Title

Conservation and Metapopulation Management of the Federally Endangered Tidewater Gobies (Genus Eucyclogobius)

Author
Spies, Brenton Tyler

Publication Date
2022

Peer reviewed|Thesis/dissertation

UNIVERSITY OF CALIFORNIA

Los Angeles

Conservation and Metapopulation Management of the Federally Endangered

Tidewater Gobies (Genus *Eucyclogobius*)

A dissertation submitted in partial satisfaction of the

requirements for the degree Doctor of Philosophy

in Biology

by

Brenton Tyler Spies

2022

ABSTRACT OF THE DISSERTATION

Conservation and Metapopulation Management of the Federally Endangered

Tidewater Gobies (Genus *Eucyclogobius*)

by

Brenton Tyler Spies

Doctor of Philosophy in Biology

University of California, Los Angeles, 2022

Professor David K. Jacobs, Chair

This project is directed towards implementing aspects of the tidewater goby recovery plan in coordination with, and funded by, the US Fish & Wildlife Service (USFWS) through a Section 6 Cooperative Agreement awarded to the University of California, Los Angeles on May 15, 2015. The primary focus of this dissertation was to developed a quantitative framework to complete a metapopulation viability analysis (MVA) for the endangered tidewater gobies in the genus *Eucyclogobius*. Modeling tidewater goby metapopulation dynamics is an essential component in constructing long-term management plans rangewide throughout the California Coast. This dissertation examines more closely how these dynamics affect viability, connectivity, and long-term persistence of tidewater goby metapopulations throughout the California coast.

In the first chapter of this dissertation, I conducted annual population surveys (2014, 2015, and 2017-2018) in 117 estuaries and lagoons to assess the current health and status of the

tidewater gobies in five of the six Recovery Units, spanning from Bodega Bay to San Diego, CA. This massive effort has provided continuous coastal surveys over four years, and over 300 observations, which helped create the framework for a robust and comprehensive presence/absence dataset to help inform metapopulation management and recovery actions. In the second chapter of this dissertation collated all existing rangewide occupancy data, metapopulation descriptors, wetland site characteristics, and repository specimen collections into an open access database. This database will provide critical information relative to the federally endangered tidewater gobies and help inform the metapopulation viability analysis model developed in this study, as well as support continued research on the conservation and management of these incredible fish species and the coastal wetland ecosystems they inhabit. In the third chapter of this dissertation I review the general biology, conservation status, habitat impacts, and metapopulation dynamics of the northern tidewater goby (*Eucyclogobius newberryi*) and southern tidewater goby (*Eucyclogobius kristinae*). In addition, I demonstrate the effectiveness of a Bayesian approach to provide a flexible method to generate metapopulation viability analyses and provide a detailed summary of the MVA model framework, including limitations, required corrections, and future amendments that need to be addressed in order to meet the recovery criterion envisioned in the recovery plan.

The dissertation of Brenton Tyler Spies is approved.

Richard F. Ambrose

Howard Bradley Shaffer

James O. Lloyd-Smith

Mark Adams Steele

David K. Jacobs, Committee Chair

University of California, Los Angeles

2022

DEDICATION

To all the small, strange, slimy, spiny, scary, unattractive, non-charismatic species that are such an important and beautiful part of our diverse natural world.

"Look closely at nature. Every species is a masterpiece, exquisitely adapted to the environment in which it has survived. Who are we to destroy or even diminish biodiversity?"

~ E.O. Wilson ~

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENTS

First and foremost, I'd like to thank my advisor, David Jacobs, for his ongoing guidance, support, and extreme patience throughout this research project. Dave, you've opened my eyes to many new and exciting questions about our world and all the critters and ecosystems that make it so special. Beyond being my tidewater goby partner in crime, your mentorship has helped me develop as a scientist and conservationist, but more importantly as an individual, and I am forever grateful. You provided a setting that allowed me to formulate and develop my own questions and ideas, even when it seemed more then I could handle. No matter how busy or brain dead you were, you always made time for me whenever I needed you. Thank you for believing in me, I am eternally grateful for your support, guidance, and friendship. I look forward to continuing our work together on the tidewater goby and the many other research projects we've talked about over the years. There is much more to do!

I'd also like to thank my committee members Rich Ambrose, Brad Schaffer, Mark Steele, and Jamie Lloyd-Smith. You have been extremely valuable, and incredibly patience, especially over this final push. Thank you for your encouragement and availability. Your mentorship over the past NINE years has been invaluable and inspiring.

Shout out to Team Tidewater goby! We have created something special, and I am so appreciative for all your help and support over the years. I look forward to continuing our work together, there is so much more that needs to be done. Special thanks to Chris Dellith, Cat Darst, and Eric Morrisette at USFWS for all your support and guidance. Camm Swift for always willing to share your wealth of knowledge, field notes, and mentorship. Daniel Stofka for your friendship and many hours helping in the field trekking through the deepest and muddiest habitats. This project would not have been possible without the many years of tidewater goby documentation and field assistance by numerous biologists at sites across California, particularly Douglas Rischbieter, Rosi Dagit, Rosemary Thompson, Ramona Swenson, Jerry Smith, Don Alley, Greg Goldsmith, Carl Page, Darren Fong, Daniel Chase, Michael Rouse, Andrew Kinziger, Tom Taylor, Gage Dayton, Jeff Hagar, and Dan Holland for your wealth of knowledge and field support.

To my friends and family, thank you for all your love and support throughout this wild ride they call grad school. I can't thank you enough for helping me get to the finish line. I love you all and look forward having more time to reconnect. Love you Mom, Dad, Alice, Stew, Brooke-Childress Family, Casa Bacallao, CSUCI-ESRM Family, and the CSUN - Steele Lab.

Most importantly, to my Love and Life Partner Amelia Brooke. You have been my rock and biggest supporter through this journey. I couldn't have done any of this without you. I love the family and home we've built together and can't wait for this next chapter of our lives to begin. So many adventures ahead for us. I Love you Pickle!

Lastly, I would like to acknowledge the funding sources that helped support this research project. Thanks to: University of California, Los Angeles Department of Ecology and Evolutionary Biology for your support with research and teaching fellowships, the U.S. Fish and Wildlife Service Cooperative Agreement Award (F15AC00320), the UCLA La Kretz Center for California Conservation Science, National Parks Service, and California State Parks for supporting our rangewide occupancy surveys.

Thank You!

CURRICULUM VITAE

Brenton Tyler Spies

EDUCATION

2010 – 2014	M.Sc. Biology, California State University, Northridge
2005 – 2008	B.Sc. Biology, San Diego State University

RESEARCH EXPERIENCE

2021 – 2022	Graduate Research Assistant, University of California, Los Angeles California Grunion (*Leuresthes tenuis*) populations genomics throughout the Southern California Bight. Principle Investigator: Dr. David Jacobs
2020 –	Technical Advisory Committee, Northern Tidewater Goby Recovery, LA/Ventura Unit
2020 –	Technical Advisory Committee, California Trout, Aquatic Species Assessment Tool
2019 –	Assistant Curator, Tidewater Goby Repository, University of California, Los Angeles
2014 –	Marine Field Technician, California State University, Northridge SONGS Mitigation Monitoring Project. Principle Investigator: Dr. Mark Steele
2013 –	Ph.D. Candidate, University of California, Los Angeles Dissertation: Seasonally closed estuaries of California: community ecology, metapopulation dynamics, and conservation of endangered species. Chair: Dr. David Jacobs
2010 – 2014	Graduate Research Assistant, California State University, Northridge SONGS Mitigation Monitoring Project. Principle Investigator: Dr. Mark Steele
2010 – 2014	Masters Student, Fish Ecology Lab, California State University, Northridge Thesis: The effects of temperature and latitude on larval traits of the endangered tidewater goby (*Eucyclogobius newberryi*) and its sister species the arrow goby (*Clevelandia ios*). Chair: Dr. Mark Steele

TEACHING EXPERIENCE

2021 – 2022	Lecturer: Restoration Ecology, ESRM 352, CSU, Channel Islands
2020 –	Lecturer: Field Methods, ESRM 351, CSU, Channel Islands
2017 – 2022	Lecturer: Conservation Biology, ESRM/BIO 313, CSU, Channel Islands
2021	Lecturer: Field Professionalism, ESRM 301, CSU, Channel Islands
2021	Lecturer: Environmental Speaker Series, ESRM/COMM 496, CSU, Channel Islands
2021	Teaching Fellow: Animal Behavior & Ecology, EEB 100, UC, Los Angeles
2019 – 2021	Teaching Fellow: California Ecosystems, EEB 154, University of California, Los Angeles
2019 – 2020	Teaching Fellow: Finding Ecological Solutions to Environmental Problems, EEB 183, UC, Los Angeles
2018 – 2020	Teaching Fellow: Conservation Biology, EEB 116, UC, Los Angeles
2015 & 2016	Teaching Associate: Community Ecology, EEB 155, UC, Los Angeles
2014 & 2017	Teaching Associate: Field Ecology, EEB 124A, UC, Los Angeles, Gump Research Station, Mo'orea, French Polynesia
2014 & 2017	Teaching Associate: Experimental Marine Invertebrate Biology, EEB 106, UC, Los Angeles, Gump Research Station, Mo'orea, French Polynesia
2011 – 2013	Teaching Associate: General Biology, Bio106L, California State University, Northridge
2011	Teaching Associate: Life in the Sea, Bio325L, California State University, Northridge
2011	Graduate Assistant: Biometry, Bio502 & 502L, California State University, Northridge
2003 – 2011	Marine Science Naturalist, Santa Monica Pier Aquarium, "Key to the Sea" Program, K-12

PUBLICATIONS

Blanchette A, Chow J, Eminhizer S, Franco N, Gu K, Turba R, Spies BT, and Jacobs DK (2021). Damselfish territories facilitate coral recovery on impacted fringing reefs of Mo'orea, French Polynesia. (*In Print)*

Swift CC, Spies BT, Ellingson RA, Jacobs DK (2016) A new species of the bay goby genus *Eucyclogobius*, endemic to Southern California: evolution, conservation, and decline. PLoS ONE 11(7): e0158543.doi:10.1371/journal.pone.0158543

Spies BT, Tarango BC, Steele MA (2014). Larval duration, settlement, and larval growth rates of the endangered tidewater goby (*Eucyclogobius newberryi*) and the arrow goby (*Clevelandia ios*) (Pisces, Teleostei). Bulletin of Southern California Academy of Sciences 113(3):165-175. doi:http://dx.doi.org/10.3160/0038-3872-113.3.165

Spies BT, Tarango BC, Steele MA (2014). Larval duration, settlement, and larval growth rates of the endangered tidewater goby (*Eucyclogobius newberryi*) and the arrow goby (*Clevelandia ios*) (Pisces, Teleostei). Bulletin of Southern California Academy of Sciences 113(3):165-175. doi:http://dx.doi.org/10.3160/0038-3872-113.3.165

Spies BT (2014). The effects of temperature and latitude on larval traits of the endangered tidewater goby (*Eucyclogobius newberryi*) and its sister species the arrow goby (*Clevelandia ios*). MS Thesis. Department of Biology, California State University, Northridge.

