/10.1016/j.jaridenv.2014.10.012

Capon, S. J. (2003). Plant community responses to wetting and drying in a large arid floodplain. River Research and Applications, 19(5-6), 509-520. doi:10.1002/rra.730

Carini, G. H., J. M.; Bunn, S. E. (2006). The role of waterholes as ‘refugia’ in sustaining genetic diversity and variation of two freshwater species in dryland river systems (Western Queensland, Australia). Freshwater Biology, 51(8), 1434-1446. doi:10.1111/j.1365-2427.2006.01585.x

Castillo, V. M. M., W. M.; Garcia, C. Conesa; Barbera, G. G.; Cano, J. A. Navarro; Lopez-Bermudez, F. (2007). Effectiveness and geomorphological impacts of check dams for soil erosion control in a semiarid Mediterranean catchment: El Carcavo (Murcia, Spain). Catena, 70(3), 416-427. doi:10.1016/j.catena.2006.11.009

Castro-Larragoitia, J. K., U.; Monroy-Fernandez, M. G.; Viera-Decida, F.; Garcia-Gonzalez, E. G. (2013). Heavy metal and arsenic dispersion in a copper-skarn mining district in a Mexican semi-arid environment: sources, pathways and fate. Environmental Earth Sciences, 69(6), 1915-1929. doi:10.1007/s12665-012-2024-1

Cerasale, D. J. G., Christopher G. (2010). An Integrative Assessment of the Effects of Tamarisk on Stopover Ecology of a Long-Distance Migrant Along the San Pedro River, Arizona The Auk, 127(3), 636-646. doi:10.1525/auk.2010.09124
Chen, Y. C., Yapeng; Xu, Changchun; Ye, Zhaoxia; Li, Zhongqin; Zhu, Chenggang; Ma, Xiaodong. (2010). Effects of ecological water conveyance on groundwater dynamics and riparian vegetation in the lower reaches of Tarim River, China. Hydrological Processes, 24(2), 170-177. doi:http://dx.doi.org/10.1002/hyp.7429

Chen, Y. L., Weihong; Zhou, Honghua; Chen, Yapeng; XinmingHao,; Fu, Aihong; Ma, Jianxin. (2017). Experimental study on water transport observations of desert riparian forests in the lower reaches of the Tarim River in China. International Journal of Biometeorology, 61(6), 1055-1062. doi:10.1007/s00484-016-1285-x

Choudhari, J. S. (1985). Dissolved Inorganic Phosphorus in Streams of the Indian Arid Zone. Journal of Hydrology, 78(1-2), 49-59. doi:Doi 10.1016/0022-1694(85)90153-2

Choy, S. C. T., C. B.; Marshall, J. C. (2002). Ecological condition of central Australian arid-zone rivers. Water Science and Technology, 45(11), 225-232.

Cohen, H. L., J. B. (2005). High rates of sediment transport by flashfloods in the Southern Judean Desert, Israel. Hydrological Processes, 19(8), 1687-1702. doi:10.1002/hyp.5630

Cohen, H. L., J. B.; Reid, I. (2010). Simplicity and complexity of bed load response during flash floods in a gravel bed ephemeral river: A 10 year field study. Water Resources Research, 46, 1-14. doi:10.1029/2010wr009160

Conesa-Garcia, C. G.-L., R. (2009). Effectiveness of check dams in the control of general transitory bed scouring in semiarid catchment areas (South-East Spain). Water and Environment Journal, 23(1), 1-14. doi:10.1111/j.1747-6593.2007.00099.x

Costelloe, J. F. I., Elizabeth C.; Western, Andrew W.; Herczeg, Andrew L. (2009). Groundwater recharge and discharge dynamics in an arid-zone ephemeral lake system, Australia. Limnology and Oceanography, 54(1), 86-100. doi:10.4319/lo.2009.54.1.0086

Costelloe, J. F. R., K. L. (2014). Identifying conservation priorities for aquatic refugia in an arid zone, ephemeral catchment: a hydrological approach. Ecohydrology, 7(6), 1534-1544. doi:10.1002/eco.1476

Costelloe, J. F. S., A.; Grayson, R. B.; McMahon, T. A. (2007). Determining loss characteristics of arid zone river waterbodies. River Research and Applications, 23(7), 715-731. doi:10.1002/rra.991

Costelloe, J. W., A.; Irvine, E.; Herczeg, A. (2005). Recharge Rates to Shallow Groundwater from Streamflow in Arid Zone Catchments. Modsim 2005: International Congress on Modelling and Simulation: Advances and Applications for Management and Decision Making: Advances and Applications for Management and Decision Making, 2897-2903.

Cowley, D. E. W., R. C.; Sallenave, R. (2007). Fish assemblages and seasonal movements of fish in irrigation canals and river reaches of the middle Rio Grande, New Mexico (USA). Ecology of Freshwater Fish, 16(4), 548-558. doi:10.1111/j.1600-0633.2007.00250.x

Dansie, A. P. W., G. F. S.; Thomas, D. S. G. (2017). Iron and nutrient content of wind-erodible sediment in the ephemeral river valleys of Namibia. Geomorphology, 290, 335-346. doi:10.1016/j.geomorph.2017.03.016

Davies, N. S. S., Anthony P.; McMahon, William J. (2017). Short-Term Evolution of Primary Sedimentary Surface Textures (Microbial, Abiotic, Ichnological) on a Dry Stream Bed: Modern Observations and Ancient Implications. Palaios, 32(3), 125-134. doi:10.2110/palo.2016.064

de Araújo, J. C. G. P., Julio Iván. (2009). Comparative hydrology: analysis of a semiarid and a humid tropical watershed. Hydrological Processes, 23(8), 1169-1178. doi:10.1002/hyp.7232

De Boer, D. H. (1992). Constraints on spatial transference of rainfall-runoff relationships in semiarid basins drained by ephemeral streams. Hydrological Sciences Journal, 37(5), 491-504. doi:10.1080/02626669209492614

De Boer, D. H. C., Ian A. (1990). Runoff chemistry as an indicator of runoff sources and routing in semi-arid, badland drainage basins. Journal of Hydrology, 121(1-4), 379-394. doi:10.1016/0022-1694(90)90242-p

de Figueiredo, J. V. d. A., José Carlos; Medeiros, Pedro Henrique Augusto; Costa, Alexandre C. (2016). Runoff initiation in a preserved semiarid Caatinga small watershed, Northeastern Brazil. Hydrological Processes, 30(13), 2390-2400. doi:10.1002/hyp.10801

de Soyza, A. G. K., K. T.; Whitford, W. G. (2004). Plant water relations and photosynthesis during and after drought in a Chihuahuan desert arroyo. Journal of Arid Environments, 59(1), 27-39. doi:http://dx.doi.org/10.1016/j.jaridenv.2004.01.011

del Campo, R. G., Rosa. (2016). Exposure of wood in floodplains affects its chemical quality and its subsequent breakdown in streams. Science of the Total Environment, 543, Part A, 652-661. doi:https://doi.org/10.1016/j.scitotenv.2015.11.050

Delemos, J. L. B., Benjamin C.; Quicksall, Andrew N.; Landis, Joshua D.; George, Christine C.; Slagowski, Naomi L.; Rock, Tommy; Brugge, Doug; Lewis, Johnnye; Durant, John L. (2008). Rapid Dissolution of Soluble Uranyl Phases in Arid, Mine-Impacted Catchments near Church Rock, NM. Environmental Science & Technology, 42(11), 3951-3957.

DeLong, S. B. J., Joel P. L.; Whipple, Kelin X. (2014). Arroyo channel head evolution in a flash-flood-dominated discontinuous ephemeral stream system. Geological Society of America Bulletin, 126(11-12), 1683-1701. doi:http://dx.doi.org/10.1130/B31064.1

Dent, C. L. G., Nancy B.; Martí, Eugènia; Edmonds, Jennifer W.; Henry, Julia Curro; Welter, Jill R. (2007). Variability in surface-subsurface hydrologic interactions and implications for nutrient retention in an arid-land stream. Journal of Geophysical Research: Biogeosciences, 112(G4), 1-13. doi:10.1029/2007JG000467

Diaz, A. M. A., Maria Luisa Suarez; Gutierrez, Maria Rosario Vidal-Abarca. (2008). Biological traits of stream macroinvertebrates from a semi-arid catchment: patterns along complex environmental gradients. Freshwater Biology, 53(1), 1-21. doi:http://dx.doi.org/10.1111/j.1365-2427.2007.01854.x

Dogramaci, S. S., Grzegorz; Dodson, Wade; Grierson, Pauline F. (2012). Stable isotope and hydrochemical evolution of groundwater in the semi-arid Hamersley Basin of subtropical northwest Australia. Journal of Hydrology, 475, 281-293. doi:10.1016/j.jhydrol.2012.10.004

Dunkerley, D. L. (1992). Channel geometry, bed material, and inferred flow conditions in ephemeral stream systems, barrier range, western N.S.W. Australia. Hydrological Processes, 6(4), 417-433. doi:10.1002/hyp.3360060404

Dzikiti, S. S., K.; Naiken, V.; Gush, M.; Moses, G.; Le Maitre, D. C. (2013). Water relations and the effects of clearing invasive Prosopis trees on groundwater in an arid environment in the Northern Cape, South Africa. Journal of Arid Environments, 90, 103-113. doi:10.1016/j.jaridenv.2012.10.015

El-Hasan, T. J., A. (2001). Heavy metal distribution in valley sediments in wadi Al-Karak catchment area, south Jordan. Environmental Geochemistry and Health, 23(2), 105-116. doi:10.1023/a:1010918014577

Ellis, M. V. T., J. E.; Rayner, L. (2017). Growth characteristics of Eucalyptus camaldulensis trees differ between adjacent regulated and unregulated rivers in semi-arid temperate woodlands. Forest Ecology and Management, 398, 1-9. doi:10.1016/j.foreco.2017.05.004

Faithful, J. W. G., Dilwyn J. (2000). Turbid flow through a tropical reservoir (Lake Dalrymple, Queensland, Australia): Responses to a summer storm event. Lakes & Reservoirs: Research & Management, 5(4), 231-247. doi:10.1046/j.1440-1770.2000.00123.x

Fall, P. L. (1987). Pollen Taphonomy in a Canyon Stream. Quaternary Research, 28(3), 393-406. doi:Doi 10.1016/0033-5894(87)90006-8

Fellman, J. B. P., K. C.; Grierson, P. F. (2013). Leaf litter age, chemical quality, and photodegradation control the fate of leachate dissolved organic matter in a dryland river. Journal of Arid Environments, 89, 30-37. doi:10.1016/j.jaridenv.2012.10.011

Free, C. L. B., G. S.; Dickman, C. R.; Lisle, A.; Leung, L. K. P. (2015). Diversity and Community Composition of Vertebrates in Desert River Habitats. PLoS One, 10(12), 1-18. doi:10.1371/journal.pone.0144258; http://dx.doi.org/10.1371/journal.pone.0144258

Free, C. L. B., Greg S.; Dickman, Christopher R.; Leung, Luke K. P. (2013). Resource Pulses in Desert River Habitats: Productivity-Biodiversity Hotspots, or Mirages? PLoS One, 8(10), 1-13. doi:10.1371/journal.pone.0072690

Galal, T. M. F., A. G. (2012). Plant diversity and community structure of Wadi Gimal protected area, Red Sea Coast of Egypt. African Journal of Ecology, 50(3), 266-276. doi:10.1111/j.1365-2028.2012.01320.x

Gallardo, B. D., Sylvain; Paillex, Amael; Arscott, David B.; Sheldon, Fran; Zilli, Florencia; Mérigoux, Sylvie; Castella, Emmanuel; Comín, Francisco A. (2014). Response of benthic macroinvertebrates to gradients in hydrological connectivity: a comparison of temperate, subtropical, Mediterranean and semiarid river floodplains. Freshwater Biology, 59(3), 630-648. doi:10.1111/fwb.12292

Gallo, E. L. B., Paul D.; Lohse, Kathleen A.; McLain, Jean E. T. (2013). Land cover controls on summer discharge and runoff solution chemistry of semi-arid urban catchments. Journal of Hydrology (Amsterdam), 485(Sp. Iss. SI), 37-53. doi:10.1016/j.jhydrol.2012.11.054

Gallo, E. L. L., K. A.; Brooks, P. D.; McIntosh, J. C.; Meixner, T.; McLain, J. E. T. (2012). Quantifying the effects of stream channels on storm water quality in a semi-arid urban environment. Journal of Hydrology, 470, 98-110. doi:10.1016/j.jhydrol.2012.08.047

Gardner, J. L. (1951). Vegetation of the creosotebush area of the Rio Grande Valley in New Mexico. Ecological Monographs, 21((4)), 379-403. doi:10.2307/1948655

Gazal, R. M. S., R. L.; Goodrich, D. C.; Williams, D. G. (2006). Controls on transpiration in a semiarid riparian cottonwood forest. Agricultural and Forest Meteorology, 137(1-2), 56-67. doi:10.1016/j.agrformet.2006.03.002