GRANTS & CONTRACTS

2020 – 2021	California State Parks / RCDSMM Research Contract: $20,000
2018 – 2019	UCLA La Kretz Center Graduate Research Grant: $1,000
2015 – 2018	US Fish & Wildlife Cooperative Agreement: $111,626
2016 – 2017	CSU Chancellors Doctoral Incentive Mini Grant: $2,500
2015 – 2016	UCLA La Kretz Center Graduate Research Grant: $800
2015 – 2016	National Parks Service Research Grant: $4,500
2014 – 2015	UCLA La Kretz Center Graduate Research Grant: $1,000
2014 – 2015	UCLA Institute IoES Venture Grant: $20,000
2014 – 2015	National Parks Service Research Grant: $5,000
2014 – 2015	Southern California Coastal Waters Research Project Grant: $7,000
2013 – 2014	UCLA La Kretz Center Graduate Research Grant: $1,100
2011 – 2013	Norris Field Trip Grant: $250

Awards & Fellowships

2021	UCLA Bartholomew Field Research Fellowship: $9500
2019	UCLA EEB Dissertation Quarter Fellowship: $13,800
2019	UCLA EEB Departmental Research Award: $2000
2019	UCLA Holmes O. Miller Summer Fellowship: $7000
2018	UCLA Bartholomew Field Research Fellowship: $9500
2017	WSN Rafe Sagarin Award for Best Paper in Observational Ecology
2015 – 2018	CSU Chancellors Doctoral Incentive Awardee: $30,000
2015 – 2016	UCLA Dean's Field Biology Award: $6,000
2014 – 2016	UCLA EEB Summer Research Fellowship: $8,000
2011 – 2015	IWFA Scholarship Trust Award: $1,000
2011 – 2012	Graduate Thesis Support Program Award: $1,000

Collection Permits and Permissions

California Department of Fish and Wildlife scientific collecting permit (#SC-10750)
U.S. Fish & Wildlife endangered species permit – tidewater goby (#TE43944A-0)
California State Parks – coast wide access
National Parks Service – Golden Gate & Point Reyes National Recreation Area
Department of Defense – Camp Pendleton (USMC), Vandenberg (USAF)

CHAPTER 1

Metapopulation Status of the Tidewater Gobies: A Federally Endangered California Coastal Endemic Fish Genus (*Eucyclogobius*)

Brenton T. Spies and David K. Jacobs

Abstract

The federally endangered northern tidewater goby (*Eucyclogobius newberryi*) and the newly described southern tidewater goby (*Eucyclogobius kristinae*) are currently in review for reclassification, despite the shortage of thorough population surveys needed to conduct the appropriate metapopulation viability analysis (MVA) listed in the U.S. Fish and Wildlife Service (USFWS) Recovery Plan for reclassification. Given the recent extreme and volatile weather patterns that have occurred in California over the past few years, ranging from severe drought to record rains, many coastal estuaries and lagoons where the tidewater gobies occur continue to be heavily impacted and degraded. Therefore, we conducted annual population surveys (2014, 2015, and 2017-2018) in 117 estuaries and lagoons to assess the current health and status of the tidewater gobies in five of the six Recovery Units, spanning from Bodega Bay to San Diego, CA. This massive effort has provided continuous coastal surveys over four years, and over 300 observations, which helped create the framework for a robust and comprehensive presence/absence dataset to help inform metapopulation management and recovery actions. Surveys revealed a high degree of endangerment of both species, mainly in Southern California – south of Point Conception, due to habitat desiccation and the presence of invasive species. Endangerment is especially high in the South Coast Recovery Unit of San Diego County, where the southern tidewater goby has been reduced from nine to four lagoonal populations on Marine Corps Camp Pendleton. Additionally, surveys revealed a range expansion of the microsporidian parasite *Kabatana newberryi* in 24 localities south of Rodeo lagoon, Marin County to Topanga Canyon, Los Angeles County.

Introduction

Occupancy (presence/absence) surveys can provide wildlife managers a wide range of beneficial information on populations, or metapopulations, of conservation concern in a variety of contexts, such as annual monitoring and demographics, habitat impacts and threats, and identifying populations of high value or that need restoration or reintroduction (MacKenzie 2005). Two species of conservation concern where annual occupancy surveys are critically important to inform management actions and restoration efforts are the tidewater gobies (family Gobionellidae), *Eucyclogobius newberryi* (Girard 1856, Fig. 1-1) and *Eucyclogobius kristinae* (Swift et al. 2016, Fig. 1-1). These two small annual fish species are endemic to California and inhabit low-flow, shallow, brackish zones of coastal streams, marshes, estuaries, and lagoons (Fig. 1-2). The tidewater goby (*E. newberryi*), previously considered a single species, has been federally listed as endangered since 1994. The southern tidewater goby (*E. kristinae*) has been recently described as a distinct species in the genus *Eucyclogobius* but is currently being managed as a component of the northern tidewater goby (*E. newberryi*) under the Endangered Species Act (1974) until a separate Species Status Assessment and Recovery Plan have been developed.

Individuals of these species seldom exceed 55mm in standard length (SL) and are considered benthic microcarnivores that primarily feed on aquatic invertebrates such as amphipods, ostracods, and chironomid larvae (Swift et al. 1989; Swenson and McCray 1996, Swenson et al. 1999). The northern tidewater goby's range spans from the Smith River in Del Norte County to Topanga Creek in Los Angeles County (Swift et al. 2016). The historic range of the southern tidewater goby spanned from Aliso Creek in Orange County to Agua Hedionda in San Diego

County; however, its current range has been reduced by over 50% to a <30km stretch of coastline on Marine Corps Base Camp Pendleton (Swift et al. 2016). Loss and degradation of suitable habitat, resulting from coastal development and land use practices such as: conversion of coastal wetlands to marinas, highway and railroad bridge construction, freshwater diversions, flood control, grazing, agriculture, introduction of non-native predators, and artificial breaching of seasonal lagoons (Lafferty et al. 1996; USFWS 2005) endanger these species. Causes of extirpation that have been documented include high-flow events, post-fire debris runoff (Fig. 1-3), native predators, and site desiccation usually due to drought (Fig. 1-4). Extirpation events resulting from site desiccation have been documented in the field in a few small systems (Fig. 1-4) along the California coast over the past few decades and can also be observed using aerial photography (Jacobs et al. 2005).

Another potential threat facing numerous tidewater goby populations is a parasitic microsporidian (*Kabatana newberryi*, Fig. 1-5) that infects the muscle tissue, causing round to ovoid shaped skin lesions, skin depressions, and tissue discoloration (McGourty et al. 2007). It is suspected that *K. newberryi* is a host-specific parasite to the northern tidewater goby, primarily infecting populations in northern California with a southern range description of Rodeo Lagoon, Marin County (McGourty et al. 2007). However, similar infections were documented during this study in numerous sites in central and southern California, expanding south as far as Topanga Canyon, Los Angeles County. These microsporidian infections have been confirmed through genetic sequencing to be a microsporidia in the genus *Kabatana*, likely *K. newberryi* (Jacobs Lab unpublished data). The dispersal mechanism of *K. newberryi* is not well known, and further investigation into the impacts on tidewater goby populations are needed to assess whether this parasite poses a potential threat. Documenting the spread of infection throughout the tidewater gobies range and which populations are most heavily impacted is a first step in further understanding the *Kabatana* population history, dispersal, and impacts on *Eucyclogobius.* Such information may facilitate reduction of future impacts due to infection.

The absence of thorough population surveys since listing affects our understanding of tidewater goby viability, connectivity, and long-term persistence of tidewater goby metapopulations throughout the California coast. This occupancy data discrepancy continues to get better each year with more frequent and expansive rangewide surveys being conducted and reported. However, there are still major data gaps in parts of the coast where surveys are infrequent and/or inadequate. Here, we conducted three annual occupancy surveys (2014, 2015, 2017-18) to assess population status of the northern and southern tidewater goby in 117 sites within five of the six Recovery Units. These coastal surveys were used to develop the required dataset (Chapter 2 - Spies et al. *In Prep*) and metapopulation viability analysis (MVA) model (Chapter 3 – Spies et al. *In Review*) listed in the Recovery Plan as a major criterion necessary to assess status and future management actions.

<u>Materials and Methods</u>

Study Sites

In order to account for the lack of continuous rangewide annual occupancy data available since listing in 1994, we conducted three years (2014, 2015, and 2017-18) of occupancy surveys in 117 sites within five of the six Recovery Units (USFWS 2005, Fig. 1-2, Tables 1-1 to 1-4), spanning from Sonoma County south to San Diego County. Each of the 117 sites in this study were surveyed at least one year, with 92 sites surveyed all three years (Tables 1-1 to 1-4). Sites consisted primarily of shallow brackish water estuaries, lagoons, marshes, streams, and river habitats along the coast. In some rare cases, tidewater gobies were found in tide-gated irrigation channels and ponds used for agriculture. All localities within these five Recovery Units with records of tidewater gobies since 1990 were included in these coastwide surveys except the six sites surrounding San Francisco Bay in Marin, Alameda, and San Francisco Bay County, and the nine sites located on Hollister Ranch, Santa Barbara County. In coastal order, from north to south, these sites include Corte Madera Creek, Novato Creek, Strawberry Creek, Lake Merritt, Cliff House Restaurant, Lake Merced, Canada del Cojo, Canada del Pescado, Canada de las Agujas, Arroyo el Bulito, Canada del Agua, Canada de Santa Anita, Sacate, Canada de Alegria, Canada de Agua Caliente.