Ghalib, H. B. S., Ali Riza. (2014). Environmental Isotopic Characterization of Groundwater and Surface Water in Northeast Missan Province, South Iraq. Acta Geologica Sinica - English Edition, 88(4), 1227-1238. doi:10.1111/1755-6724.12285

Gombeer, S. R., J. B.; Eckardt, F. D.; Seely, M.; Cowan, D. A. (2015). The influence of surface soil physicochemistry on the edaphic bacterial communities in contrasting terrain types of the Central Namib Desert. Geobiology, 13(5), 494-505. doi:10.1111/gbi.12144

Gómez, R. A., Antonia Dolores; Picón, José María; Del Campo, Rubén; Arce, María Isabel; del Mar Sánchez-Montoya, María; Suárez, María Luisa; Vidal-Abarca, María Rosario. (2016). The effect of water salinity on wood breakdown in semiarid Mediterranean streams. Science of the Total Environment, 541, 491-501. doi:https://doi.org/10.1016/j.scitotenv.2015.09.040

Gómez, R. G., Victoria; Vidal-Abarca, Rosario; Suárez, Luisa. (2009). Effect of intermittency on N spatial variability in an arid Mediterranean stream. Journal of the North American Benthological Society, 28(3), 572-583. doi:10.1899/09-016.1
Gómez, R. H., I.; Suárez, M. L.; Vidal-Abarca, M. R. (2005). Ramblas in south-east Spain: threatened and valuable ecosystems. Aquatic Conservation: Marine and Freshwater Ecosystems, 15(4), 387-402. doi:10.1002/aqc.680

Gonzalez-Alcaraz, M. N. J.-C., F. J.; Alvarez, Y.; Alvarez-Rogel, J. (2014). Gradients of soil salinity and moisture, and plant distribution, in a Mediterranean semiarid saline watershed: a model of soil-plant relationships for contributing to the management. Catena, 115, 150-158. doi:10.1016/j.catena.2013.11.011

Gonzalez-Fernandez, O. J.-R., A. M.; Queralt, I. (2011). Geochemical and Mineralogical Features of Overbank and Stream Sediments of the Beal Wadi (Cartagena-La Union Mining District, SE Spain): Relation to Former Lead-Zinc Mining Activities and Its Environmental Risk. Water Air and Soil Pollution, 215(1-4), 55-65. doi:10.1007/s11270-010-0458-1

Graf, W. L. (1983). Flood-related channel change in an arid-region river. Earth Surface Processes and Landforms, 8(2), 125-139. doi:10.1002/esp.3290080204

Graf, W. L. (1985). Mercury Transport in Stream Sediments of the Colorado Plateau. Annals of the Association of American Geographers, 75(4), 552-565.

Graf, W. L. C., Sandra L.; Kammerer, Martin T.; Lehman, Ted; Randall, Kris; Schroeder, Rolf. (1991). Geomorphology of heavy metals in the sediments of Queen Creek, Arizona, USA. Catena, 18(6), 567-582. doi:https://doi.org/10.1016/0341-8162(91)90039-Z

Gray, J. E. H., Mark E.; Biester, Harald. (2006). Mercury methylation influenced by areas of past mercury mining in the Terlingua district, Southwest Texas, USA. Applied Geochemistry, 21(11), 1940-1954. doi:10.1016/j.apgeochem.2006.08.016

Greenbaum, N. M., Adina; Schick, Asher P.; Sharon, David; Baker, Victor R. (1998). A high magnitude storm and flood in a hyperarid catchment, Nahal Zin, Negev Desert, Israel. Hydrological Processes, 12(1), 1-23. doi:10.1002/(SICI)1099-1085(199801)12:1<1::AID-HYP559>3.0.CO;2-6

Greenbaum, N. S., Uri; Benito, Gerardo; Porat, Naomi; Cloete, Gert C.; Enzel, Yehouda. (2014). Paleohydrology of extraordinary floods along the Swakop River at the margin of the Namib

Desert and their paleoclimate implications. Quaternary Science Reviews, 103, 153-169. doi:10.1016/j.quascirev.2014.08.021

Grenfell, S. E. G., M. C.; Rowntree, K. M.; Ellery, W. N. (2014). Fluvial connectivity and climate: A comparison of channel pattern and process in two climatically contrasting fluvial sedimentary systems in South Africa. Geomorphology, 205, 142-154. doi:https://doi.org/10.1016/j.geomorph.2012.05.010

Hackett, T. D. K., Carmi; Holderied, Marc W. (2013). The Importance of Acacia Trees for Insectivorous Bats and Arthropods in the Arava Desert. PLoS One, 8(2), 1-10. doi:10.1371/journal.pone.0052999; http://dx.doi.org/10.1371/journal.pone.0052999
Hagen, E. M. S., John L. (2014). Temporal variability in insectivorous bat activity along two desert streams with contrasting patterns of prey availability. Journal of Arid Environments, 102, 104-112. doi:https://doi.org/10.1016/j.jaridenv.2013.11.016

Hale, J. R. M., Meryl C.; Bogan, Michael T.; Olden, Julian D. (2015). Links between two interacting factors, novel habitats and non-native predators, and aquatic invertebrate communities in a dryland environment. Hydrobiologia., 746(1), 313-326.

Hamdan, A. M., S. W. (2016). Biogeomorphic Relationships and Riparian Vegetation Changes Along Altered Ephemeral Stream Channels: Florence to Marana, Arizona. Professional Geographer, 68(1), 26-38. doi:10.1080/00330124.2015.1007431

Hassan, M. A. (2005). Characteristics of Gravel Bars in Ephemeral Streams. Journal of Sedimentary Research, 75(1), 29-42. doi:10.2110/jsr.2005.004

Hassan, M. A. E., R.; Parker, G. (2006). Experiments on the effect of hydrograph characteristics on vertical grain sorting in gravel bed rivers. Water Resources Research, 42(9), 1-15. doi:10.1029/2005wr004707

Hassan, M. A. E., Roey. (2001). Impact of wastewater discharge on the channel morphology of ephemeral streams. Earth Surface Processes and Landforms, 26(12), 1285-1302. doi:10.1002/esp.273

Hassan, M. A. M., Philip M.; Schwartz, Uri. (2009). Bar structure in an arid ephemeral stream. Sedimentary Geology, 221(1–4), 57-70. doi:https://doi.org/10.1016/j.sedgeo.2009.07.012

Helmus, A. M. F., A. G.; VanLeeuwen, D. M.; Abbott, L. B.; Ulery, A. L.; Baker, T. T. (2009). Surface Water Seepage Effects on Shallow Ground-Water Quality Along the Rio Grande in Northern New Mexico. Journal of the American Water Resources Association, 45(2), 407-418. doi:10.1111/j.1752-1688.2008.00293.x

Higgins, S. I. R., K. H.; Kemper, J. (1997). A description of the functional vegetation pattern of a semi-arid floodplain, South Africa. Plant Ecology, 129(1), 95-101.

Holmes, R. M. F., S. G.; Grimm, N. B. (1994). Parafluvial nitrogen dynamics in a desert stream ecosystem. Journal of the North American Benthological Society, 13(4), 468-478.

Hooke, J. (2003). Coarse sediment connectivity in river channel systems; a conceptual framework and methodology. Geomorphology, 56(1-2), 79-94. doi:http://dx.doi.org/10.1016/S0169-555X(03)00047-3

Hooke, J. M. (2016a). Geomorphological impacts of an extreme flood in SE Spain. Geomorphology, 263, 19-38. doi:10.1016/j.geomorph.2016.03.021

Hooke, J. M. (2016b). Morphological impacts of flow events of varying magnitude on ephemeral channels in a semiarid region. Geomorphology, 252, 128-143. doi:10.1016/j.geomorph.2015.07.014

Horton, J. L. K., T. E.; Hart, S. C. (2001). Responses of riparian trees to interannual variation in ground water depth in a semi-arid river basin. Plant, Cell and Environment, 24 (3) pp. 293-304, 2001.

Howard, K. B., L.; Ward, K.; Stokeld, D. (2016). Preliminary evidence suggests freshwater turtles respond positively to an environmental water delivery during drought. Australian Journal of Zoology, 64(5), 370-373. doi:10.1071/zo16076

Huang, T. P., Zhonghe; Li, Jie; Xiang, Yong; Zhao, Zhijiang. (2017). Mapping groundwater renewability using age data in the Baiyang alluvial fan, NW China. Mapeo de la renovabilidad del agua subterránea utilizando datos de edad en el abanico aluvial de Baiyang, NW de China., 25(3), 743-755. doi:10.1007/s10040-017-1534-z

Hutmacher, A. M. Z., George N.; Martin, Jonathan; Green, Douglas M. (2014). Vegetation structure along urban ephemeral streams in southeastern Arizona. Urban Ecosystems, 17(1), 349-368. doi:http://dx.doi.org/10.1007/s11252-013-0293-4

Hutmacher, A. M. Z., George N.; Martin, Jonathan; Green, Douglas M. (2015). Vegetative litter decomposition along urban ephemeral streams in Southeastern Arizona. Urban Ecosystems, 18(2), 431-448. doi:http://dx.doi.org/10.1007/s11252-014-0405-9

Isaacson, S. B., D. G.; Ephrath, J. E.; Rachmilevitch, S.; Ginat, H.; Maman, S. (2017). Long and short term population dynamics of acacia trees via remote sensing and spatial analysis: Case study in the southern Negev Desert. Remote Sensing of Environment, 198, 95-104. doi:http://dx.doi.org/10.1016/j.rse.2017.05.035

Jacobson, K. M. J., Peter J.; Miller, Orson K., Jr. (1999). The autecology of Battarrea stevenii in ephemeral rivers of southwestern Africa. Mycological Research, 103(1), 9-17. doi:10.1017/s0953756298006662

Jacobson, P. J. J., K. M.; Angermeier, P. L.; Cherry, D. S. (1999). Transport, retention, and ecological significance of woody debris within a large ephemeral river. Journal of the North American Benthological Society, 18 (4) pp. 429-444, 1999.

Jacobson, P. J. J., K. M.; Angermeier, P. L.; Cherry, D. S. (2000a). Hydrologic influences on soil properties along ephemeral rivers in the Namib Desert. Journal of Arid Environments, 45(1), 21-34. doi:10.1006/jare.1999.0619

Jacobson, P. J. J., K. M.; Angermeier, P. L.; Cherry, D. S. (2000b). Variation in material transport and water chemistry along a large ephemeral river in the Namib Desert. Freshwater Biology, 44(3), 481-491. doi:10.1046/j.1365-2427.2000.00604.x
Jacoby, Y. G., Tamir; Enzel, Yehouda; Porat, Naomi; McDonald, Eric V.; Dahan, Ofer. (2008). Late Holocene upper bounds of flood magnitudes and twentieth century large floods in the ungauged, hyperarid alluvial Nahal Arava, Israel. Geomorphology, 95(3–4), 274-294. doi:https://doi.org/10.1016/j.geomorph.2007.06.008

Jaeger, K. L. W., Ellen. (2011). Channel response in a semiarid stream to removal of tamarisk and Russian olive. Water Resources Research, 47(2), 1-7. doi:10.1029/2009WR008741

Jansen, J. D. (2006). Flood magnitude-frequency and lithologic control on bedrock river incision in post-orogenic terrain. Geomorphology, 82(1-2), 39-57. doi:10.1016/j.geomorph.2005.08.018

Jia, X. W., Haibing. (2014). Element Geochemical Analysis of the Contribution of Aeolian Sand to Suspended Sediment in Desert Stream Flash Floods. Scientific World Journal, 1-12. doi:10.1155/2014/620610

Jones-Lepp, T. L. S., C.; Alvarez, D. A.; Wilson, D. C.; Taniguchi-Fu, R. L. (2012). Point sources of emerging contaminants along the Colorado River Basin: Source water for the arid Southwestern United States. Science of the Total Environment, 430, 237-245. doi:10.1016/j.scitotenv.2012.04.053

Jones, K. B. E., Curtis E.; Slonecker, E. Terrance; Wickham, James D.; Neale, Anne C.; Wade, Timothy G.; Riitters, Kurt H.; Kepner, William G. (2008). Detecting changes in riparian habitat conditions based on patterns of greenness change: A case study from the Upper San Pedro River Basin, USA. Ecological Indicators, 8(1), 89-99. doi:10.1016/j.ecolind.2007.01.001

Kamp, K. V. R., M.; Troelstrup, N. H.; Smart, A. J.; Wylie, B. (2013). Detecting Channel Riparian Vegetation Response to Best-Management-Practices Implementation in Ephemeral Streams With the Use of Spot High-Resolution Visible Imagery. Rangeland Ecology & Management, 66(1), 63-70. doi:10.2111/rem-d-11-00153.1

Kampf, S. K. F., Joshua; Shaw, Jeremy R.; Sutfin, Nicholas A.; Cooper, David J. (2016). Rain and channel flow supplements to subsurface water beneath hyper-arid ephemeral stream channels. Journal of Hydrology, 536, 524-533. doi:https://doi.org/10.1016/j.jhydrol.2016.03.016

Khomo, L. R., Kevin H. (2009). Stream order controls geomorphic heterogeneity and plant distribution in a savanna landscape. Austral Ecology, 34(2), 170-178. doi:http://dx.doi.org/10.1111/j.1442-9993.2008.01918.x

Kijowska-Strugala, M. W., L.; Lekach, J.; Bucala-Hrabia, A. (2017). Diversification of the hydromorphological state and the habitat quality of streams in the Negev Desert (Israel). Environmental Earth Sciences, 76(3), 1-10. doi:10.1007/s12665-016-6347-1

Knighton, A. D. N., G. C. (2001). An event-based approach to the hydrology of arid zone rivers in the Channel Country of Australia. Journal of Hydrology (Amsterdam), 254(1-4), 102-123.

Knighton, A. D. N., Gerald C. (1994). Waterholes and their significance in the anastomosing channel system of Cooper Creek, Australia. Geomorphology, 9(4), 311-324.

Knighton, A. D. N., Gerald C. (2002). Inbank and overbank velocity conditions in an arid zone anastomosing river. Hydrological Processes, 16(9), 1771-1791. doi:10.1002/hyp.1076

Lalley, J. S. V., H. A.; Copeman, N.; Cowley, C.; Wiser, S. (2006). The influence of multi-scale environmental variables on the distribution of terricolous lichens in a fog desert. Journal of Vegetation Science, 17(6), 831-838. doi:http://dx.doi.org/10.1658/1100-9233(2006)17[831:TIOMEV]2.0.CO;2

Laronne, J. B. R., Ian; Yitshak, Yitshak; Frostick, Lynne E. (1994). The non-layering of gravel streambeds under ephemeral flood regimes. Journal of Hydrology, 159(1-4), 353-363. doi:10.1016/0022-1694(94)90266-6

Lawes, R. A. G., Anthony C. (2007). Controlling infestations of Parkinsonia aculeata in a riparian zone at the landscape scale. Austral Ecology, 32(3), 287-293. doi:10.1111/j.1442-9993.2007.01691.x

Leduc, C. B., John; Schroeter, Pierre. (1997). Water Table Fluctuation and Recharge in Semi-Arid Climate: Some Results of the HAPEX-Sahel Hydrodynamic Survey (Niger). Journal of Hydrology (Amsterdam), 188(1), 123-138.

Leigh, C. B., N.; Boulton, A. J.; Hugueny, B.; Larned, S. T.; Vorste, R. V.; Datry, T. (2016). Invertebrate assemblage responses and the dual roles of resistance and resilience to drying in intermittent rivers. Aquatic Sciences, 78(2), 291-301. doi:10.1007/s00027-015-0427-2

Leigh, C. S., Fran. (2008). Hydrological changes and ecological impacts associated with water resource development in large floodplain rivers in the Australian tropics. River Research and Applications, 24(9), 1251-1270. doi:http://dx.doi.org/10.1002/rra.1125

Lekach, J. A., Rivka; Grodek, Tamir; Schick, Asher P. (1998). Fluvio-pedogenic processes in an ephemeral stream channel, Nahal Yael, Southern Negev, Israel. Geomorphology, 23(2–4), 353-369. doi:https://doi.org/10.1016/S0169-555X(98)00015-4

Lekach, J. S., A. P. (1983). Evidence for transport of bedload in waves: Analysis of fluvial sediment samples in a small upland stream channel. Catena, 10(1–2), 267-279. doi:https://doi.org/10.1016/S0341-8162(83)80022-8

Lewis, D. B. G., N. B.; Harms, T. K.; Schade, J. D. (2007). Subsystems, flowpaths, and the spatial variability of nitrogen in a fluvial ecosystem. Landscape Ecology, 22(6), 911-924. doi:10.1007/s10980-007-9078-6

Li, J. B., Charlie S.; Luthi, Stefan M.; Donselaar, Marinus E. (2015). Dryland anabranching river morphodynamics: Río Capilla, Salar de Uyuni, Bolivia. Geomorphology, 250, 282-297. doi:https://doi.org/10.1016/j.geomorph.2015.09.011

Lite, S. J. B., K. J.; Stromberg, J. C. (2005). Riparian plant species richness along lateral and longitudinal gradients of water stress and flood disturbance, San Pedro River, Arizona, USA. Journal of Arid Environments, 63(4), 785-813. doi:http://dx.doi.org/10.1016/j.jaridenv.2005.03.026

Lobera, G. A.-D., I.; Lopez-Tarazon, J. A.; Millan-Romero, P.; Valles, F.; Vericat, D.; Batalla, R. J. (2017). Bed disturbance below dams: observations from two Mediterranean rivers. Land Degradation & Development, 28(8), 2493-2512. doi:10.1002/ldr.2785

Long, J. W. T., A.; Burnette, B. M. (2003). Marsh development at restoration sites on the White Mountain Apache Reservation, Arizona. Journal of the American Water Resources Association, 39(6), 1345-1359. doi:10.1111/j.1752-1688.2003.tb04422.x

Lostrom, S. E., Jonathan P.; Grierson, Pauline F.; Collin, Shaun P.; Davies, Peter M.; Kelley, Jennifer L. (2015). Linking stream ecology with morphological variability in a native freshwater fish from semi-arid Australia. Ecology and Evolution, 5(16), 3272-3287. doi:http://dx.doi.org/10.1002/ece3.1590

Lottermoser, B. G. A., P. M. (2006). Physical dispersion of radioactive mine waste at the rehabilitated Radium Hill uranium mine site, South Australia. Australian Journal of Earth Sciences, 53(3), 485-499. doi:10.1080/08120090600632383

Lottermoser, B. G. A., P. M.; Costelloe, M. T. (2005). Contaminant dispersion at the rehabilitated Mary Kathleen uranium mine, Australia. Environmental Geology, 48(6), 748-761. doi:10.1007/s00254-005-0014-2

Mabidi, A. B., Matthew S.; Perissinotto, Renzo. (2017). Distribution and diversity of aquatic macroinvertebrate assemblages in a semi-arid region earmarked for shale gas exploration (Eastern Cape Karoo, South Africa). PLoS ONE, 12(6), 1-27. doi:10.1371/journal.pone.0178559

Malmon, D. V. R., Steven L.; Katzman, Danny; Lavine, Alexis; Lyman, Jared. (2007). Suspended sediment transport in an ephemeral stream following wildfire. Journal of Geophysical Research. F. Earth Surface, 112(F2), 1-16. doi:http://dx.doi.org/101029/2005JF000459

Maltchik, L. P., Fabio. (2001). Responses of Aquatic Macrophytes to Disturbance by Flash Floods in a Brazilian Semiarid Intermittent Stream. Biotropica, 33(4), 566-572. doi:10.1646/0006-3606(2001)033[0566:ROAMTD]2.0.CO;2

Marcus, W. A. (1987). Copper dispersion in ephemeral stream sediments. Earth Surface Processes and Landforms, 12(3), 217-228. doi:10.1002/esp.3290120302

Martin, J. K., S. A.; Zaimes, G.; Crimmins, M.; Hutmacher, A.; Green, D. (2012). Elevated air temperatures in riparian ecosystems along ephemeral streams: The role of housing density. Journal of Arid Environments, 84, 9-18. doi:10.1016/j.jaridenv.2012.03.019

Mather, A. E. H., A. (2005). Flow events on a hyper-arid alluvial fan: Quebrada Tambores, Salar de Atacama, northern Chile. Alluvial Fans: Geomorphology, Sedimentology, Dynamics, 251, 9-24. doi:10.1144/gsl.sp.2005.251.01.02

McIntyre, R. E. S. A., M. A.; Grierson, P. E. (2009). Nitrogen mineralization potential in rewetted soils from a semi-arid stream landscape, north-west Australia. Journal of Arid Environments, 73(1), 48-54. doi:10.1016/j.jaridenv.2008.09.011

McIntyre, R. E. S. A., Mark A.; Ford, Douglas J.; Grierson, Pauline F. (2009). Rewetting and litter addition influence mineralisation and microbial communities in soils from a semi-arid intermittent stream. Soil Biology and Biochemistry, 41(1), 92-101. doi:http://dx.doi.org/10.1016/j.soilbio.2008.09.021

McJannet, D. M., Steve; Kinsey-Henderson, Anne; Petheram, Cuan; Wallace, Jim. (2014). Persistence of in-stream waterholes in ephemeral rivers of tropical northern Australia and potential impacts of climate change. Marine and Freshwater Research, 65(12), 1131-1144. doi:http://dx.doi.org/10.1071/MF14035

McMahon, T. A. F., B. L. (2003). Droughts and anti-droughts: the low flow hydrology of Australian rivers. Freshwater Biology, 48(7), 1147-1160. doi:10.1046/j.1365-2427.2003.01098.x

Medeiros, E. S. F. M., L. (2001). Fish assemblage stability in an intermittently flowing stream from the Brazilian semiarid region. Austral Ecology, 26(2), 156-164. doi:10.1046/j.1442-9993.2001.01099.x

Medeiros, E. S. M., Leonardo. (1999). The Effects of Hydrological Disturbance on the Intensity of Infestation of Lernaea cyprinacea in an Intermittent Stream Fish Community. Journal of Arid Environments, 43(3), 351–356.

Melcher, A. H. O., Raymond; Schmutz, Stefan. (2012). Spatial and seasonal fish community patterns in impacted and protected semi-arid rivers of Burkina Faso. Ecological Engineering, 48, 117-129. doi:https://doi.org/10.1016/j.ecoleng.2011.07.012

Melo, G. F., W. K. (1999). Dispersion of gold and associated elements in stream sediments under semi-arid conditions, northeast Brazil. Journal of Geochemical Exploration, 67(1-3), 235-243. doi:10.1016/s0375-6742(99)00053-9

Merritt, D. M. W., E. E. (2003). Downstream hydraulic geometry and channel adjustment during a flood along an ephemeral, arid-region drainage. Geomorphology, 52(3-4), 165-180. doi:10.1016/s0169-555x(02)00241-6

Mesa-Zavala, E. A.-C., S.; Galina-Tessaro, P.; Troyo-Dieguez, E.; Guerrero-Cardenas, I. (2012). Terrestrial vertebrates recorded by camera traps in areas with seasonal streams and creeks of superficial waters in a semiarid habitat of Baja California Sur, Mexico. Revista Mexicana De Biodiversidad, 83(1), 235-245.
Metcalf, J. S. R., R.; Cox, P. A.; Codd, G. A. (2012). Cyanotoxins in desert environments may present a risk to human health. Science of the Total Environment, 421, 118-123. doi:10.1016/j.scitotenv.2012.01.053

Miller, M. P. B., Anne M. D. (2011). Differences in macroinvertebrate community structure in streams and rivers with different hydrologic regimes in the semi-arid Colorado Plateau. River Systems, 19(3), 225-238. doi:10.1127/1868-5749/2011/019-0017

Mitchell, C. H., S. M.; Giles, D.; Hulme, K. (2015). El Nino-La Nina cycles and biogeochemical sampling: variability of element concentrations within E-camaldulensis leaves in semi-arid Australia. Geochemistry-Exploration Environment Analysis, 15(4), 350-360. doi:10.1144/geochem2014-304

Mohammadi, A. C., Justin Francis; Ryu, Dongryeol. (2017). Application of time series of remotely sensed normalized difference water, vegetation and moisture indices in characterizing flood dynamics of large-scale arid zone floodplains. Remote Sensing of Environment, 190, 70-82. doi:10.1016/j.rse.2016.12.003

Moody, E. K. S., John L. (2013). Crayfish Impact Desert River Ecosystem Function and Litter-Dwelling Invertebrate Communities through Association with Novel Detrital Resources. PLoS ONE, 8(5), 1-9. doi:10.1371/journal.pone.0063274

Moran-Ordonez, A. P., A.; Pinder, A. M.; Sim, L.; Sunnucks, P.; Thompson, R. M.; Davis, J. (2015). Aquatic communities in arid landscapes: local conditions, dispersal traits and landscape

configuration determine local biodiversity. Diversity and Distributions, 21(10), 1230-1241. doi:10.1111/ddi.12342

Moreno, J. L. A., D. G.; De las Heras, J. (2010). Seasonal dynamics of macroinvertebrate communities in a semiarid saline spring stream with contrasting environmental conditions. Aquatic Ecology, 44(1), 177-193. doi:10.1007/s10452-009-9251-x

Moreno, J. L. M., A.; Suarez, M. L.; Vidal-Abarca, M. R.; Velasco, J. (1997). Aquatic coleoptera and heteroptera assemblages in waterbodies from ephemeral coastal streams ("ramblas") of south-eastern Spain. Archiv Fur Hydrobiologie, 141(1), 93-107.