Collection Methods

Occupancy surveys for tidewater gobies occurred in water depths <1.5m and between 05:00am and 07:00pm (PST). The time of year surveys were conducted varied each year depending on logistics and permitting. Most surveys were conducted before winter rains began to avoid surveying during non-breeding season when population size is typically at its lowest and when lagoons are more likely to breach. Surveys in 2014 were conducted from October – December, 2015 July – September, and 2017-18 from October - February. The most common method to survey tidewater gobies throughout this study was a 3.7m X 1.8m beach seine with a 3.2mm mesh. Depending on habitat structure and the availability of field assistance, a small 1.5m X 1.8m meter beach seine with a 3.2mm mesh or a 1.0m X 0.5m one-person push net (Strawn 1954) with a 1.6mm mesh was used in areas with deep pools or attached vegetation, and when field assistance was limited. On a few occasions a 9.1m X 1.5m beach seine with a 3.2mm mesh was used when field assistance was available in sites with large stretches of shallow sandy habitat with minimal algae or vegetation cover. All sites found to be occupied by tidewater gobies were inspected for microsporidia (*K. newberryi*) infection (McGourty et al. 2007) by examining sub-adult and adult gobies for white ovoid shaped spores, visible to the naked eye, that cause skin lesions and noticeable changes in skin pigmentation (Fig. 1-5). Additionally, observations on tidewater goby demographics, physical and biological habitat characterization, and water quality were taken during each survey and documented in the tidewater goby database (Chapter 2 - Spies et al. *In Prep*).

Records (North to South)

North Coast Recovery Unit

No sites within the North Coast (N.C.) Recovery Unit were surveyed for this study. The primary reason for conducting these coastwide surveys was to account for the lack of continuous rangewide annual occupancy data available to inform the development of a MVA model. Recent studies out of the Kinziger Lab at Humboldt State University suggest that this unit does not appear to function as a traditional metapopulation, rather individual isolated populations with little to no dispersal that have been self-sustaining for decades (Kinziger et al. 2015). Therefore, no coastal surveys were conducted in this Recovery Unit during this study.

Greater Bay Area Recovery Unit

A total of 41 study sites in the Greater Bay Area (G.B.A) Recovery Unit were surveyed at least one year, with 29 sites surveyed all three years. Occupancy status and the presence of microsporidia fungal infection for each site surveyed in 2014, 2015, and 2017-18 can be found in Table 1-1. Surveys showed that 31/41 (75.6%) sites were occupied by northern tidewater gobies at least one of the three years surveyed. Occupancy varied slightly year to year, with 25/32 (78.1%) sites occupied in 2014, 29/38 (76.3%) sites occupied in 2015, and 22/35 (62.9%) of sites occupied in 2017-18. Of the 29 sites surveyed all three years, 18 (62.1%) were occupied every year. There is still a significant amount of uncertainty on the genetic structure and metapopulation dynamics of these sub-units that requires further surveys and assessments.

Microsporidia infection was documented in 17/41 (41.5%) of sites (Fig. 1-2, Table 1-1), 13 of which were documented south of the documented southern range limit of Rodeo lagoon, Marin County (McGourty et al. 2007). Highest infection rates occurred in Rodeo Lagoon, Marin County, San Gregorio Creek, San Mateo County, Bennett Slough, Monterey County, and Old Salinas irrigation channel, Monterey County every year surveyed (2014, 2015, 2017-18). Microsporidia infection appears to be of concern in the G.B.A. Recovery Unit, however, further investigation on the mechanisms of dispersion and spread of this parasite are needed before proper assessment can be made.

There are a number of sites and observations in the G.B.A. Recovery Unit worth mentioning. Northern tidewater gobies have been documented for the first time in Tunitas Creek (2015 – Rischbieter pers. comm.), Yankee Jim Gulch (2015 – Rischbieter pers. comm.), and Gazos Creek (2015 – Spies). In addition, northern tidewater gobies were found in Schwan Lagoon (2017 - Spies) for the first time since 1975 (Swift et al. 1989), Watsonville Slough (2014 – Dayton pers. comm.), Elkhorn Slough (2016 – Tenera pers. comm.), and Old Salinas irrigation Channel (2014-2017 – Spies). Recent multi-year absences have been documented in Lagunitas Creek and Tomasini Creek in Tomales Bay (2016-present), with no clear evidence as to the cause. Numerous habitat impacts continue to occur in the G.B.A. Recovery Unit that threaten tidewater goby persistence and metapopulation dynamics, including coastal development, cattle grazing, agriculture, introduction of non-native predators, and site desiccation from severe and prolonged drought conditions.

Central Coast Recovery Unit

A total of 22 study sites in the Central Coast (C.C.) Recovery Unit were surveyed at least one year, with 19 sites surveyed all three years. Occupancy status and the presence of microsporidia fungal infection for each site surveyed in 2014, 2015, and 2017-18 can be found in Table 1-2. Surveys showed that 15/22 (68.2%) sites were occupied by northern tidewater gobies at least one of the three years surveyed. Occupancy varied slightly year to year, with 14/20 (70.0%) sites occupied in 2014, 15/21 (71.4%) sites occupied in 2015, and 14/22 (63.6%) of sites occupied in 2017-18. Of the 19 sites surveyed all three years, 13 (68.4%) were occupied every year.

Microsporidia infection was documented in 4/22 (18.2%) of sites (Fig. 1-2, Table 1-2), with no sites found to be highly infected. At this time, microsporidia infection does not appear to be of immediate concern, however, further investigation on dispersion and spread of this parasite is needed before proper assessment can be made.

There are several sites and observations in the C.C. Recovery Unit worth mentioning. Northern tidewater gobies have been documented for the first time in Willow Creek (2015 – Spies) since 2008, and Morro Creek (Bell – 2018) since 1916. This Recovery Unit was heavily impacted by the 2014 and 2015 drought, with many smaller sites being reduced to near desiccation (Fig. 1-4). Additionally, numerous other habitat impacts continue to occur in the C.C. Recovery Unit that threaten tidewater goby persistence and metapopulation dynamics, including coastal development, cattle grazing, agricultural runoff, and introduction of non-native predators.

Conception Recovery Unit

A total of 29 study sites in the Conception (C.O.) Recovery Unit were surveyed at least one year, with 23 sites surveyed all three years. Occupancy status and the presence of microsporidia fungal infection for each site surveyed in 2014, 2015, and 2017-18 can be found in Table 1-3. Surveys showed that 21/29 (72.4%) sites were occupied by northern tidewater gobies at least one of the three years surveyed. Occupancy was consistent year to year, with 18/28 (64.3%) sites occupied in 2014, 15/24 (62.5%) sites occupied in 2015, and 17/26 (65.4%) of sites occupied in 2017-18. Of the 23 sites surveyed all three years, 11 (47.8%) were occupied every year.

Microsporidia infection was documented in 5/29 (17.2%) of sites (Fig. 1-2, Table 1-3), with no sites found to be highly infected. At this time, microsporidia infection does not appear to be of immediate concern, however, further investigation on dispersion and spread of this parasite is needed before proper assessment can be made.

There are a number of sites and observations in the C.O. Recovery Unit worth mentioning. Northern tidewater gobies have been documented for the first time in Carpenter Creek (2012 – Rischbieter pers. comm.), Meadow Creek (2014 – Rischbieter pers. comm.), and Oso Flaco Lagoon (2017 – Rischbieter pers. comm.). These habitats are important in maintaining metapopulation dynamics within the region and require further investigation to better understand genetic structure and metapopulation dynamics within this Recovery Unit. No surveys were conducted on the nine systems on Hollister Ranch, Santa Barbara County. Given the limited amount of data from this coastline, it is difficult to properly assess the current status of this metapopulation until more continuous sampling is completed. Additionally, the CO4 sub-unit (metapopulation) has experienced a significant amount of impacts since listing, including the extirpation of Arroyo Hondo (2007), Tecolote Canyon (2014), Winchester/Bell Canyon (2014), and Devereaux Slough (2014). In addition, the recent extirpation of Rincon Creek (2017), and the heavy impacts and population reductions in Arroyo Paredon and Carpinteria Creek from the Thomas fire (Fig. 1-3), may have severe long-lasting impacts on this sub-units metapopulation dynamics. Numerous habitat impacts continue to occur in the C.O. Recovery Unit that threaten tidewater goby persistence and metapopulation dynamics, including coastal development, introduction of non-native predators, and site desiccation from severe and prolonged drought conditions. Continued sampling of all sites within this sub-unit, in addition to genetic analysis, is needed before any status assessments and recommendations are given.

L.A./Ventura Recovery Unit

A total of 14 study sites in the L.A./Ventura (L.V.) Recovery Unit were surveyed at least one year, with 12 sites surveyed all three years. Occupancy status and the presence of microsporidia fungal infection for each site surveyed in 2014, 2015, and 2017-18 can be found in Table 1-4. Surveys showed that 3/14 (21.4%) sites were occupied by northern tidewater gobies at least one of the three years surveyed. However, occupancy varied year to year, with 3/13 (23.1%) sites occupied in 2014, 3/14 (21.4%) sites occupied in 2015, and 3/13 (23.1%) of sites occupied in 2017-18. Of the 12 sites surveyed all three years, 3 (25.0%) were occupied every year.

Microsporidia infection was documented in 2/14 (14.3%) of sites (Fig. 1-2, Table 1-4), with no sites found to be highly infected. At this time, microsporidia infection does not appear to be of immediate concern, however, further investigation on dispersion and spread of this parasite is needed before proper assessment can be made. Topanga Canyon is the southernmost site that *K.*

newberryi has been documented. Individuals from Topanga Canyon have been sequenced and *Kabatana spp.* microsporidia has been confirmed.

Northern tidewater gobies were documented for the first time in 2008 (Swift pers. comm.) and again in 2013 and 2014 (Dagit and Spies, pers. comm.). The lagoonal habitat at Big Sycamore Canyon appears to be suitable for tidewater gobies, however, this site is considered intermittent due to periods of extreme drought and confinement of the lagoon mouth. Despite three years of absence documented in Santa Clara River and Malibu Lagoon for this study, northern tidewater gobies have been documented in the Santa Clara River (Rosi Thompson, Cardno – 2017) and Malibu Lagoon (Rosi Dagit, RCDSMM – 2017) multiple times during this study. However, the population size in these systems appears minimal and presence has been uncommon since 2014. Numerous habitat impacts continue to occur in the L.V. Recovery Unit that threaten tidewater goby persistence and metapopulation dynamics, including coastal development, introduction of non-native predators, and site desiccation from severe and prolonged drought conditions. Endangerment is especially high in the L.V. Recovery Unit and we consider it the most critically threatened of all the northern tidewater goby management units. Continued sampling of all sites within this sub-unit, in addition to genetic analysis, is needed before any status assessments and recommendations are given.