Munoz-Robles, C. R., Nick; Frazier, Paul; Tighe, Matthew; Briggs, Sue V.; Wilson, Brian. (2010). Factors related to gully erosion in woody encroachment in south-eastern Australia. Catena, 83(2-3), 148-157. doi:10.1016/j.catena.2010.08.002

Munoz, M. O. W., Hannes; Johnsson, Fredrick; Bhattacharya, Prosun; Sracek, Ondra; Thunvik, Roger; Quintanilla, Jorge; Bundschuh, Jochen. (2013). Geogenic arsenic and other trace elements in the shallow hydrogeologic system of Southern Poopo Basin, Bolivian Altiplano. Journal of Hazardous Materials, 262, 924-940. doi:10.1016/j.jhazmat.2013.06.078

Murthy, K. N. K. B., D. N. (1982). Effect of an ephemeral stream on the groundwater level and groundwater quality in an arid zone of India. Journal of Hydrology, 57(1-2), 107-111. doi:10.1016/0022-1694(82)90106-8

Nachshon, U. (2016). Seepage weathering impacts on erosivity of arid stream banks: A new conceptual model. Geomorphology, 261, 212-221. doi:https://doi.org/10.1016/j.geomorph.2016.03.011

Nafus, M. G. E., Todd C.; Averill-Murray, Roy C.; Nussear, Kenneth E.; Swaisgood, Ronald R. (2017). Habitat drives dispersal and survival of translocated juvenile desert tortoises. Journal of Applied Ecology, 54(2), 430-438. doi:10.1111/1365-2664.12774

Nazari Samani, A. W., R. J.; Malekian, Arash. (2011). Application of multiple sediment fingerprinting techniques to determine the sediment source contribution of gully erosion: Review and case study from Boushehr province, southwestern Iran. Progress in Physical Geography, 35(3), 375-391. doi:10.1177/0309133311401643

Nearing, M. K., A.; Nicholas, M.; Ritchie, J.; Anonymous,. (2006). Spatial patterns of soil erosion and deposition in two small, semi-arid watersheds. Journal of Soil and Water Conservation, 61(3), 1-11.

Nelson, S. M. (2003). The Western Viceroy butterfly (Nymphalidae: Limenitis archippus obsoleta): an indicator for riparian restoration in the arid southwestern United States? Ecological Indicators, 3(3), 203–211. doi:10.1016/S1470-160X(03)00044-X

Nguyen, U. G., Edward P.; Nagler, Pamela L.; Scott, Russell L. (2015). Long-term decrease in satellite vegetation indices in response to environmental variables in an iconic desert riparian ecosystem: the Upper San Pedro, Arizona, United States. Ecohydrology, 8(4), 610-625. doi:10.1002/eco.1529

Nichols, M. H. M., K.; Reed, C. (2012). Short-term soil moisture response to low-tech erosion control structures in a semiarid rangeland. Catena (Giessen), 98, 104-109. doi:http://dx.doi.org/10.1016/j.catena.2012.06.010

Nogueras, P. B., Francesc; Gallart, Francesc; Puigdefàbregas, Joan. (2000). Recent gully erosion in the El Cautivo badlands (Tabernas, SE Spain). Catena, 40(2), 203-215. doi:https://doi.org/10.1016/S0341-8162(99)00048-X

Oliva-Paterna, F. J. V.-G., A.; Torralva, M. (2003). Condition of Barbus sclateri from semi-arid aquatic systems: effects of habitat quality disturbances. Journal of Fish Biology, 63(3), 699-709. doi:10.1046/j.1095-8649.2003.00183.x

Ortega-Becerril, J. A. G., G.; Bejar-Pizarro, M.; Martinez-Diaz, J. J. (2016). Towards an increase of flash flood geomorphic effects due to gravel mining and ground subsidence in Nogalte stream (Murcia, SE Spain). Natural Hazards and Earth System Sciences, 16(10), 2273-2286. doi:10.5194/nhess-16-2273-2016

Ortiz, C. A., R.; Briones, E.; Suarez, F.; Tore, C.; Munoz, J. F. (2014). Sources of surface water for the Soncor ecosystem, Salar de Atacama basin, northern Chile. Hydrological Sciences Journal-Journal Des Sciences Hydrologiques, 59(2), 336-350. doi:10.1080/02626667.2013.829231

Osem, Y. P., A.; Kigel, J. (2002). Grazing effect on diversity of annual plant communities in a semi-arid rangeland: interactions with small-scale spatial and temporal variation in primary productivity. Journal of Ecology, 90(6), 936-946. doi:10.1046/j.1365-2745.2002.00730.x

Osem, Y. P., Avi; Kigel, Jaime. (2006). Size traits and site conditions determine changes in seed bank structure caused by grazing exclusion in semiarid annual plant communities. Ecography, 29(1), 11-20. doi:http://dx.doi.org/10.1111/j.2006.0906-7590.04283.x

Overdieck, D. Z., D.; De Yu, R. (2013). Gas exchange of Populus euphratica leaves in a riparian zone. Journal of Arid Land, 5(4), 531-541. doi:http://dx.doi.org/10.1007/s40333-013-0178-7

Oyarzun, J. C., D.; Maturana, H.; Kretschmer, N.; Soto, G.; Amezaga, J. M.; Rotting, T. S.; Younger, P. L.; Oyarzun, R. (2012). Abandoned tailings deposits, acid drainage and alluvial sediments geochemistry, in the arid Elqui River Basin, North-Central Chile. Journal of Geochemical Exploration, 115, 47-58. doi:10.1016/j.gexplo.2012.02.008

Oyarzun, J. C., M. J.; Maturana, H.; Nunez, J.; Kretschmer, N.; Amezaga, J. M.; Rotting, T. S.; Strauch, G.; Thyne, G.; Oyarzun, R. (2013). Hydrochemical and isotopic patterns in a calc-alkaline Cu- and Au-rich arid Andean basin: The Elqui River watershed, North Central Chile. Applied Geochemistry, 33, 50-63. doi:10.1016/j.apgeochem.2013.01.014

Oyarzun, J. O., R.; Lillo, J.; Higueras, P.; Maturana, H.; Oyarzun, R. (2016). Distribution of chemical elements in calc-alkaline igneous rocks, soils, sediments and tailings deposits in northern central Chile. Journal of South American Earth Sciences, 69, 25-42. doi:10.1016/j.jsames.2016.03.004

Paquette, S. R. B., Sandra M.; O'Brien, Susan H.; Brenneman, Rick A.; Louis, Edward E.; Lapointe, Francois-Joseph. (2007). Riverbeds demarcate distinct conservation units of the radiated tortoise (Geochelone radiata) in southern Madagascar. Conservation Genetics, 8(4), 797-807. doi:http://dx.doi.org/10.1007/s10592-006-9227-5

Parker, A. H. W., E. T. (1999). Long-term impacts of abundant perennial water provision for game on herbaceous vegetation in a semi-arid African savanna woodland. Journal of Arid Environments, 41(3), 309-321.

Parsons, M. T., M. C. (2013). Patterns of vegetation greenness during flood, rain and dry resource states in a large, unconfined floodplain landscape. Journal of Arid Environments, 88, 24-38. doi:http://dx.doi.org/10.1016/j.jaridenv.2012.07.023

Pasternak, G. B., L. R.; Kienzle, S.; Fuller, A.; Barrett, L.; Henzi, S. P. (2013). Population ecology of vervet monkeys in a high latitude, semi-arid riparian woodland. Koedoe, 55(1), 1-9. doi:10.4102/koedoe.v55i1.1078

Patz, M. J. R., K. J.; Skinner, Q. D. (2006). Trace Elements in Coalbed Methane Produced Water Interacting with Semi-Arid Ephemeral Stream Channels. Water, Air, & Soil Pollution, 170(1-4), 55-67. doi:http://dx.doi.org/10.1007/s11270-006-3114-z

Patz, M. J. R., Katta J.; Skinner, Quentin D. (2004). Chemistry of Coalbed Methane Discharge Water Interacting with Semi-Arid Ephemeral Stream Channels. Journal of the American Water Resources Association, 40(5), 1247-1255. doi:10.1111/j.1752-1688.2004.tb01583.x

Pedro, F. M., L.; Bianchini, I., Jr. (2006). Hydrologic cycle and dynamics of aquatic macrophytes in two intermittent rivers of the semi-arid region of Brazil. Brazilian Journal of Biology, 66(2B), 575-585. doi:10.1590/s1519-69842006000400002

Peng, X. X., Shengchun; Cheng, Guodong; Xiao, Honglang; Tian, Quanyan; Zhang, Qibing. (2017). Human activity impacts on the stem radial growth of Populus euphratica riparian forests in China's Ejina Oasis, using tree-ring analysis. Trees: Structure and Function, 31(2), 379-392. doi:http://dx.doi.org/10.1007/s00468-015-1287-z

Perignon, M. C. T., G. E.; Griffin, E. R.; Friedman, J. M. (2013). Effects of riparian vegetation on topographic change during a large flood event, Rio Puerco, New Mexico, USA. Journal of Geophysical Research: Earth Surface, 118(3), 1193-1209. doi:10.1002/jgrf.20073

Polyakov, V. O. N., M. N.; Nearing, M. A. (2017). Determining soil erosion rates on semi-arid watersheds using radioisotope-derived sedimentation chronology. Earth Surface Processes and Landforms, 42(6), 987-993. doi:http://dx.doi.org/10.1002/esp.4057

Pool, D. R. (2005). Variations in climate and ephemeral channel recharge in southeastern Arizona, United States. Water Resources Research, 41(11), 1-24. doi:10.1029/2004wr003255

Pool, D. R. E., J. H. (1995). Measurements of Aquifer-Storage Change and Specific Yield Using Gravity Surveys. Ground Water, 33(3), 425-432. doi:DOI 10.1111/j.1745-6584.1995.tb00299.x

Pool, T. K. O., Julian D. (2015). Assessing long-term fish responses and short-term solutions to flow regulation in a dryland river basin. Ecology of Freshwater Fish, 24(1), 56-66. doi:10.1111/eff.12125

Potts, D. L. W., D. G. (2004). Response of tree ring holocellulose delta C-13 to moisture availability in Populus fremontii at perennial and intermittent stream reaches. Western North American Naturalist, 64(1), 27-37.

Powell, D. M. B., Richard; Parsons, Anthony; Wainwright, John; Nichols, Mary. (2007). Sediment transfer and storage in dryland headwater streams. Geomorphology, 88(1-2), 152-166. doi:http://dx.doi.org/10.1016/j.geomorph.2006.11.001
Powell, D. M. R., I.; Laronne, J. B. (2001). Evolution of bed load grain size distribution with increasing flow strength and the effect of flow duration on the caliber of bed load sediment yield in ephemeral gravel bed rivers. Water Resources Research, 37(5), 1463-1474. doi:10.1029/2000wr900342

Qashu, H. K. B., S. W. (1967). Hydraulic and micromorphological properties of stream channel sediments. Water Resources Research, 3(2), 465-469. doi:http://dx.doi.org/10.1029/WR003i002p00465

Ran, L. L., Lingyu; Tian, Mingyang; Yang, Xiankun; Yu, Ruihong; Zhao, Ji; Wang, Lixin; Lu, X. X. (2017). Riverine CO2 emissions in the Wuding River catchment on the Loess Plateau: Environmental controls and dam impoundment impact. Journal of Geophysical Research: Biogeosciences, 122(6), 1439–1455. doi:10.1002/2016JG003713

Rayner, T. S. J., K. M.; Kingsford, R. T. (2009). Small environmental flows, drought and the role of refugia for freshwater fish in the Macquarie Marshes, arid Australia. Ecohydrology, 2(4), 440-453. doi:10.1002/eco.73

Reid, I. F., L. E. (1987). Flow dynamics and suspended sediment properties in arid zone flash floods. Hydrological Processes, 1(3), 239-253.

Reid, I. L., J. B.; Powell, D. M. (1998). Flash-flood and bedload dynamics of desert gravel-bed streams. Hydrological Processes, 12(4), 543-557. doi:10.1002/(sici)1099-1085(19980330)12:4<543::aid-hyp593>3.0.co;2-c

Reid, I. L., Jonathan B. (1995). Bed Load Sediment Transport in an Ephemeral Stream and a Comparison with Seasonal and Perennial Counterparts. Water Resources Research, 31(3), 773-781. doi:10.1029/94wr02233

Reynolds, L. V. C., D. J.; Hobbs, N. T. (2014). Drivers of Riparian Tree Invasion on a Desert Stream. River Research and Applications, 30(1), 60-70. doi:10.1002/rra.2619

Reynolds, L. V. S., Patrick B. (2017). Riparian plant composition along hydrologic gradients in a dryland river basin and implications for a warming climate. Ecohydrology, 10(6), 1-13. doi:10.1002/eco.1864

Rhoton, F. E. E., W. E.; Goodrich, D. C.; Miller, S. N.; McChesney, D. S. (2006). Soil geomorphological characteristics of a semiarid watershed: Influence on carbon distribution and transport. Soil Science Society of America Journal, 70(5), 1532-1540. doi:10.2136/sssaj2005.0239

Riha, K. M. M., Greg; Gallo, Erika L.; Lohse, Kathleen A.; Brooks, Paul D.; Meixner, Tom. (2014). High Atmospheric Nitrate Inputs and Nitrogen Turnover in Semi-arid Urban Catchments. Ecosystems, 17(8), 1309-1325. doi:http://dx.doi.org/10.1007/s10021-014-9797-x

Ritchie, J. C. N., Mark A.; Rhoton, Fred E. (2009). Sediment budgets and source determinations using fallout Cesium-137 in a semiarid rangeland watershed, Arizona, USA. Journal of Environmental Radioactivity, 100(8), 637-643. doi:http://dx.doi.org/10.1016/j.jenvrad.2009.05.008

Rocha, L. G. M., E. S. F.; Andrade, H. T. A. (2012). Influence of flow variability on macroinvertebrate assemblages in an intermittent stream of semi-arid Brazil. Journal of Arid Environments, 85, 33-40. doi:https://doi.org/10.1016/j.jaridenv.2012.04.001

Salinas, M. J. B., G.; Romero, A. T. (2000). Riparian Vegetation and Water Chemistry in a Basin Under Semiarid Mediterranean Climate, Andarax River, Spain. Environmental Management, 26(5), 539-552. doi:http://dx.doi.org/10.1007/s002670010111

Salinas, M. J. C., J. Jesús. (2007). Riparian vegetation of two semi-arid Mediterranean rivers: Basin-scale responses of woody and herbaceous plants to environmental gradients. Wetlands, 27(4), 831-845. doi:10.1672/0277-5212(2007)27[831:rvotsm]2.0.co;2

Salinas, M. J. G., José. (2002). Riparian Plant Restoration in Summer-Dry Riverbeds of Southeastern Spain. Restoration Ecology, 10(4), 695-702. doi:10.1046/j.1526-100X.2002.01050.x

Sanchez-Martinez, M. A. M.-R., A. J.; Millan-Gomez, R.; Sanchez-Gonzalez, A.; Magallanes-Ordonez, V. R.; Romero-Guadarrama, J. A.; Murillo-Jimenez, J. M. (2013). Sediment accumulation of Ag, Cu, and Ni through a semi-arid basin as a by-product of the El Triunfo gold mine, Baja California Sur, Mexico. Journal of Iberian Geology, 39(1), 97-110. doi:10.5209/rev_JIGE.2013.v39.n1.41752

Schachtschneider, K. R., Karl. (2014). Riparian trees as common denominators across the river flow spectrum: are ecophysiological methods useful tools in environmental flow assessments? Water SA (Pretoria), 40(2), 287-295. doi:10.4314/wsa.v40i2.11

Scheibler, E. E. R.-J., Sergio A.; Claps, M. Cristina. (2014). Chironomid (Insecta: Diptera) assemblages along an Andean altitudinal gradient. Aquatic Biology, 20(2), 169-184. doi:http://dx.doi.org/10.3354/ab00554

Schneider, N. A. G., Michael. (2009). Influence and value of different water regimes on avian species richness in arid inland Australia. Biodiversity and Conservation, 18(2), 457-471. doi:http://dx.doi.org/10.1007/s10531-008-9501-6

Schriever, T. A. B., M. T.; Boersma, K. S.; Canedo-Arguelles, M.; Jaeger, K. L.; Olden, J. D.; Lytle, D. A. (2015). Hydrology shapes taxonomic and functional structure of desert stream invertebrate communities. Freshwater Science, 34(2), 399-409. doi:10.1086/680518

Schriever, T. A. L., D. A. (2016). Convergent diversity and trait composition in temporary streams and ponds. Ecosphere, 7(5), 1-12. doi:10.1002/ecs2.1350
Scott, M. L. L., G. C.; Auble, G. T. (2000). Channel incision and patterns of cottonwood stress and mortality along the Mojave River, California. Journal of Arid Environments, 44(4), 399-414. doi:http://dx.doi.org/10.1006/jare.1999.0614

Seong, Y. B. L., Phillip H.; Dorn, Ronald I.; Yu, Byung Yong. (2016). Evaluating process domains in small arid granitic watersheds: Case study of Pima Wash, South Mountains, Sonoran Desert, USA. Geomorphology, 255, 108-124. doi:https://doi.org/10.1016/j.geomorph.2015.12.014

Shamir, E. B.-M., L.; Ronen, A.; Grodek, T.; Enzel, Y.; Georgakakos, K. P.; Morin, E. (2013). Geomorphology-based index for detecting minimal flood stages in arid alluvial streams. Hydrology and Earth System Sciences, 17(3), 1021-1034. doi:10.5194/hess-17-1021-2013

Sharma, K. D. V., N. S.; Choudhari, J. S. (1984). Sediment Transport Characteristics of the Desert Streams in India. Journal of Hydrology, 67(1-4), 261-272. doi:Doi 10.1016/0022-1694(84)90245-2

Shaw, J. R. C., D. J. (2008). Linkages among watersheds, stream reaches, and riparian vegetation in dryland ephemeral stream networks. Journal of Hydrology, 350(1-2), 68-82. doi:10.1016/j.jhydrol.2007.11.030

Sheldon, F. B., A. J.; Puckridge, J. T. (2002). Conservation value of variable connectivity: aquatic invertebrate assemblages of channel and floodplain habitats of a central Australian arid-zone river, Cooper Creek. Biological Conservation, 103(1), 13-31.

Sher, A. A. W., K.; Ward, D. (2010). Do Acacia and Tamarix trees compete for water in the Negev desert? Journal of Arid Environments, 74(3), 338-343. doi:https://doi.org/10.1016/j.jaridenv.2009.09.007

Shumilin, E. M., N.; Choumiline, K.; Ostrooumov, M. (2015). Increasing arsenic mobility in the fine fraction of the dry stream sediments of the semi-arid San Antonio gold mining district (Baja California peninsula, Mexico). Environmental Earth Sciences, 73(8), 4689-4700. doi:10.1007/s12665-014-3753-0

Si, J. H. F., Q.; Cao, S. K.; Yu, T. F.; Zhao, C. Y. (2014). Water use sources of desert riparian Populus euphratica forests. Environmental Monitoring and Assessment, 186(9), 5469-5477. doi:10.1007/s10661-014-3796-4

Siebers, A. R. P., Neil E.; Skrzypek, Grzegorz; Fellman, Jason B.; Dogramaci, Shawan; Grierson, Pauline F. (2016). Alluvial ground water influences dissolved organic matter biogeochemistry of pools within intermittent dryland streams. Freshwater Biology, 61(8), 1228-1241. doi:http://dx.doi.org/10.1111/fwb.12656

Sims, D. H., Amanda; Keller, John; Konstantinos, Vatalis; Konstantinos, Modis P. (2017). Trace Element Scavenging in Dry Wash Surficial Sediments in an Arid Region of Southern Nevada, USA. Transport von Spurenelementen aus ausgetrockneten Oberflächensedimenten in einer ariden Region in Südnevada, USA., 36(1), 124-132. doi:10.1007/s10230-015-0379-8

Smit, I. P. J. F., Sam M. (2010). Management intervention affects river-bound spatial dynamics of elephants. Biological Conservation, 143(9), 2172-2181. doi:http://dx.doi.org/10.1016/j.biocon.2010.06.001

Smit, I. P. J. G., Cornelia C.; Devereux, Bernard J. (2007). Do artificial waterholes influence the way herbivores use the landscape? Herbivore distribution patterns around rivers and artificial surface water sources in a large African savanna park. Biological Conservation, 136(1), 85-99. doi:10.1016/j.biocon.2006.11.009

Smith, R. L. R., Deborah A.; Hart, Charles P. (2009). Geochemistry of Inorganic Nitrogen in Waters Released from Coal-Bed Natural Gas Production Wells in the Powder River Basin, Wyoming. Environmental Science & Technology, 43(7), 2348-2354. doi:10.1021/es802478p

Spiller, L. G., P. F.; Davies, P. M.; Hemmi, J.; Collin, S. P.; Kelley, J. L. (2017). Functional diversity of the lateral line system among populations of a native Australian freshwater fish. Journal of Experimental Biology, 220(12), 2265-2276. doi:10.1242/jeb.151530

Sponseller, R. A. F., S. G. (2008). The influence of drainage networks on patterns of soil respiration in a desert catchment. Ecology, 89(4), 1089-1100. doi:10.1890/06-1933.1

Sponseller, R. A. F., Stuart G. (2006). Drainage Size, Stream Intermittency, and Ecosystem Function in a Sonoran Desert Landscape. Ecosystems, 9(3), 344-356. doi:10.1007/s10021-005-0167-6

Sponseller, R. A. G., Nancy B.; Boulton, Andrew J.; Sabo, John L. (2010). Responses of macroinvertebrate communities to long-term flow variability in a Sonoran Desert stream. Global Change Biology, 16(10), 2891-2900. doi:10.1111/j.1365-2486.2010.02200.x

Stanley, E. H. B., D.; Boulton, A. J.; Grimm, N. B.; Fisher, S. G. (1994). Invertebrate resistance and resilience to intermittency in a desert stream. American Midland Naturalist, 131(2), 288-300.

Stavi, I. S.-T., R.; Gourjon, E.; Ragolski, G.; Shlomi, Y.; Ginat, H. (2016). Effects of 'red unit' deposit on Acacia trees in the hyper-arid southern Israel. Catena, 145, 316-320. doi:10.1016/j.catena.2016.06.030

Stavi, I. S.-T., R.; Shlomi, Y.; Be, G.; Yizhaq, H. (2015). Recruitment and decay rate of Acacia seedlings in the hyper-arid Arava Valley, Israel. Catena, 131, 14-21. doi:10.1016/j.catena.2015.03.004

Stone, P. A. (2001). Movements and demography of the Sonoran mud turtle, Kinosternon sonoriense. Southwestern Naturalist, 46(1), 41-53.
Strauch, A. M. K., A. R.; Jost, C. C. (2009). Impact of livestock management on water quality and streambank structure in a semi-arid, African ecosystem. Journal of Arid Environments, 73(9), 795-803. doi:https://doi.org/10.1016/j.jaridenv.2009.03.012

Stromberg, J. C. (1993). Instream Flow Models for Mixed Deciduous Riparian Vegetation within a Semiarid Region. Regulated Rivers-Research & Management, 8(3), 225-235. doi:DOI 10.1002/rrr.3450080303

Stromberg, J. C. (2001). Biotic integrity of Platanus wrightii riparian forests in Arizona: first approximation. Forest Ecology and Management, 142(1-3), 251-266.

Stromberg, J. C. (2007). Seasonal reversals of upland-riparian diversity gradients in the Sonoran Desert. Diversity and Distributions, 13(1), 70-83. doi:http://dx.doi.org/10.1111/j.1472-4642.2006.00295.x

Stromberg, J. C. (2013). Root patterns and hydrogeomorphic niches of riparian plants in the American Southwest. Journal of Arid Environments, 94, 1-9. doi:10.1016/j.jaridenv.2013.02.004

Stromberg, J. C. B., K. J.; Leenhouts, J. M.; Lite, S. J.; Makings, E. (2005). Effects of stream flow intermittency on riparian vegetation of a semiarid region river (San Pedro River, Arizona). River Research and Applications, 21(8), 925-938. doi:10.1002/rra.858

Stromberg, J. C. H., A. F.; White,. (2009). Plant species richness in ephemeral and perennial reaches of a dryland river. Biodiversity and Conservation, 18(3), 663-677. doi:http://dx.doi.org/10.1007/s10531-008-9532-z

Stromberg, J. C. L., S. J.; Dixon, M. D. (2010). Effects of stream flow patterns on riparian vegetation of a semiarid river: Implications for a changing climate. River research and applications., 26(6), 712-729.