South Coast Recovery Unit

A total of 11 study sites in the South Coast (S.C.) Recovery Unit were surveyed at least one year, with 9 sites surveyed all three years. Occupancy status and the presence of microsporidia fungal infection for each site surveyed in 2014, 2015, and 2017-18 can be found in Table 1-4. Surveys showed that 4/11 (36.4%) sites were occupied by northern tidewater gobies at least one of the three years surveyed. However, occupancy varied year to year, with 3/8 (37.5%) sites occupied in 2014, 3/11 (27.3%) sites occupied in 2015, and 4/11 (36.4%) of sites occupied in 2017-18. Of the 8 sites surveyed all three years, 3 (37.5%) were occupied every year. Surveys for this study were completed in 2015. All remaining occupancy surveys were reported by USFWS

Microsporidia infection has never been documented in a southern tidewater goby or in any sites located in the S.C. Recovery Unit. This species has been reduced from nine to four lagoonal populations on Camp Pendleton, Northern San Diego County since 2010, only two of which (San Onofre Creek and Cockleburr Canyon Lagoon) are currently considered stable (Swift et al. 2016, Spies & Jacobs pers. comm.). Drastic declines in this metapopulation have appeared to be connected to a variety of factors. Introduction of non-natives, mobilization of fire debris runoff into lagoons from the 2014 Tomahawk fire, and repeated drought conditions have caused some systems to completely desiccate all of which are associated with extirpation events in individual lagoons. The stability of the four remaining habitats is currently at risk from severe drought and strong winter flooding, further increasing the risk of complete extinction of this newly described species.

Discussion and Conclusions

This study documented a total of 285 instances of northern tidewater gobies and 30 southern tidewater gobies (315 total observations) in 117 sites and five of the six Recovery Units ranging from Sonoma County south or San Diego County. This substantial field effort has provided three sets of continuous coastal surveys over a four-year period and has helped create the framework for a robust and comprehensive presence/absence dataset to inform preliminary metapopulation viability analysis (MVA) models and help develop future management and recovery plans for both species. Surveys conducted in this study also documented the impacts of severe prolonged drought, wildfires and post-fire debris flows, high winter flow events, presence of native and non-native predators, and a considerable range expansion of the microsporidia parasite infection *K. newberryi* in 24 systems south of Rodeo Lagoon down to Topanga Canyon, Los Angeles County. Overall, this study provided a substantial amount of observational data on the current status and health of tidewater goby populations, and metapopulations, throughout California. However, this study also confirms the need for continued surveying, especially in parts of the coast where occupancy and habitat data is limited.

Many factors affect the health and viability of populations, and metapopulations, of both tidewater goby species throughout their extensive coastal California range. Many other factors, such as habitat size and function, mouth closure dynamics, and the presence of aquatic vegetation, influence occupancy and persistence and warrant further investigation. The interaction of tidewater gobies and lagoonal habitats and the nature of persistence are known to be complex. Many metapopulation models for other species assume that area is a consistently positive predictor of persistence, because they tend to support larger average population size, all else being equal. However, based on our experience the relationship between habitat size and persistence appears to be complex because all else is not equal. For example, larger lagoons are subject to larger numbers of invasive species, and native predators, which are detrimental to tidewater gobies. In addition, larger lagoons are thought to breach more frequently, and stable water level and closed lagoon conditions are associated with successful reproduction in tidewater gobies. Conversely, small lagoons may have a lower risk of invasion, and have less tidal driven variation in water level, but these habitats are at a substantially greater risk of desiccation. This suggests an intermediate lagoon size maximum in population persistence. Other habitat attributes have additional effects that may or may not be related to size. In particular, submerged and emergent aquatic vegetation, such as *Ruppia maritima, Ruppia chirrosa, Zannichellia paustris, Stuckenia pectinata, Potamogeton pectinatus, Typha latifola, and Scirpus spp.,* provide protection from predators and high flow events. Thus, aquatic vegetation is a critical habitat characteristic that appears to have strong positive relationship with tidewater goby occurrence in lagoons and likely enhances persistence. Lastly, anthropogenic phenomena such as channelization, which limits escape from high flows, or upstream impoundment which limits scour, appear to negatively impact the temporal continuity of habitat at many localities.

Furthermore, climate change is expected to impact lagoon dynamics and tidewater goby metapopulations. In Mediterranean regions, such as California, climate variations are predicted to increase and continued climate change, resulting in warmer, often drier, and more variable precipitation with more intense drought and flood (Valiela et al. 2009, Klausmeyer and Shaw 2009, Berg & Hall 2015, Williams et al. 2015). These climate patterns have become more noticeable over the past decade, especially in the coastal zones of Southern and Central California. It is not clear how climate change will affect closed vs. open estuarine habitats along the coast of California, because variations in climate patterns over large latitudinal scales can have considerable effects on the overall size, function, and distribution of estuarine habitats (Scavia et al. 2002, Day et al. 2008). A rise in global temperature is expected to shift the evaporation/precipitation regime, causing increased evaporation at lower latitudes and increased precipitation in the higher latitudes (Roessig et al. 2005). This could cause longer durations of estuary closure in southern California and more frequent opening conditions in northern California. It has been found that stream flow, not tidal patterns, are the primary cause of breaching in California estuaries (Jacobs et al. 2011). Warming will likely facilitate desiccation and invasion of non-native predators with negative impacts on small and large systems respectively. Variation in precipitation is also thought to likely increase with more frequent large precipitation events (Berg & Hall 2015). Greater episodicity of precipitation should have implications for scour-maintenance of lagoon habitat, breaching frequency and desiccation of systems. However, none of these impacts have been assessed.

With the more variable and severe climate patterns predicted to occur over the next 100 years, it is possible the California coast could experience one or more droughts similar to, or more extreme, or of longer duration than the 2011-2017 drought. Additionally, the federal register document for reclassification states that sea-level rise and the hydrological changes associated with climate change are anticipated to have significant effects on tidewater goby habitat over the next several decades. Sea-level rise poses a substantial threat to the species, potentially causing more frequent inundation of systems by breaching of the sandbar. This would eliminate a substantial amount of suitable habitat designated for the tidewater goby and numerous other species adapted to these habitats. It is important to note that maintaining genetic diversity among populations is essential for long-term persistence of this species, as the unique genetic signatures found within this species contain the required raw genetic material needed for adapting to local conditions. This could prove to be critically important for these species in the face of climate change and sea-level rise. Inference regarding how regional climate change along the California coast may influence tidewater goby metapopulation processes can help inform future conservation and management actions and be included in metapopulation viability analysis in the future.

Lastly, extreme events by their nature occur episodically. Thus, regular observations over limited timespans (years or decades) may not adequately sample these. Impacts from recent fires on coastal lagoons have shown that dramatic impacts over suites of systems can occur (Spies personal observations). Fires such as the Thomas fire, which affected multiple tidewater goby habitats in the same event (Fig. 1-3), and the relationship of these larger events to climate change is under active investigation. There is a significant likelihood of expansion in size and frequency of fires with changing climate. Increased frequency of large coastal fires such as the recent Thomas fire (Kolden and Abatzoglou 2018), which extirpated the Rincon Creek population and significantly reduced population sizes in Arroyo Paredon and Carpinteria Creek, would likely have significant impacts reducing probabilities of persistence of units due to their ability to impact multiple populations in the same event. Understanding how regional extreme events may simultaneously impact multiple sites in a metapopulation is important when developing long-term management plans for both tidewater goby species moving forward.

Acknowledgements

This study was supported by research fellowships by the University of California, Los Angeles Department of Ecology and Evolutionary Biology and by the U.S. Fish and Wildlife Service Cooperative Agreement Award (F15AC00320). Additional research funding from the UCLA La Kretz Center for California Conservation Science, National Parks Service, and California State Parks supported our rangewide occupancy surveys. The authors would like to give special thanks to Chris Dellith, Cat Darst, and Eric Morrisette at USFWS for all your support and guidance. This project would not have been possible without the many years of tidewater goby documentation and field assistance by numerous biologists at sites across California, particularly Camm Swift, Kevin Lafferty, Douglas Rischbieter, Rosi Dagit, Rosemary Thompson, Ramona Swenson, Darren Fong, Daniel Stofka, Daniel Chase, and Gage Dayton. This research was

conducted under the permitted support of California State Parks, National Parks Service, U.S. Fish and Wildlife Service (recovery permit #TE-43944A-0), and the CA Department of Fish and Wildlife (permit #SC-10750).

Table 1-1. Greater Bay Area Recovery Unit study sites surveyed in 2014, 2015, and 2017-18 for northern tidewater goby occupancy and *K. newberryi* microsporidian infection, with corresponding latitude/longitude coordinates.