Stromberg, J. C. M., David M. (2016). Riparian plant guilds of ephemeral, intermittent and perennial rivers. Freshwater Biology, 61(8), 1259-1275. doi:http://dx.doi.org/10.1111/fwb.12686

Stromberg, J. C. R., Tyler J.; Dixon, Mark D. (2009). Return of Fire to a Free-Flowing Desert River: Effects on Vegetation. Restoration Ecology, 17(3), 327-338. doi:10.1111/j.1526-100X.2007.00347.x

Stromberg, J. C. T., M. G. F.; Hazelton, A. F.; Ajami, H. (2010). A century of riparian forest expansion following extreme disturbance: Spatio-temporal change in Populus/Salix/Tamarix forests along the Upper San Pedro River, Arizona, USA. Forest Ecology and Management, 259(6), 1181-1189. doi:10.1016/j.foreco.2010.01.005

Stromberg, J. C. T., R.; Richter, B. (1996). Effects of groundwater decline on riparian vegetation of semiarid regions: The San Pedro, Arizona. Ecological Applications, 6(1), 113-131. doi:10.2307/2269558
Sun, Z. M., Rui; Wang, Yanxin; Hu, Yalu; Sun, Lujian. (2016). Hydrogeological and hydrogeochemical control of groundwater salinity in an arid inland basin: Dunhuang Basin, northwestern China. Hydrological Processes, 30(12), 1884-1902. doi:10.1002/hyp.10760

Sutfin, N. A. S., J. R.; Wohl, E. E.; Cooper, D. J. (2014). A geomorphic classification of ephemeral channels in a mountainous, arid region, southwestern Arizona, USA. Geomorphology, 221, 164-175. doi:10.1016/j.geomorph.2014.06.005

Taleb, A. B., Nouria; Gagneur, James. (2004). Water quality before and after dam building on a heavily polluted river in semi-arid Algeria. River Research and Applications, 20(8), 943-956. doi:http://dx.doi.org/10.1002/rra.800

Taleb, A. B., Nouria; Sanchez-Perez, Jose-Miguel; Vervier, Philippe; Sauvage, Sabine; Gagneur, James. (2008). The role of the hyporheic zone in the nitrogen dynamics of a semi-arid gravel bed

stream located downstream of a heavily polluted reservoir (Tafna wadi, Algeria). River Research and Applications, 24(2), 183-196. doi:http://dx.doi.org/10.1002/rra.1039

Tang, C. M., Isao; Shindo, Shizuo; Kondoh, Akihiko; Sakura, Yasuo. (2001). Chemical and isotopic methods for confirming the roles of wadis in regional groundwater recharge in a regional arid environment: a case study in Al Ain, UAE. Hydrological Processes, 15(11), 2195-2202. doi:10.1002/hyp.277

Tao, H. G., Marco; Song, Yudong; Jiang, Tong. (2008). Ecohydrological responses on water diversion in the lower reaches of the Tarim River, China. Water Resources Research, 44(8), 1-10. doi:http://dx.doi.org/10.1029/2007WR006186

Taylor, M. P. H.-E., K. A. (2008). The dispersal and storage of sediment-associated metals in an arid river system: The Leichhardt River, Mount Isa, Queensland, Australia. Environmental Pollution, 152(1), 193-204. doi:http://dx.doi.org/10.1016/j.envpol.2007.05.011

Taylor, M. P. K., Robert G. H. (2002). Heavy metal contamination of an arid river environment; Gruben River, Namibia. Geomorphology, 42(3-4), 311-327.

Taylor, M. P. M., Alana; Kuypers, Tabitha; Hudson-Edwards, Karen. (2009). Mining and urban impacts on semi-arid freshwater aquatic systems: the example of Mount Isa, Queensland. JEM Journal of Environmental Monitoring, 11(5), 977-986. doi:10.1039/b819026g

Thoman, R. W. N., S. L. (2008). Determining Erodibility, Critical Shear Stress, and Allowable Discharge Estimates for Cohesive Channels: Case Study in the Powder River Basin of Wyoming. Journal of Hydraulic Engineering-Asce, 134(12), 1677-1687. doi:10.1061/(asce)0733-9429(2008)134:12(1677)

Thorburn, P. J. W., Glen R. (1994). Variations in stream water uptake by Eucalyptus camaldulensis with differing access to stream water. Oecologia, 100(3), 293-301. doi:10.1007/bf00316957

Tooth, S. (2000). Downstream changes in dryland river channels: the Northern Plains of arid central Australia. Geomorphology, 34(1–2), 33-54. doi:https://doi.org/10.1016/S0169-555X(99)00130-0

Tooth, S. N., G. C. (2004). Forms and processes of two highly contrasting rivers in arid central Australia, and the implications for channel-pattern discrimination and prediction. Geological Society of America Bulletin, 116(7-8), 802-816. doi:10.1130/b25308.1

Tornés, E. A., Vicenç; Dahm, Clifford N.; Sabater, Sergi. (2015). Flood disturbance effects on benthic diatom assemblage structure in a semiarid river network. Journal of Phycology, 51(1), 133-143. doi:10.1111/jpy.12260

Torres-Garcia, U. P.-V., C. X.; Herreria-Diego, Y.; Pineda-Lopez, R. F. (2014). Effects of environmental factors over aquatic hemimetabola and Coleoptera diversity in the Xichu's basin, Guanajuato, Mexico. Revista de Biologia Tropical, 62, 69-80.

Vidal-Abarca, M. R. S.-M., M. M.; Guerrero, C.; Gomez, R.; Arce, M. I.; Garcia-Garcia, V.; Suarez, M. L. (2013). Effects of intermittent stream flow on macroinvertebrate community composition and biological traits in a naturally saline Mediterranean stream. Journal of Arid Environments, 99, 28-40. doi:10.1016/j.jaridenv.2013.09.008

Villarreal, M. L. D., S.; Marsh, S. E.; McCoy, A. L. (2012). The Influence of Wastewater Subsidy, Flood Disturbance and Neighbouring Land Use on Current and Historical Patterns of Riparian Vegetation in a Semi-Arid Watershed. River Research and Applications, 28(8), 1230-1245. doi:10.1002/rra.1510

Vivoni, E. R. B., Robert S.; Wyckoff, Robert L.; Jakubowski, Ryan T.; Richards, Kate E. (2006). Analysis of a monsoon flood event in an ephemeral tributary and its downstream hydrologic effects. Water Resources Research, 42(3), 1-11. doi:10.1029/2005WR004036

Wakelin-King, G. A. W., J. A. (2007). Threshold-dominated fluvial styles in an arid-zone mud-aggregate river: The uplands of Fowlers Creek, Australia. Geomorphology, 85(1-2), 114-127. doi:10.1016/j.geomorph.2006.03.011

Wallace, J. S., Robert J.; Swann, Don E. (2010). Habitat Characteristics of Lowland Leopard Frogs in Mountain Canyons of Southeastern Arizona. Journal of Wildlife Management, 74(4), 808-815. doi:http://dx.doi.org/10.2193/2009-207

Wang, Z. T., Wanquan. (2016). Hyper-concentrated flow response to aeolian and fluvial interactions from a desert watershed upstream of the Yellow River. Catena, 147, 258-268. doi:10.1016/j.catena.2016.07.033

Watson, M. D., H. F. (2013). Bioassessment in ephemeral rivers: constraints and challenges in applying macroinvertebrate sampling protocols. African Journal of Aquatic Science, 38(1), 35-51. doi:10.2989/16085914.2012.742419

Welter, J. R. F., Stuart G. (2016). The influence of storm characteristics on hydrological connectivity in intermittent channel networks: implications for nitrogen transport and denitrification. Freshwater Biology, 61(8), 1214-1227. doi:http://dx.doi.org/10.1111/fwb.12734

Westerhoff, P. A., D. (2000). Concentrations and characteristics of organic carbon in surface water in Arizona: influence of urbanization. Journal of Hydrology, 236(3-4), 202-222. doi:10.1016/s0022-1694(00)00292-4

Whitney, B. B. H., J. V. (2015). Geomorphological evidence of neotectonic deformation in the Carnarvon Basin, Western Australia. Geomorphology, 228, 579-596. doi:10.1016/j.geomorph.2014.10.020

Whitney, J. E. G., Keith B.; Hedden, Skyler C.; Macpherson, G. L.; Pilger, Tyler J.; Propst, David L.; Turner, Thomas F. (2017). Identifying the source population of fish re-colonizing an arid-land stream following wildfire-induced extirpation using otolith microchemistry. Hydrobiologia, 797(1), 29-45. doi:http://dx.doi.org/10.1007/s10750-017-3143-1

Williams, D. G. S., R. L.; Huxman, T. E.; Goodrich, D. C.; Lin, G. (2006). Sensitivity of riparian ecosystems in arid and semiarid environments to moisture pulses. Hydrological Processes, 20(15), 3191-3205. doi:10.1002/byp.6327

Williams, D. P., Nathalie; Henschel, Joh; Cowlishaw, Guy; Douglas, Caitlin M. S. (2014). Impact of alien trees on mammal distributions along an ephemeral river in the Namib Desert. African Journal of Ecology, 52(4), 404-413. doi:http://dx.doi.org/10.1111/aje.12134

Xi, H. Y. Z., L.; Feng, Q.; Si, J. H.; Chang, Z. Q.; Yu, T. F.; Li, J. G. (2015). The spatial heterogeneity of riverbed saturated permeability coefficient in the lower reaches of the Heihe River Basin, Northwest China. Hydrological Processes, 29(23), 4891-4907. doi:10.1002/hyp.10544

Yair, A. G., Naftali; Shachar, Yossi. (2017). Hydropedology of a mildly-arid loess covered area, southern Israel. Earth Surface Processes and Landforms, 42(5), 781-788. doi:10.1002/esp.4021

Yuill, B. N., Mary; Yager, Elowyn. (2010). Coarse bed material patch evolution in low-order, ephemeral channels. Catena (Giessen), 81(2), 126-136. doi:http://dx.doi.org/10.1016/j.catena.2010.02.002

Zeglin, L. H. D., Clifford N.; Barrett, John E.; Gooseff, Michael N.; Fitpatrick, Shannon K.; Takacs-vesbach, Cristina D. (2011). Bacterial Community Structure Along Moisture Gradients in the Parafluvial Sediments of Two Ephemeral Desert Streams. Microbial Ecology, 61(3), 543-556. doi:http://dx.doi.org/10.1007/s00248-010-9782-7

Zhang, X. L., Zhanbin; Li, Peng; Cheng, Shengdong; Zhang, Yang; Tang, Shanshan; Wang, Tian. (2015). A model to study the grain size components of the sediment deposited in aeolian-fluvial interplay erosion watershed. Sedimentary Geology, 330, 132-140. doi:http://dx.doi.org/10.1016/j.sedgeo.2015.10.002

Zhu, X. Y., Guofu; Yi, Xiaobo; Du, Tao. (2017). Quantifying the impacts of river hydrology on riparian vegetation spatial structure: Case study in the lower basin of the Tarim River, China. Ecohydrology, 10(7), 1-9. doi:10.1002/eco.1887

Zoppini, A. A., N.; Amalfitano, S.; Casella, P.; Patrolecco, L.; Polesello, S. (2014). Organic priority substances and microbial processes in river sediments subject to contrasting hydrological conditions. Science of the Total Environment, 484, 74-83. doi:10.1016/j.scitotenv.2014.03.019

REFERENCES

Acuña, V., Hunter, M., & Ruhí, A. (2017). Managing temporary streams and rivers as unique rather than second-class ecosystems. *Biological Conservation, 211*, 12-19. doi:10.1016/j.biocon.2016.12.025

Alluvium. (2010). *Key ecosystem functions and their environmental water requirements*. Retrieved from Commonwealth of Australia:

Arthington, A. H. B., J. M.; Ilheu, M. (2014). Temporary Rivers: Linking Ecohydrology, Ecological Quality and Reconciliation Ecology. *River Research and Applications, 30*(10), 1209-1215. doi:10.1002/rra.2831

Bagstad, K. J., Lite, S. J., Stromberg, J. C. (2006). Vegetation, soils, and hydrogeomorphology of riparian patch types of a dryland river. *Western North American Naturalist, 66*(1), 23-44. doi:10.3398/1527-0904(2006)66[23:vsahor]2.0.co;2

Bailey, R. G. (2005). Identifying Ecoregion Boundaries. *Environmental Management, 34*(S1), S14-S26. doi:10.1007/s00267-003-0163-6

Berkowitz, J., Casper, A. F., & Noble, C. (2011). A multiple watershed field test of hydrogeomorphic functional assessment of headwater streams—Variability in field measurements between independent teams. *Ecological Indicators, 11*(5), 1472-1475. doi:10.1016/j.ecolind.2011.01.004

Bogan, M. T. B., Kate S.; Lytle, David A. (2013). Flow intermittency alters longitudinal patterns of invertebrate diversity and assemblage composition in an arid-land stream network. *Freshwater Biology, 58*(5), 1016-1028. doi:http://dx.doi.org/10.1111/fwb.12105

Bonada, N., Doledec, S., & Statzner, B. (2007). Taxonomic and biological trait differences of stream macroinvertebrate communities between mediterranean and temperate regions: implications for future climatic scenarios. *Global Change Biology, 13*(8), 1658-1671. doi:10.1111/j.1365-2486.2007.01375.x

Bonada, N., Zamora-Munoz, C., Rieradevall, M., & Prat, N. (2005). Ecological and historical filters constraining spatial caddisfly distribution in Mediterranean rivers. *Freshwater Biology, 50*(5), 781-797. doi:10.1111/j.1365-2427.2005.01357.x

Boulton, A. J. (2014). Conservation of ephemeral streams and their ecosystem services: what are we missing? *Aquatic Conservation (Online), 24*(6), 733-738. doi:http://dx.doi.org/10.1002/aqc.2537

Boys, C. A., Thoms, Martin C. (2006). A Large-scale, Hierarchical Approach for Assessing Habitat Associations of Fish Assemblages in Large Dryland Rivers. *Hydrobiologia, 572*(1), 11-31. doi:10.1007/s10750-005-0004-0

Brinson, M. M. (1993). *A Hydrogeomorphic Classification for Wetlands*. (Technical Report WRP-DE-4). Vicksburg, MS: United States Army Corps of Engineers, Waterways Experiment Station.

Brinson, M. M., Rheinhardt, R. D., Hauer, F. R., Lee, L. C., Nutter, W. L., Smith, R. D., & Whigham, D. (1995). *A Guidebook for Application of Hydrogeomorphic Assessments to Riverine Wetlands*. (Wetlands Research Program Technical Report WRP-DE-11). Vicksburg, MS: U.S. Army Corps of Engineers, Waterways Experiment Station.