County	Site	Latitude	Longitude	Occupancy 2014	Occupancy 2015	Occupancy 2017/2018	Microsporidia *K. newberryi*
Sonoma	Scotty Creek	38°23'06.30	-123°04'59.45		Absent	Absent	
	Marshal Gulch	38°22'11.58	-123°04'25.07		Absent	Absent	
	Salmon Creek	38°21'18.00	-123°04'00.00	Present	Present	Present	Present
	Johnson Gulch - Bodega Bay	38°20'01.98	-123°03'00.28	Absent			
	Cheney Gulch - Bodega Bay	38°19'11.09	-123°02'04.23	Absent	Absent	Absent	
Marin	Estero Americano	38°18'34.76	-122°56'08.62	Present	Present	Present	Present
	Estero de San Antonio	38°16'39.19	-122°56'54.11	Present	Present	Present	Present
	Walker Creek	38°12'30.00	-122°55'45.00	Absent	Absent	Absent	
	Indian Beach - Tomales Bay	38°08'12.79	-122°53'49.60	Absent			
	Papermill Creek - Tomales Bay	38°04'14.75	-122°48'51.78	Present			
	Lagunitas Creek - Tomales Bay	38°03'52.61	-122°48'18.86	Present	Present	Absent	
	Redwood Creek Lagoon	37°51'36.96	-122°34'34.43		Absent		
	Tennessee Valley Lagoon	37°50'30.73	-122°33'05.12	Absent	Absent	Absent	
	Rodeo Lagoon	37°49'51.00	-122°31'48.00	Present	Present	Present	Present
San Mateo	Lobitos Creek	37°22'35.17	-122°24'31.47		Absent		
	Tuniitas Creek	37°21'24.53	-122°23'58.66		Present		
	San Gregorio Creek	37°19'16.18	-122°24'08.54	Present	Present	Present	Present
	Pompino Creek	37°17'56.76	-122°24'18.90	Present	Present	Present	
	Pescadero Creek	37°15'50.00	-122°24'22.00	Present	Present	Present	Present
	Arroyo de los Frijoles/Bean Hollow	37°13'29.58	-122°24'24.92	Present	Present	Present	Present
	Yankee Jim	37°11'34.76	-122°23'53.34	Absent	Absent	Absent	
	Gazos Creek	37°09'55.26	-122°21'41.70	Present	Present	Absent	
Santa Cruz	Waddell Creek	37°05'33.00	-122°16'32.00	Present	Present	Absent	Present
	Scott Creek	37°02'26.30	-122°13'46.13	Present	Present	Present	Present
	Laguna Creek	36°58'60.00	-122°09'10.00	Present	Present	Present	
	Baldwin Creek	36°58'02.23	-122°07'24.67	Present	Present	Present	
	Lombardi Creek	36°57'44.23	-122°06'46.01		Present	Present	Present
	Old Dairy Creek	36°57'17.51	-122°05'29.21		Present	Present	
	Wilder Creek	36°57'13.05	-122°04'38.77	Present	Present	Present	
	Younger Lagoon	36°57'02.00	-122°04'00.00	Present	Present	Present	Present
	Moore Creek	36°57'02.18	-122°03'31.20	Present	Present	Present	Present
	San Lorenzo River	36°57'53.00	-122°00'46.00	Absent	Present	Present	
	Schwan Lagoon	36°57'45.25	-121°59'48.59		Absent	Present	
	Corcoran Lagoon	36°57'36.76	-121°59'03.46	Present	Present	Present	
	Moran Lake	36°57'24.93	-121°58'39.50	Present	Present	Present	Present
	Soquel Creek	36°58'18.58	-121°57'07.84	Present	Present	Absent	
	Aptos Creek	36°58'10.09	-121°54'23.28	Present	Present	Present	Present
Monterey	Pajaro River	36°51'15.08	-121°48'36.05	Present	Present	Absent	Present
	Bennett Slough	36°49'22.00	-121°46'39.00	Present	Present	Absent	Present
	Old Salinas River Irrigation Channel	36°46'16.27	-121°47'25.11	Present	Present	Present	Present
	Salinas River	36°44'52.49	-121°48'04.44		Present	Present	

Table 1-2. Central Coast Recovery Unit study sites surveyed in 2014, 2015, and 2017-18 for northern tidewater goby occupancy and *K. newberryi* microsporidian infection, with corresponding latitude/longitude coordinates.

County	Site	Latitude	Longitude	Occupancy 2014	Occupancy 2015	Occupancy 2017/2018	Microsporidia *K. newberryi*
San Luis Obispo	Arroyo de la Cruz	35°42'36.20	-121°18'35.43	Absent		Absent	
	Arroyo del Oso	35°41'33.32	-121°17'25.53	Absent	Absent	Absent	
	Arroyo de Corral	35°41'05.04	-121°17'10.56	Present	Present	Present	
	Oak Knoll Creek/ Arroyo Laguna	35°39'06.98	-121°13'10.61	Present	Present	Present	
	Arroyo de Tortuga	35°38'50.25	-121°12'41.32	Present	Present	Present	
	Arroyo del Puerto	35°38'36.68	-121°11'20.57	Present	Present	Present	
	Broken Bridge Creek	35°38'32.09	-121°10'57.51	Present	Present	Present	
	Little Pico Creek	35°38'02.10	-121°09'48.59	Present	Present	Present	Present
	Pico Creek	35°36'57.33	-121°08'55.01	Present	Present	Present	Present
	San Simeon Creek	35°35'44.62	-121°07'31.99	Present	Present	Present	
	Leffingwell Creek	35°34'53.00	-121°07'04.00	Absent	Absent	Absent	
	Santa Rosa Creek	35°34'00.20	-121°06'28.93	Present	Present	Present	
	Villa Creek	35°27'40.52	-120°58'12.19	Present	Present	Present	Present
	San Geronimo Creek	35°26'53.99	-120°56'03.34	Present	Present	Present	
	Cayucos Creek	35°26'59.44	-120°54'27.32	Present	Present	Present	Present
	Little Cayucos Creek	35°26'54.11	-120°54'13.58	Present	Present	Present	
	Old Creek	35°26'07.78	-120°53'15.25		Absent	Absent	
	Willow Creek	35°25'41.74	-120°52'56.15		Present	Present	
	Toro Creek	35°24'46.00	-120°52'23.00	Present	Present	Absent	
	Morro Creek	35°22'35.00	-120°51'48.00	Absent	Absent	Absent	
	Chorro Creek - Morro Bay	35°21'18.41	-120°49'28.57	Absent	Absent	Absent	
	Oso Creek - Morro Bay	35°19'48.24	-120°49'04.29	Absent	Absent	Absent	

Table 1-3. Conception Recovery Unit study sites surveyed in 2014, 2015, and 2017-18 for northern tidewater goby occupancy and *K. newberryi* microsporidian infection, with corresponding latitude/longitude coordinates.

County	Site	Latitude	Longitude	Occupancy 2014	Occupancy 2015	Occupancy 2017/2018	Microsporidia *K. newberryi*
San Luis Obispo	San Luis Obispo Creek	35°10'49.16	-120°44'15.54	Present	Present	Present	Present
	Pismo Creek	35°08'09.73	-120°38'22.74	Present	Present	Present	
	Carpenter Creek	35°07'42.55	-120°38'08.62	Present		Present	
	Meadow Creek	35°06'14.62	-120°37'40.79	Present		Present	
	Arroyo Grande	35°05'58.00	-120°37'45.00	Absent	Present	Present	
	Oso Flaco Lake	35°01'46.50	-120°37'29.05			Present	
	Santa Maria River	34°58'11.50	-120°38'35.33	Present	Present		Present
Santa Barbara	Shuman Creek	34°50'41.00	-120°35'44.00	Present	Present	Present	
	San Antonio Creek	34°48'07.00	-120°37'06.00	Present	Present	Present	
	Santa Ynez River	34°41'31.00	-120°36'03.00	Present	Present	Present	
	Canada Honda	34°36'31.00	-120°38'12.00	Absent	Absent	Absent	
	Jalama Beach	34°30'40.00	-120°30'06.00	Present	Present	Present	Present
	Gaviota creek	34°28'18.00	-120°13'34.81	Present	Present	Present	
	Arroyo Honda	34°28'24.00	-120°08'25.00	Absent	Absent	Absent	
	Refugio Creek	34°27'46.00	-120°04'09.00	Present	Present	Present	Present
	Eagle Canyon	34°26'08.69	-119°55'45.78	Absent	Absent	Absent	
	Tecolote Canyon	34°25'56.06	-119°55'03.74	Absent	Absent	Absent	
	Winchester / Bell Canyon	34°25'46.44	-119°54'45.80	Absent	Absent	Absent	
	Devereaux Slough	34°24'35.72	-119°52'46.95	Absent			
	Goleta Slough (mouth)	34°25'04.66	-119°49'46.36	Absent			
	Arroyo Burro	34°24'11.10	-119°44'34.86	Present	Present	Present	
	Mission Creek	34°24'45.14	-119°41'16.51	Present	Absent	Absent	
	Laguna Channel	34°24'48.41	-119°41'07.77	Present	Absent	Absent	
	Sycamore Creek	34°25'01.72	-119°40'00.93	Absent	Present	Present	Present
	Andre Clark Bird Refuge	34°25'03.52	-119°39'48.20	Present	Absent	Present	
	Arroyo Paredon	34°24'49.00	-119°33'33.00	Present	Present	Present	
	Carpinteria Salt Marsh	34°24'03.00	-119°32'08.00	Absent	Absent	Absent	
	Carpinteria Creek	34°23'26.49	-119°31'10.30	Present	Present	Present	
	Rincon Creek	34°22'25.75	-119°28'36.82	Present	Present	Absent	

Table 1-4 LA/Ventura and South Coast Recovery Unit study sites surveyed in 2014, 2015, and 2017-18 for northern tidewater goby occupancy and *K. newberryi* microsporidian infection, with corresponding latitude/longitude coordinates.

County	Site	Latitude	Longitude	Occupancy 2014	Occupancy 2015	Occupancy 2017/2018	Microsporidia *K. newberryi*
Ventura	Ventura River Lagoon	34°16'30.24	-119°18'27.52	Present	Present	Present	
	Santa Clara River	34°14'08.00	-119°15'25.71	Absent	Absent	Absent	
	Ormond Lagoon	34°08'13.00	-119°11'00.00	Present	Present	Present	Present
	Calleguas Creek	34°06'45.36	-119°04'52.43	Absent	Absent	Absent	
Los Angeles	Big Sycamore Canyon	34°04'17.11	-119°00'52.95	Absent	Absent	Absent	
	Trancas Canyon	34°01'48.25	-118°50'30.90	Absent	Absent	Absent	
	Zuma Lagoon	34°00'53.30	-118°49'14.59	Absent	Absent	Absent	
	Escondido Canyon	34°01'33.47	-118°45'57.30	Absent	Absent	Absent	
	Solstice Canyon	34°01'58.86	-118°44'32.72	Absent	Absent	Absent	
	Corral Canyon	34°01'59.58	-118°44'03.65	Absent	Absent	Absent	
	Malibu Lagoon, CA	34°02'00.71	-118°40'58.55	Absent	Absent		
	Las Flores Canyon	34°02'12.05	-118°38'11.51	Absent	Absent	Absent	
	Topanga Creek	34°02'19.56	-118°34'58.98	Present	Present	Present	Present
	Santa Monica Canyon	34°01'39.07	-118°31'11.73		Absent	Absent	
San Diego	San Mateo Creek Lagoon	33°23'10.31	-117°35'38.32	Absent	Absent	Absent	
	San Onofre Creek	33°22'51.97	-117°34'42.65	Present	Present	Present	
	Las Flores Creek	33°17'27.40	-117°27'50.24	Absent	Absent	Present	
	Hidden Lagoon	33°16'31.97	-117°27'05.92	Present	Present	Present	
	Aliso Canyon Lagoon	33°15'52.63	-117°26'32.08	Absent	Absent	Absent	
	French Lagoon	33°15'44.00	-117°26'26.00	Absent	Absent	Absent	
	Cockleburr Canyon Lagoon	33°15'01.39	-117°25'52.96	Present	Present	Present	
	Santa Margarita River	33°13'55.00	-117°24'55.00	Absent	Absent	Absent	
	San Luis Rey	33°12'10.62	-117°23'27.24		Absent	Absent	
	Loma Alta Creek	33°10'38.73	-117°22'06.47		Absent	Absent	
	Canyon de las Encinas	33°06'57.04	-117°19'29.71		Absent	Absent	

Figure 1-1. (Top) northern tidewater goby (*E. newberryi*). (Bottom) newly described southern tidewater goby (*E. kristinae*). Photos by Brenton Spies.

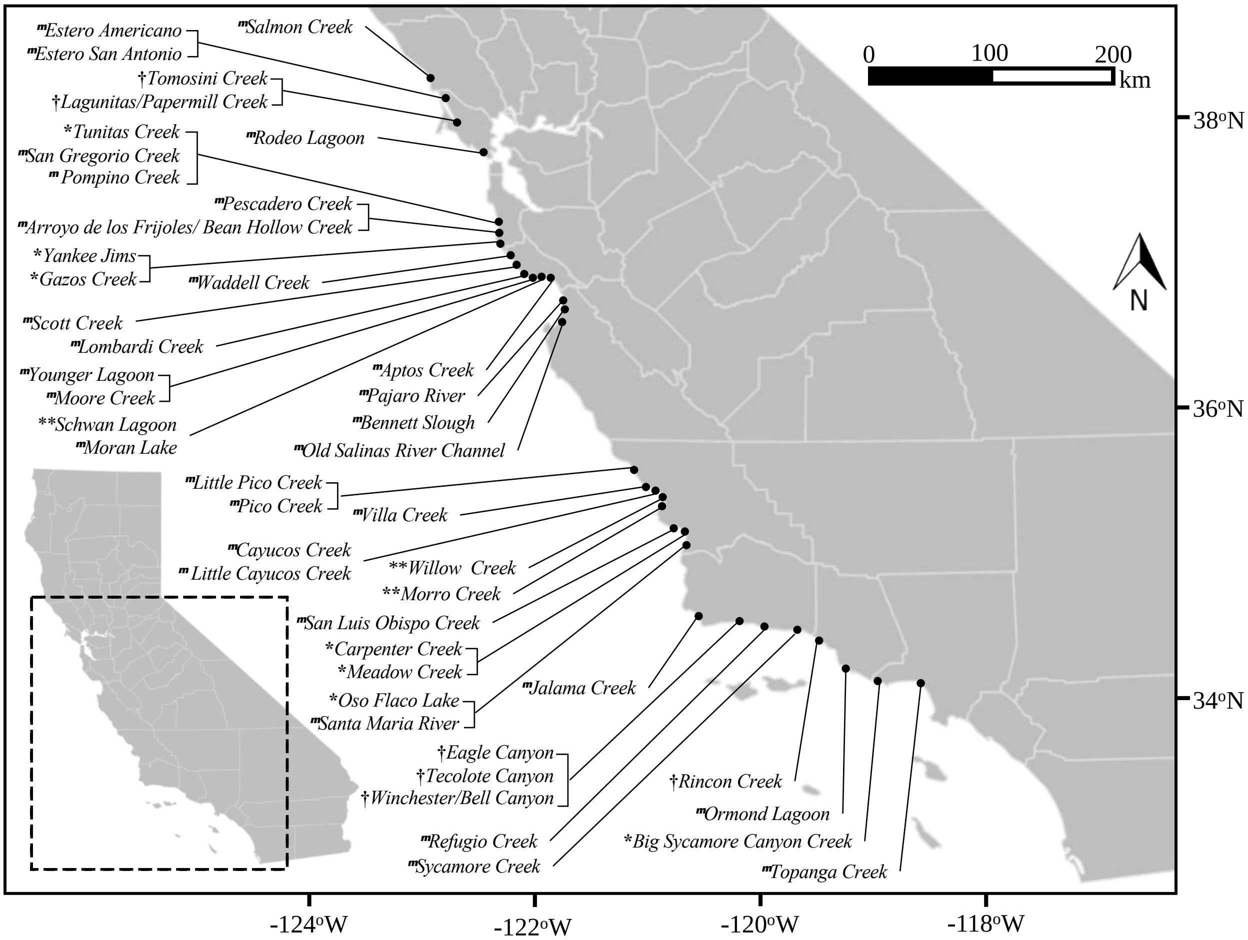

Figure 1-2. Coastal California with notable locality records of northern tidewater gobies and microsporidia infections. (*) New population documented since 2005 Recovery Plan (USFWS 2005). (**) Population documented after extended (10+ years) absence. (*m*) Microsporidia infection present. (†) Sites considered extirpated within the past 10 years.

Figure 1-3. (A and B) Arroyo Paredon, Santa Barbara County. (C) Carpinteria Creek, Santa Barbara County. (D) Rincon Creek, Ventura County. Photos taken on March 1, 2018 post Thomas fire debris flow. Note that the Thomas fire affected multiple systems simultaneously. Northern tidewater gobies have been documented in Arroyo Paredon (A and B) and Carpinteria Creek (C) post-fire, but population abundance has drastically declined. No gobies have been documented in Rincon (D) post-fire and this population is currently considered extirpated. Photos by Brenton Spies.

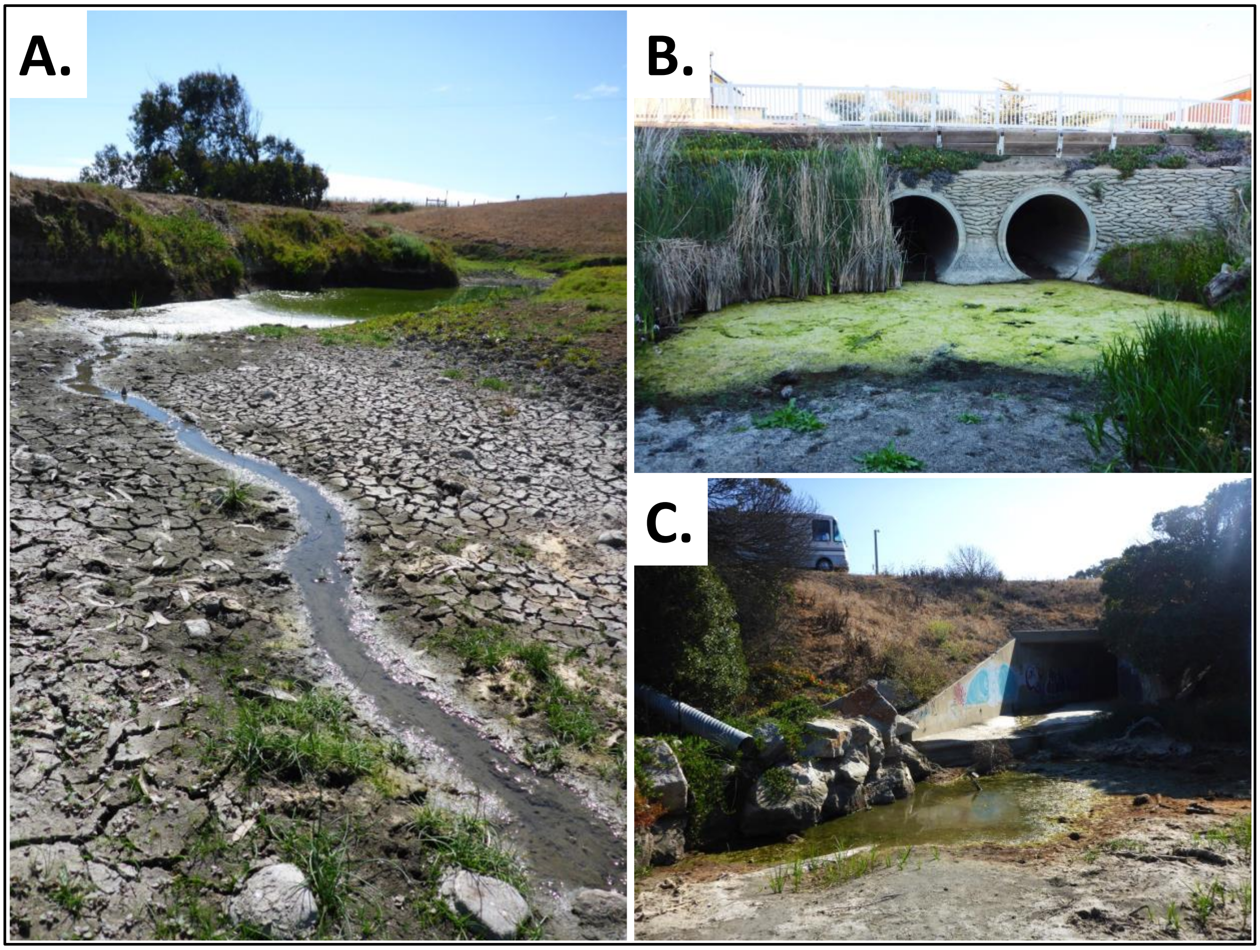

Figure 1-4. (A) Arroyo del Corral, San Luis Obispo County on July 9, 2015 (B) Little Pico Creek, San Luis Obispo County on July 10, 2015 (C) Willow Creek, San Luis Obispo County on July 11, 2015. Photos show the impact of the severe 2015 drought on small coastal estuaries and lagoons in the Central Coast. Despite near desiccation and minimal suitable habitat, northern tidewater gobies were collected at each of the locations above. Photos by Brenton Spies.

Figure 1-5. Northern tidewater gobies collected on October 5, 2017, from San Gregorio Creek, San Mateo County with microsporidia *K. newberryi* infection. Red arrows show white ovoid shaped microsporidia spores under skin tissue. Photo by Brenton Spies.

References

Ahnelt H, Go¨schl J, Dawson MN, Jacobs DK (2004) Geographical variation in the cephalic lateral line canals of *Eucyclogobius newberryi* (Teleostei: Gobiidae) and its comparison with molecular phylogeography. Folia Zoologica 53:385–398

Barlow, M (2002) Phylogeographic structure of the tidewater goby, *Eucyclogobius newberryi* (Teleostei: Gobiidae), in the San Francisco Bay area and Ventura County: Implications for Conservation Management. A thesis submitted in partial satisfaction of the requirements for the degree Master of Arts in Biology, University of California at Los Angeles.

Cousins M, Stacey MT, Drake JL (2010) Effects of seasonal stratification on turbulent mixing in a hypereutrophic coastal lagoon. Limnology and Oceanography 55:172–186

Day JW, Christian RR, Boesch DM, Yáñez-Arancibia A, Morris J, Twilley RR, Naylor L, Schaffner L, Stevenson C (2008) Consequences of climate change on the ecogeomorphology of coastal wetlands. Estuaries Coasts 31:477–491

Girard C (1856) Contributions to the Ichthyology of the Western Coast of the United States, from Specimens in the Msueum of the Smithsonian Institution. Proceedings of the Academy of Natural Sciences of Philadelphia.