Bull, L. J., & Kirkby, M. J. (2002). *Dryland Rivers: Hydrology and Geomorphology of Semiarid Channels*. New York: John Wiley & Sons, Inc.

California Wetlands Monitoring Group. (2013). *California Rapid Assessment Method (CRAM) for Wetlands User's Manual; Version 6.1*. Retrieved from http://www.cramwetlands.org/documents

Cimorelli, A. J. (2005). Tackling the Dilemma of the Science-Policy Interface in Environmental Policy Analysis. *Bulletin of Science, Technology & Society, 25*(3), 276-284. doi:10.1177/0270467605277412

Clairain, J., Ellis J., Dana R. Sanders, Sr., Hanley K. Smith, Charles V. Klimas. (1985). *Wetlands Functions And Values Study Plan*. (TECHNICAL REPORT Y-83-2). Vicksburg, MS: U.S. Army Corps of Engineers, Waterways Experiment Station.

Cui, D., Liang, S., & Wang, D. (2021). Observed and projected changes in global climate zones based on Köppen climate classification. *WIREs Climate Change, 12*(3), e701. doi:https://doi.org/10.1002/wcc.701

Datry, T., Boulton, A. J., Bonada, N., Fritz, K., Leigh, C., Sauquet, E., . . . Vamosi, S. (2018). Flow intermittence and ecosystem services in rivers of the Anthropocene. *Journal of Applied Ecology, 55*(1), 353-364. doi:10.1111/1365-2664.12941

Datry, T., Fritz, K. E. N., & Leigh, C. (2016). Challenges, developments and perspectives in intermittent river ecology. *Freshwater Biology, 61*(8), 1171-1180. doi:10.1111/fwb.12789

Datry, T., Larned, S. T., & Tockner, K. (2014). Intermittent Rivers: A Challenge for Freshwater Ecology. *Bioscience, 64*(3), 229-235. doi:10.1093/biosci/bit027

David, G. C. L., Somerville, D. E., McCarthy, J. M., Fitzpatrick, F., MacNeil, S. D., Evans, R., & Wilson, D. (2021). *Technical Guide for the Development, Evaluation, and*

Modification of Stream Assessment Methods for the Corps Regulatory Program. (ERDC/CRREL SR-21-2). Cold Regions Research and Engineering Laboratory (U.S.) Engineer Research and Development Center (U.S.) Retrieved from http://dx.doi.org/10.21079/11681/42182.

Davies, N. M., Norris, R. H., & Thoms, M. C. (2000). Prediction and assessment of local stream habitat features using large-scale catchment characteristics. *Freshwater Biology, 45*(3), 343-369. doi:10.1046/j.1365-2427.2000.00625.x

de Groot, R. (2006). Function-analysis and valuation as a tool to assess land use conflicts in planning for sustainable, multi-functional landscapes. *Landscape and Urban Planning, 75*(3-4), 175-186. doi:10.1016/j.landurbplan.2005.02.016

DeFries, R. S., Foley, J. A., & Asner, G. P. (2004). Land-use choices: balancing human needs and ecosystem function. *Frontiers in Ecology and the Environment, 2*(5), 249-257. doi:10.1890/1540-9295(2004)002[0249:lcbhna]2.0.co;2

Detenbeck, N. E. (2002). *Methods for Evaluating Wetland Condition: Wetlands Classification*. (EPA-822-R-02-017). Washington, DC.

Field, J. J., & Lichvar, R. W. (2007). *Review and Synopsis of Natural and Human Controls on Fluvial Channel Processes in the Arid West*. (ERDC/CRREL TR-07-16). Hanover, NH: U.S. Army Engineer Research and Development Center.

Fischenich, J. C. (2006). *Functional Objectives for Stream Restoration*. (EMRRP Technical Notes Collection (ERDC TN-EMRRP SR-52)). Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Fisher, S. G., Heffernan, J. B., Sponseller, R. A., & Welter, J. R. (2007). Functional ecomorphology; feedbacks between form and function in fluvial landscape ecosystems. *Geomorphology, 89*(1-2), 84-96. doi:http://dx.doi.org/10.1016/j.geomorph.2006.07.013

Flotemersch, J. E., Stribling, J. B., & Paul, M. J. (2006). *Concepts and Approaches for the Bioassessment of Non-wadeable Streams and Rivers*. (EPA/600/R-061127). Cincinnati, Ohio: U.S. Environmental Protection Agency.

Flotemersch, J. E., Thorp, J. H., & Williams, B. S. (2010). *Application of the Riverine Ecosystem Synthesis (RES) and the Functional Process Zone (FPZ) Approach to EPA Environmental Mission Tasks for Rivers*. (EPA/600/R-11/089). Washington, D.C.: U.S. Environmental Protection Agency.

Graf, W. L. (1988). *Fluvial Processes in Dryland Rivers*. Caldwell, NJ: The Blackburn Press.

Graf, W. L. (1992). Science, Public-Policy, And Western American Rivers. *Transactions of the Institute of British Geographers, 17*(1), 5-19. doi:10.2307/622633

Grippo, M., Hayse, J. W., & O'Connor, B. L. (2015). Solar Energy Development and Aquatic Ecosystems in the Southwestern United States: Potential Impacts, Mitigation, and Research Needs. *Environmental Management, 55*(1), 244-256. doi:http://dx.doi.org/10.1007/s00267-014-0384-x

Hammond, J. C., Zimmer, M., Shanafield, M., Kaiser, K., Godsey, S. E., Mims, M. C., . . . Allen, D. C. (2021). Spatial Patterns and Drivers of Nonperennial Flow Regimes in the Contiguous United States. *Geophysical Research Letters, 48*(2), e2020GL090794. doi:https://doi.org/10.1029/2020GL090794

Harman, W., Starr, R., Carter, M., Tweedy, K., Clemmons, M., Suggs, K., & Miller, C. (2012). *A Function-Based Framework for Stream Assessment & Restoration Projects*. (EPA 843-K-12-006). Washington, DC: US Environmental Protection Agency, Office of Wetlands, Oceans, and Watersheds.

Hart, D. D., & Finelli, C. M. (1999). Physical-Biological Coupling in Streams: The Pervasive Effects of Flow on Benthic Organisms. *Annual Review of Ecology and Systematics, 30*(1), 363-395. doi:10.1146/annurev.ecolsys.30.1.363

Harvey, J., & Gooseff, M. (2015). River corridor science: Hydrologic exchange and ecological consequences from bedforms to basins. *Water Resources Research, 51*(9), 6893-6922. doi:10.1002/2015wr017617

HydroGeoLogic. (2008). *Hydrology And Ecology Of Southwestern Intermittent Streams, Dry Washes, And Adjacent Riparian Zones*. Paper presented at the Southwest Region Threatened, Endangered, and At-Risk Species; Workshop, Tucson, Arizona.

L.C. Lee & Associates, I., & National Wetland Science Training Cooperative. (2001). *Draft Guidebook for Reference-Based Assessment of the Functions of Riverine Waters/Wetlands Ecosystems in the South Coast Region of Santa Barbara County*. Santa Barbara County Water Agency, Santa Barbara, California.

Lee, L. C., Rains, M. C., Mason, J. A., & Kleindl, W. J. (1997). *Draft Guidebook to HGM Functional Assessments in Riverine Waters/Wetlands of the Santa Margarita Watershed*. San Francisco, California.

Lefebvre, L., Lichvar, R., & Curtis, K. (2013). *Survey of OHWM Indicator Distribution Patterns across Arid West Landscapes*. (ERDC/CRREL TR-13-2). Hanover, NH: US Army Engineer Research and Development Center.

Lefebvre, L., Lichvar, R., Curtis, K., & Gillrich, J. (2013). *Channel Classification across Arid West Landscapes in Support of OHW Delineation*. (ERDC/CRREL TR-13-3). Hanover, NH: US Army Engineer Research and Development Center.

Leibowitz, S. G., Wigington, P. J., Rains, M. C., & Downing, D. M. (2008). Non-navigable streams and adjacent wetlands: addressing science needs following the Supreme Court's Rapanos decision. *Frontiers in Ecology and the Environment, 6*(7), 366-373. doi:10.1890/070068

Leigh, C., Boulton, A. J., Courtwright, J. L., Fritz, K., May, C. L., Walker, R. H., & Datry, T. (2016). Ecological research and management of intermittent rivers: an historical review and future directions. *Freshwater Biology, 61*(8), 1181-1199. doi:10.1111/fwb.12646

Leopold, L., B. Wolman, M. Gordon, J.P. Miller. (1964). *Fluvial Processes in Geomorphology*. New York: Dover Publications, Inc.

Levick, L. R., Goodrich, D. C., Hernandez, M., Fonseca, J., Semmens, D. J., Stromberg, J., . . . Kepner, W. G. (2008). *The Ecological and Hydrological Significance of Ephemeral and Intermittent Streams in the Arid and Semi-arid American Southwest*. (EPA/600/R-08/134, ARS/233046). U.S. Environmental Protection Agency and USDA/ARS Southwest Watershed Research Center.

Li, J., Bristow, C. S., Luthi, S. M., & Donselaar, M. E. (2015). Dryland anabranching river morphodynamics: Río Capilla, Salar de Uyuni, Bolivia. *Geomorphology, 250*, 282-297. doi:https://doi.org/10.1016/j.geomorph.2015.09.011

Lichvar, R., Cate, D., Photos, C., Dixon, L., Allen, B., & Byersdorfer, J. (2009). *Vegetation and Channel Morphology Responses to Ordinary High Water Discharge Events in Arid West Stream Channels*. (ERDC/CRREL TR-09-5). Hanover, NH: USACE Engineer Research and Development Center.

Lichvar, R. W., & McColley, S. M. (2008). *A Field Guide to the Identification of the Ordinary High Water Mark (OHWM) in the Arid West Region of the Western United States: A Delineation Manual*. (ERDC/CRREL TR-08-12). Hanover, NH: U.S. Army Engineer Research and Development Center.

Lohse, K. A., Gallo, E. L., & Meixner, T. (2020). Influence of Climate and Duration of Stream Water Presence on Rates of Litter Decomposition and Nutrient Dynamics in Temporary Streams and Surrounding Environments of Southwestern USA. *Frontiers in Water, 2*, 16. doi:10.3389/frwa.2020.571044

Macknick, J., Beatty, B., & Hill, G. (2013). *Overview of Opportunities for Co-Location of Solar Energy Technologies and Vegetation*. (NREL/TP-6A20-60240). U.S. Department of Energy.

MacNeil, S. D. (2001). *Hydrogeomorphic Assessment of Aliso Creek Watershed Streams: Developing a Foundation for Holistic Permitting and Management.* (Doctor o f Environmental Science and Engineering), University of California, Los Angeles.

McDonough, O. T., Jacob D. Hosen, Margaret A. Palmer. (2011). *Temporary Streams: The Hydrology, Geography, and Ecology of Non-Perennially Flowing Waters* L. E. M. Hannah S. Elliot (Ed.) *River Ecosystems: Dynamics, Management and Conservation*

McNab, W. H., David T. Cleland, Jerry A. Freeouf, James E. Keys, Jr., Gregory J. Nowacki, Constance A. Carpenter. (2005). *Description of "Ecological Subregions: Sections of the Conterminous United States"*. Washington, DC: U.S. Department of Agriculture, Forest Service.

Meitzen, K. M., Doyle, M. W., Thoms, M. C., & Burns, C. E. (2013). Geomorphology within the interdisciplinary science of environmental flows. *Geomorphology, 200*, 143-154. doi:10.1016/j.geomorph.2013.03.013

Mersel, M. K., Lefebvre, L. E., & Lichvar, R. W. (2014). *A Review of Land and Stream Classifications in Support of Developing a National Ordinary High Water Mark (OHWM) Classification*. (ERDC/CRREL TR-14-12). Hanover, NH: U.S. Army Engineer Research and Development Center.

Meyer, J. L., Kaplan, L. A., Newbold, D., Strayer, D. L., Woltemade, C. J., Zedler, J. B., . . . Zedler, P. H. (2003). Where Rivers Are Born: The Scientific Imperative for Defending Small Streams and Wetlands (pp. 24): American Rivers and Sierra Club.

Millennium Ecosystem Assessment. (2005). *Ecosystems and Human Well-being: Desertification Synthesis*

Mount, J. F. (1995). *California Rivers and Streams: The Conflict between Fluvial Process and Land Use*. Berkeley and Los Angeles, CA: University of California Press.

Nadeau, T. L., & Rains, M. C. (2007). Hydrological connectivity between headwater streams and downstream waters: How science can inform policy. *Journal of the American Water Resources Association, 43*(1), 118-133. doi:10.1111/j.1752-1688.2007.00010.x

Naiman, R. J. L., Joshua J.; Pettit, Neil E.; Olden, Julian D. (2008). Flow variability and the biophysical vitality of river systems. *Comptes Rendus Geoscience, 340*(9–10), 629-643. doi:https://doi.org/10.1016/j.crte.2008.01.002

Natural Resources Conservation Service. (2008). *Hydrogeomorphic Wetland Classification System: An Overview and Modification to Better Meet the Needs of the Natural Resources Conservation Service.* (Technical Note No. 190–8–76). Washington, DC.