Jacobs DK, Louie KD, Earl DA, et al. (2005) Genetics of *Eucyclogobius newberryi* in Mission Creek Santa Barbara: A Regional Metapopulation Analysis Using Mitochondrial Control Region Sequence and Microsatellites. *Final Report Prepared for US Army Corps of Engineers* 19.

Jacobs DK., Stein ED, and Longcore T (2011) Classification of California Estuaries Based on Natural Closure Patterns: Templates for Restoration and Management. *Southern California*

Coastal Water Research Project 619.a:72.

Kinziger AP, Hellmair M, McCraney WT, Jacobs DK, Goldsmith G (2015) Temporal Genetic Analysis of the Endangered Tidewater Goby: Extinction-Colonization Dynamics or Drift in Isolation? *Molecular Ecology* 24 (22):5544–60.

Klausmeyer KR, Shaw MR (2009) Climate Change, Habitat Loss, Protected Areas and the Climate Adaptation Potential of Species in Mediterranean Ecosystems Worldwide. PLoS ONE 4(7): e6392. https://doi.org/10.1371/journal.pone.0006392

Kolden CA, Abatzoglou JY (2018) Spatial Distribution of Wildfires Ignited under Katabatic versus Non-Katabatic Winds in Mediterranean Southern California USA. *Fire* 1 (2):19.

Lafferty KD, Swenson RO, Swift CC (1996) Threatened Fishes of the World: *Eucyclogobius newberryi* Girard, 1857 (Gobiidae*). Environmental Biology of Fishes 46 (3).*

MacKenzie DI (2005) What Are the Issues with Presence-Absence Data for Wildlife Managers? *The Journal of Wildlife Management* 69(3):849 860

McGourty KR, Kinziger AP, Hendrickson GL, Goldsmith GH, Casal G, and Azevedo C (2007) A New Microsporidian Infecting the Musculature of the Endangered Tidewater Goby (Gobiidae) *The Journal of Parasitology*. 93(3):655-660

Roessig JM , Woodley CM, Cech Jr. JJ, Hansen LJ (2005) Effects of Global Climate Change on Marine and Estuarine Fishes and Fisheries. *Reviews in Fish Biology and Fisheries* 14 (2): 251–75.

Scavia D, Field JC, Boesch DF, Buddemeier RW, Burkett V, Cayan DR, Fogarty M, Harwell MA, Howarth RW, Mason C, Reed DJ, Thomas CR, Sallenger AH, and Titus JG. Climate change impacts on U.S. Coastal and Marine Ecosystems. *Estuaries* **25,** 149–164 (2002). https://doi.org/10.1007/BF02691304

Swenson RO (1999) The Ecology, Behavior, and Conservation of the Tidewate Goby, *Eucyclogobius newberryi*. *Environmental Biology of Fishes* 55 (1–2): 99–114.

Swenson RO, McCray AT (1996) Feeding Ecology of the Tidewater Goby. *Transactions of the American Fisheries Society* 125 (6): 956–70.

Swift CC, Nelson JL, Maslow C, Stein T (1989) Biology and Distribution of the Tidewater Goby, *Eucyclogobius newberryi* (Pisces:Gobiidae) of California. *Natural History Museum of Los Angeles County, Contributions in Science, No 404 Pp 19* 404.

Swift, CC, Spies BT, Ellingson RA, Jacobs DK (2016) A New Species of the Bay Goby Genus *Eucyclogobius*, Endemic to Southern California: Evolution, Conservation, and Decline. *PloS One* 11 (7): e0158543.

US Fish and Wildlife Service (2005) Recovery Plan for the tidewater goby (*Eucyclogobius newberryi*). U.S. Fish and Wildlife Service, Portland, Oregon. Vi+199 pp.

Valiela I, Kinney E, Bulbertson J, Peacock E, Smith S (2009) Global Losses of Mangroves and Salt Marshes. In: Global Loss of Coastal Habitats Rates, Causes and Consequences. In: CM Duarte (ed) Global Loss of Coastal Habitats: Rates, Causes and Consequences. Fundación BBVA, Madrid, Spain, pp. 107–14.

Williams AP, Seager R, Abatzoglou JT, Cook BI, Smerdon JE and Cook ER (2015) Contribution of anthropogenic warming to California drought during 2012 2014. Geophysical Research Letters 42(16), pp.6819-6828.

CHAPTER 2

Rangewide metapopulation occupancy and site characterization records of the endangered tidewater gobies (Genus *Eucyclogobius*) on the California coast

Brenton T. Spies, Camm C. Swift, Daniel E. Stofka,

Chris Dellith, Marcus Lin, David K. Jacobs

Abstract

The federally endangered tidewater gobies (Genus *Eucyclogobius*) are a California coastal endemic fish genus comprised of the northern tidewater goby (*Eucyclogobius newberryi*) and the newly described southern tidewater goby (*Eucyclogobius kristinae*). The tidewater gobies are the only vertebrates that are known to be exclusively associated with, and adapted to, closing estuarine systems in California. This genus is considered the most locally differentiated vertebrate taxon on the Pacific coast. It is subdivided into regional clades (Recovery Unit), which are further subdivided into long isolated entities. Clades and sub-clades (management unit) exhibit regionally distinct metapopulation processes. Each clade represents an ecologically distinct component of the species, and each sub-clade exhibits independent metapopulation dynamics at ecological timescales. Due to their metapopulation process and subdivision, as well as unique habitat preference, the tidewater gobies are of exceptional scientific interest. The main objective of these data sets was to collate all existing rangewide occupancy data, metapopulation descriptors, wetland site characteristics, and repository specimen collections while developing a quantitative framework to complete a metapopulation viability analysis (MVA) for both tidewater goby species. Modeling tidewater goby metapopulation dynamics and estimating future persistence is an essential component in constructing long-term management plans rangewide throughout the California Coast. We hope publishing these datasets will encourage other researchers to explore and develop new innovative ways to model tidewater gobies and other species with similar metapopulation dynamics. There are no copyright restrictions that apply to the use of this data set. Please cite this Data Paper when using the current data in publications or teaching events.

Introduction

The tidewater goby (*E. newberryi*) has been federally listed as endangered since 1994. The southern tidewater goby (*E. kristinae*) has been recently described as a distinct species in the genus *Eucyclogobius* but is currently being managed as *E. newberryi* under the Endangered Species Act until separate Species Status Assessments and Recovery Plans have been developed. These small, benthic associated, annual fish species are endemic to California and rarely exceed 55mm in total length. They inhabit a variety of shallow, brackish water coastal estuaries and lagoons throughout California that experience intermittent closure of mouth from the development of a sandbar or raised beach berm (Swift et al. 1989, Jacobs et al. 2011). The northern tidewater goby's range spans from the Smith River in Del Norte County to Topanga Creek in Los Angeles County (Swift et al. 2016). The historic range of the southern tidewater goby spanned from Aliso Creek in Orange County to Agua Hedionda in San Diego County; however, its current range has been reduced by over 50% to a <30km stretch of coastline on Marine Corps Base Camp Pendleton (Swift et al. 2016).

Both tidewater goby species are strongly impacted by the hydrologic variation in coastal wetlands and lagoons, and where extreme hydrologic events are a significant source of endangerment. This fish has an unusual evolutionary dynamic as a consequence of confinement from mouth closure, in addition to the lack of marine dispersal of larvae and small juveniles due to their intolerance of marine salinity (Hellmair 2011). Dispersal appears exclusive to the adult stage following hydrologic opening of lagoons during wet years (U.S. Fish and Wildlife Service 2005; Earl et al 2010). Genetic subdivision within this genus occurs at the scale of a few kilometers (Barlow 2002, Dawson et al. 2002, Earl et al. 2010). As a consequence, tidewater gobies show the highest degree of local genetic differentiation of any vertebrate on the California coast.

The tidewater gobies are subdivided into regional clades (Recovery Units, Fig. 2-1), which are further subdivided into long isolated entities. Clades and sub-clades (management units, Fig. 2-1) exhibit regionally distinct metapopulation processes (Lafferty et al. 1999ab, Earl et al. 2010). In addition, the southernmost clade is deeply divergent with a lineage separation occurring in excess of a million years ago (Ellingson et al. 2014). It is reciprocally monophyletic in nuclear and mitochondrial markers and morphologically distinct in counted lateral line attributes, fin rays, and measured characters as determined by discriminant function analysis (Swift et al. 2016). The southern tidewater goby is critically endangered, having been reduced from nine to three lagoonal populations on Camp Pendleton, Northern San Diego County since 2010 (Swift et al. 2016). This drastic population decline is likely due to a variety of factors such as introduction of non-natives, mobilization of fire debris runoff into lagoons, and ongoing drought conditions causing some systems to completely desiccate. The persistence of the three remaining habitats is currently at risk from severe drought and strong winter flooding; further increasing the risk of complete extinction of this newly described species.

The critical endangerment of these species is mainly due to loss or degradation of suitable habitat as a result to coastal development (U.S. Fish & Wildlife Service 2005). Metapopulation analysis has revealed that wetland size and annual variation in stream flow have had significant effects on tidewater goby populations. An increase in distance between source populations and suitable habitats during warm, low flow, drought seasons limits their ability to move to better habitats (Lafferty et al 1999ab). Such effects of differences in rainfall and water temperature may explain why populations of the tidewater goby are more genetically distinct and diverse south of Point Conception than north of it (Dawson et al. 2001; Earl et al. 2010). In addition, anthropogenic habitat modifications and introduction of exotics (Lafferty *et al.* 1997) in developed areas has increased extirpation events as revealed in genetic analysis (Earl et al. 2010). This long-term pressure has led to deep genetic subdivision (Dawson et al. 2001), morphologic differences (Ahnelt et al. 2004), and varied metapopulation behavior as a consequence of hydrologic variation and anthropogenic impact (Earl et al. 2010).

Under the U.S. Fish and Wildlife Service Recovery Plan (2005), a rangewide metapopulation viability analysis (MVA) is required to determine the probability of long-term persistence for each management sub-unit, or metapopulation, essential for proper assessment of recovery and ultimately downlisting of management units that meet specified criterion. The datasets included in this Data Paper will provide critical information relative to the federally endangered tidewater goby and inform the metapopulation models currently being developed (Chapter 3 - Spies et al. In Review).