Newman, B. D., Vivoni, E. R., & Groffman, A. R. (2006). Surface water–groundwater interactions in semiarid drainages of the American southwest. *Hydrological Processes, 20*(15), 3371-3394. doi:10.1002/hyp.6336

Noble, C. V., Berkowitz, J. F., & Spence, J. (2010). *Operational Draft Regional Guidebook for the Functional Assessment of High-gradient Ephemeral and Intermittent Headwater*

Streams in Western West Virginia and Eastern Kentucky. (ERDC/EL TR-10-11). US Army Engineer Research and Development Center.

Ode, P. R., Kincaid, T. M., Fleming, T., & Rehn, A. C. (2011). *Ecological Condition Assessments of California's Perennial Wadeable Streams: Highlights from the Surface Water Ambient Monitoring Program's Perennial Streams Assessment (PSA) (2000-2007)*. A collaboration between the State Water Resources Control Board's Non-Point Source Pollution Control Program (NPS Program), Surface Water Ambient Monitoring Program (SWAMP), California Department of Fish and Game Aquatic Bioassessment Laboratory, and the U.S. Environmental Protection Agency.

Omernik, J. M. (1987). Ecoregions Of The Conterminous United States. *Annals of the Association of American Geographers, 77*(1), 118-125. doi:10.1111/j.1467-8306.1987.tb00149.x

Peel, M. C., Finlayson, B. L., & McMahon, T. A. (2007). Updated world map of the Koppen-Geiger climate classification. *Hydrology and Earth System Sciences, 11*(5), 1633-1644. doi:10.5194/hess-11-1633-2007

Poff, N. L., Allan, J. D., Bain, M. B., Karr, J. R., Prestegaard, K. L., Richter, B. D., . . . Stromberg, J. C. (1997). The natural flow regime. *Bioscience, 47*(11), 769-784. doi:10.2307/1313099

Pyne, M. I., Carlisle, D. M., Konrad, C. P., & Stein, E. D. (2017). Classification of California streams using combined deductive and inductive approaches: Setting the foundation for analysis of hydrologic alteration. *Ecohydrology, 10*(3), n/a-n/a. doi:10.1002/eco.1802

Renewable Energy Action Team. (2010). *Best Management Practices and Guidance Manual: Desert Renewable Energy Projects*. (REAT-1000-2010-009-F). California Energy Commission, Siting, Transmission and Environmental Protection Division.

Richards, K., Brasington, J., Hughes, F. (2002). Geomorphic dynamics of floodplains: ecological implications and a potential modelling strategy. *Freshwater Biology, 47*(4), 559-579. doi:10.1046/j.1365-2427.2002.00920.x

Rowe, D. K., Parkyn, S., Quinn, J., Collier, K., Hatton, C., Joy, M. K., . . . Moore, S. (2009). A Rapid Method to Score Stream Reaches Based on the Overall Performance of Their Main Ecological Functions. *Environmental Management, 43*(6), 1287-1300. doi:10.1007/s00267-009-9302-z

Shanafield, M., Bourke, S. A., Zimmer, M. A., & Costigan, K. H. (2021). An overview of the hydrology of non-perennial rivers and streams. *WIREs Water, 8*(2), e1504. doi:https://doi.org/10.1002/wat2.1504

Smith, R. D., Ammann, A., Bartoldus, C., & Brinson, M. M. (1995). *An Approach for Assessing Wetland Functions Using Hydrogeomorphic Classification, Reference Wetlands, and Functional Indices*. (Wetlands Research Program Technical Report WRP-DE-9). Vicksburg, MS: U.S. Army Corps of Engineers, Waterways Experiment Station.

Somerville, D. E. (2010). *Stream Assessment And Mitigation Protocols: A Review Of Commonalities And Differences*. (EPA 843-S-12-003). Washington, D.C.: Prepared for the U.S. Environmental Protection Agency, Office of Wetlands, Oceans, and Watersheds.

Somerville, D. E., & Pruitt, B. A. (2004). Physical Stream Assessment: A Review of Selected Protocols for Use in the Clean Water Act Section 404 Program. 213.

Somerville, D. E., Pruitt, B.A. . (2004). *Physical Stream Assessment: A Review of Selected Protocols for Use in the Clean Water Act Section 404 Program*. Washington , DC: Prepared for the U.S. Environmental Protection Agency, Office of Wetlands, Oceans, and Watersheds, Wetlands Division.

Southern California Coastal Water Research Project. (2010). *An Evaluation Of The Application Of The California Rapid Assessment Method (CRAM) For Assessment Of Arid, Emphemeral Stream Condition: Draft Technical Report*. Retrieved from

Springer, D. (2007). How States Can Help to Resolve the "Rapanos/Carabell" Dilemma. *Tulane Environmental Law Journal, 21*(1), 83-100.

Stein, E. D., Vyverberg, K., Kondolf, G. M., & Janes, K. (2011). *Episodic Stream Channels: Imperatives for Assessment and Environmental Planning in California*. Paper presented at the Proceedings of a Special Technical Workshop, November 8-10, 2010, Costa Mesa, CA.

Stromberg, J., Gallo, E., Lohse, K., Meixner, T., Moody, E., Sabo, J., & Setaro, D. (2015). *Structure and Function of Ephemeral Streams in the Arid and Semiarid Southwest: Implications for Conservation and Management*. (SERDP Project RC-1726). Strategic Environmental Research and Development Program.

Stromberg, J. C., Beauchamp, V. B., Dixon, M. D., Lite, S. J., & Paradzick, C. (2007). Importance of low-flow and high-flow characteristics to restoration of riparian vegetation along rivers in arid south-western United States. *Freshwater Biology, 52*(4), 651-679. doi:http://dx.doi.org/10.1111/j.1365-2427.2006.01713.x

Stromberg, J. C., McCluney, K. E., Dixon, M. D., & Meixner, T. (2013). Dryland Riparian Ecosystems in the American Southwest: Sensitivity and Resilience to Climatic Extremes. *Ecosystems, 16*(3), 411-415. doi:http://dx.doi.org/10.1007/s10021-012-9606-3

Sullivan, S. M. P., Watzin, Mary C., Hession, W. Cully. (2004). Understanding Stream Geomorphic State in Relation to Ecological Integrity: Evidence Using Habitat

Assessments and Macroinvertebrates. *Environmental Management, 34*(5), 669-683. doi:10.1007/s00267-004-4032-8

Summers, E. A., Noble, C. V., Berkowitz, J. F., & Spilker, F. (2017). *Operational Draft Regional Guidebook for the Functional Assessment of High-Gradient Headwater Streams and Low-Gradient Perennial Streams in Appalachia*. (ERDC/EL TR-17-1). U.S. Army Engineer Research and Development Center.

Sutfin, N. A. S., J. R.; Wohl, E. E.; Cooper, D. J. (2014). A geomorphic classification of ephemeral channels in a mountainous, arid region, southwestern Arizona, USA. *Geomorphology, 221*, 164-175. doi:10.1016/j.geomorph.2014.06.005

Tal, M., & Paola, C. (2007). Dynamic single-thread channels maintained by the interaction of flow and vegetation. *Geology, 35*(4), 347-350. doi:10.1130/g23260a.1

Tchakerian, V., & Pease, P. (2015). The Critical Zone in Desert Environments. In C. H. John R. Giardino (Ed.), *Developments in Earth Surface Processes* (Vol. 19, pp. 449-472): Elsevier.

Technical Advisory Committee. (2013). *Conceptual Model For Development Of A Rapid Assessment Methods For Dryland Episodic Channels (Version 3.0)*. Retrieved from

Thoms, M. C., & Parsons, M. (2002). Eco-geomorphology: An interdisciplinary approach to river science. In F. J. T. Dyer, M. C.; Olley, J. M. (Ed.), *Structure, Function and Management Implications of Fluvial Sedimentary Systems* (pp. 113-119).

Thoms, M. C., & Parsons, M. (2003). Identifying spatial and temporal patterns in the hydrological character of the Condamine-Balonne river, Australia, using multivariate statistics. *River Research and Applications, 19*(5-6), 443-457. doi:10.1002/rra.737

Thorp, J. H., Flotemersch, J. E., Delong, M. D., Casper, A. F., Thoms, M. C., Ballantyne, F., . . . Haase, C. S. (2010). Linking Ecosystem Services, Rehabilitation, and River Hydrogeomorphology. *Bioscience, 60*(1), 67-74. doi:10.1525/bio.2010.60.1.11

Thorp, J. H., Thoms, M. C., & Delong, M. D. (2006). The riverine ecosystem synthesis: biocomplexity in river networks across space and time. *River Research and Applications, 22*(2), 123-147. doi:10.1002/rra.901

Thorp, J. H., Thoms, M. C., & Delong, M. D. (2008). The Riverine Ecosystem Synthesis Toward Conceptual Cohesiveness in River Science Preface *Riverine Ecosystem Synthesis: Towards Conceptual Cohesiveness in River Science* (pp. XI-XIV).

Tooth, S. (2000). Process, form and change in dryland rivers: a review of recent research. *Earth-Science Reviews, 51*(1-4), 67-107. doi:10.1016/s0012-8252(00)00014-3

Tooth, S., & Nanson, G. C. (2000). The role of vegetation in the formation of anabranching channels in an ephemeral river, Northern plains, arid central Australia. *Hydrological Processes, 14*(16-17), 3099-3117. doi:10.1002/1099-1085(200011/12)14:16/17<3099::aid-hyp136>3.0.co;2-4

U.S. Army Corps of Engineers. (2004). *Review of Ordinary High Water Mark Indicators for Delineating Arid Streams in the Southwestern United States*. (ERDC TR-04-1). Hanover, New Hampshire and Vicksburg, Mississippi: U.S. Army Engineer Research and Development Center.

U.S. Army Corps of Engineers. (2006). *Interim Regional Supplement to the Corps of Engineers Wetland Delineation Manual: Arid West Region*. (ed. J. S. Wakeley, R. W. Lichvar, and C. V. Noble. ERDC/EL TR-06-16). Vicksburg, MS: U.S. Army Engineer Research and Development Center.

U.S. Army Corps of Engineers. (2008a). *Regional Supplement to the Corps of Engineers Wetland Delineation Manual: Arid West Region (Version 2.0)*. (ed. J. S. Wakeley, R. W. Lichvar, and C. V. Noble. ERDC/EL TR-08-28). Vicksburg, MS U.S. Army Engineer Research and Development Center.

U.S. Army Corps of Engineers. (2008b). *U.S. Water Demand, Supply and Allocation: Trends and Outlook*. (IWR 2007-WRO-R-03). Alexandria, VA: U.S. Army, Institute for Water Resources.

U.S. Department of Agriculture, Natural Resources Conservation Service. (2006). *Land Resource Regions and Major Land Resource Areas of the United States, the Caribbean, and the Pacific Basin*. U.S. Department of Agriculture Handbook 296.

U.S. Environmental Protection Agency. (2003). Level III ecoregions of the conterminous United States. Revised May 2003. Retrieved from http://pubs.usgs.gov/tm/04/c03/virtual_CD/useco.pdf

U.S. Environmental Protection Agency. (2006). *Wadeable Streams Assessment: A Collaborative Survey of the Nation's Streams*. (EPA 841-B-06-002). Washington, D.C.: U.S. Environmental Protection Agency, Office of Research and Development.

U.S. Environmental Protection Agency, U.S. Army Corps of Engineers. (2015). *Technical Support Document for the Clean Water Rule: Definition of Waters of the United States*. U.S. Environmental Protection Agency and the U.S. Army Corps of Engineers.

U.S. Evironmental Protection Agency. (2015). *Connectivity Of Streams And Wetlands To Downstream Waters: A Review And Synthesis Of The Scientific Evidence*. (EPA/600/R-14/475F). Washington, D.C.: U.S. Environmental Protection Agency, Office of Research and Development.

Vyverberg, K. (2010). *A Review of Stream Processes and Forms in Dryland Watersheds*. California Department of Fish and Game.

Wakeley, J. S. (2002). *Developing a Regionalized Version of the Corps of Engineers Wetlands Delineation Manual: Issues and Recommendations*. (ERDC/EL TR-02-20). U.S. Army Engineer Research and Development Center ; 3909 Halls Ferry Road ; Vicksburg, MS 39180-6199: U.S. Army Corps of Engineers, Engineer Research and Development Center.

Wohl, E., Mersel, M., Allen, A., Fritz, K., Kichefski, S., Lichvar, R., . . . Vanderbilt, F. (2016). *Synthesizing the Scientific Foundation for Ordinary High Water Mark Delineation in Fluvial Systems*. (ERDC/CRREL SR-16-5). Galveston, TX: U.S. Army Corps of Engineers.

Young, W. J., Ralph W. Ogden, Andrew O. Hughes, Ian P. Prosser. (2002). *Predicting channel type from catchment and hydrological variables.* Paper presented at the The Structure, Function and Management Implications of Fluvial Sedimentary Systems, Alice Springs, Australia.