Despite their federally endangered status, the dramatic genetic differentiation that forms the basis of management units, the inherent scientific interest in metapopulation dynamics, and their implication for conservation biology, the tidewater goby has received relatively little research interest. We hope providing these open access datasets will support continued research on the conservation and management of these incredible fish species and the coastal wetland ecosystems they inhabit

Metadata

CLASS I. DATA SET DESCRIPTORS

A. Data set identity: Rangewide metapopulation occupancy and site characterization records of the endangered tidewater gobies (Genus *Eucyclogobius*) on the California coast

B. Data set and metadata identification codes

(1) TWG_HISTORIC_ANNUAL_RECORDS_BINARY_MAR2022

(2) TWG_HISTORIC_ANNUAL_RECORDS_MAR2022

(3) TWG_SITE_CHARACTERIZATION_MAR2022

(4) TWG_OCCUPANCY_SURVEY_OBSERVATIONS_MAR2022

C. Data set description

Principal Investigators:

Brenton T. Spies

Department of Ecology and Evolutionary Biology, University of California, Los Angeles, 610 Charles E. Young Dr. East, CA 90095-7239, USA

David K. Jacobs

Department of Ecology and Evolutionary Biology, University of California, Los Angeles, 610 Charles E. Young Dr. East, CA 90095-7239, USA

Abstract: Same as above

Key words: *tidewater goby, Eucyclogobius newberryi, Eucyclogobius kristinae, conservation, endangered species, management, fish, metapopulation, California, wetland, lagoon, occupancy*

CLASS II. RESEARCH ORIGIN DESCRIPTORS

A. "Overall" project description

Identity: Rangewide metapopulation occupancy and site characterization records of the endangered tidewater gobies (Genus *Eucyclogobius*) on the California coast

Originator: Brenton T. Spies

Period of Study: Dates of source observational references range from 1857 – present. This database was created in 2013 and continues to be regularly updated.

Objectives: Collate existing rangewide occupancy data, metapopulation descriptors, wetland site characteristics, and repository specimen collections of the endangered tidewater gobies (Genus *Eucyclogobius*)

Abstract: Same as above.

Sources of funding: BTS was supported by research and teaching fellowships by the University of California, Los Angeles Department of Ecology and Evolutionary Biology and by the U.S. Fish and Wildlife Service Cooperative Agreement Award (F15AC00320). Additional research funding from the UCLA La Kretz Center for California Conservation Science, National Parks Service, and California State Parks supported our rangewide occupancy surveys.

B. "Specific subproject" description

Habitat description

An estuary is commonly defined as a partially enclosed coastal body of brackish water that joins one or more freshwater streams or rivers to the ocean. However, in regions that experience Mediterranean like climate regimes, estuary mouth closure behind a sandbar or raised beach berm impounds systems of variable salinity during periods of lowered "summer" streamflow. This phenomenon, unique to a few regions throughout the globe, has profound implications for ecosystem structure and function. The degree of closure strongly influences salinity, water quality, and tidal processes (Jacobs et al. 2011). The Mediterranean regions of the world where closing estuaries and lagoons occur most extensively are typically characterized by their microtidal (Cooper 2001) and mesotidal environments (Rich and Keller 2013), wave exposure (Jacobs et al. 2011), intermittent precipitation, and highly seasonal streamflow (Jacobs *et al.* 2011; Rich and Keller 2013). Such regions include California (Elwany et al. 1998, Jacobs et al. 2011, Rich and Keller 2011), and the more extensively studied systems such as Australia (Haines et al. 2009) and South Africa (Cooper 2001, Turpie *et al.* 2002). Unfortunately, these estuarine systems, which predominate in California, have until recently fallen largely outside the purview of North American estuarine science (Jacobs et al. 2011).

The vast majority of coastal wetlands in California are partially or completely isolated from marine tidal influence due to a formation of an intermittent sandbar or raised beach berm at the estuary mouth (Jacobs et al. 2011). This event typically occurs in the warmer summer months when reduced rates of precipitation lead to reduced freshwater input (Cooper et al. 2012). In addition, the reduction of tidal exchange causes longer residence time of water, which is commonly seen in smaller estuaries in the lower latitudes, permitting warmer and more variable temperature regimes (Cousins et al. 2010). Furthermore, climate variations in California are predicted to increase due to continued population growth and development, resulting in warmer, drier, and more variable weather patterns (Klausmeyer and Shaw 2009; Valiela *et al.* 2009). Since most California estuaries have been extensively altered in the increasingly urbanized landscape, interpretation of formative and ongoing physical process is challenging. However, there is a broad need to understand the dynamics of closing estuaries and lagoonal systems moving forward, especially when influenced by anthropogenic driven factors such as greater drought, flood, and sea-level rise, in order to better inform coastal zone managers and agencies responsible for restoration planning and conservation of threatened and endangered species.

Metapopulation Dynamics and Sub-Unit Reassessment

The seasonally and episodically closed nature of the preferred estuary/lagoon habitat of tidewater gobies predisposes them to local extirpation (Lafferty et al. 1999ab). These dynamics are linked to our changeable Mediterranean climate system and provide a unique study system of exceptional scientific interest for modeling metapopulation dynamics.

Tidewater gobies clearly respond to hydrology. Extirpation and recolonization events resulting from site desiccation and flooding have been documented in a few small systems along the California coast over the past few decades. Extirpation of tidewater gobies by lagoon desiccation can also be observed in aerial photography (Jacobs et al. 2005), and initial studies by Lafferty et al. (1999ab) used field surveys and museum collection records to better understand some aspects of the metapopulation process of tidewater gobies. From these observations it is apparent that it is critically important to sample the systems in conjunction with assessment of the hydrologic state of the system. In particular, the available data indicate that there is a relationship between and extirpation across multiple systems and regional multiyear drought. This in turn suggests the development of approaches and interactive models that can treat a range of variables and that can be adjusted to address the complex dynamics of the system is essential for appropriate persistence assessment and improved management unit downlisting.

The tidewater goby recovery plan designated six recovery units, encompassing a total of 26 sub-units or metapopulations (USFWS 2005, Fig. 2-1). These management units were determined by the best available data on genetic differentiation of the species into regional clades based on mitochondrial sequencing (Dawson *et al*. 2001; Barlow 2002), in combination with variation in morphological differences in the degree and frequency of reduction of the supraorbital canal (Ahnelt *et al.* 2004). Genetic data were augmented by geomorphology. Headlands genetically isolate populations (e.g., Dawson et al. 2001), so headlands and rocky coasts were inferred to similarly limit dispersal in areas where genetic data were not densely sampled (USFWS 2005). However, after the recovery plan was published in 2005, we collected more field observations and genetic data. These include generation of microsatellite primers and confirmation of the coastwide patterns (Earl et al. 2010) described in the Recovery Plan (USFWS 2005). More detailed microsatellite studies have been performed specifically for the Central Coast Unit (Hà et al. in prep), as well as for the Conception, LA/Ventura, and South Coast (*E. Kristinae*) Units (Jacobs Lab unpublished). Detailed microsatellite work has also been published on the North Coast Unit (McCraney et al. 2010; Kinziger et al. 2015)). These largely support the previous inferences of evolutionarily significant management units and sub-units (USFWS 2005, Fig. 2-1). They also provide a better understanding of the genetic substructure of tidewater gobies, as well as their maximum dispersal distance. This information facilitates our efforts to reconstruct metapopulation dynamics of the five southernmost Recovery Units. These efforts include documentation of newly occupied sites, as well as sites that have been recently extirpated. The new evidence strongly suggests the need for reassessment of sub-unit structure and designation within these five recovery units. The appropriate association of populations into sub-units is essential to valid modeling of metapopulation dynamics that provides the best supported assessment of long-term persistence. The previous inferences of recovery unit and sub-unit structure were largely supported, with exceptions as described below, where we recommend specific sub-unit amendments by recovery unit.

Greater Bay Recovery Unit (Eucyclogobius newberryi)

Counties: Sonoma, Marin, San Mateo, Santa Cruz, Monterey

GB1-GB9:No recommended changes to any of these sub-units at this time. However, recent multi-year absences in Lagunitas Creek and Tomasini Creek in Tomales Bay (2016-present), in addition to documentation of gobies in Tunitas Creek (2015), Yankee Jim Gulch (2015), Gazos Creek (2015), and Schwan Lagoon (2017), suggest that there is still a significant amount of uncertainty on the genetic structure and metapopulation dynamics of these sub-units that requires further investigation.

GB10-11: Based on the close proximity of the sites found within these two sub-units (<5km from nearest neighbor), in addition to gobies documented in Watsonville Slough (2014), Moro Cojo Slough (2007), Elkhorn Slough (2016), and Old Salinas River Irrigation Channel (2017), our recommendation is to combine these sub-units and label as *GB10*, as they appear to be close enough to be regularly and frequently connected. However, a detailed understanding of the genetic structure and connectivity between these populations, as well as a detailed survey and assessment of any potential additional habitat in the Salinas Valley area, is needed to be confident of this ecological connectivity.

Central Coast Recovery Unit (Eucyclogobius newberryi)

Counties: San Luis Obispo

CC1-CC2: Based on the close proximity Arroyo del Corral to Arroyo Laguna (<10km), in addition to genetic evidence that suggests that Arroyo del Corral has been extirpated and recolonized in the past (Jacobs unpublished data), our recommendation is to combine these two sub-units and define as *CC1*.

CC3: No recommended changes to this sub-unit at this time. However, recent documentation of gobies in Willow Creek (2018), Morro Creek (2018), and Oso Creek – Morro Bay (2015) may require further investigation to better understand genetic structure and metapopulation dynamics within this sub-unit. For the purpose of simplicity, we recommend keeping this sub-unit as *CC3*

Conception Recovery Unit (Eucyclogobius newberryi)

Counties: San Luis Obispo, Santa Barbara

CO1: No recommended changes to this sub-unit at this time. However, recent documentation of gobies in Carpenter Creek (2018), Meadow Creek (2018), and Oso Flaco Lagoon (2018) may require further investigation to better understand genetic structure and metapopulation dynamics within this sub-unit.

CO2: The genetic structure of the Conception Recovery Unit using microsatellite analysis in the program STRUCTURE (Jacobs unpublished data) suggests that San Antonio Creek and Shuman

Lagoon function as a separate, and genetically distinct, metapopulation. Our recommendation is to define this sub-unit as *CO2.*

CO3: The genetic structure of the Conception Recovery Unit using microsatellite analysis in the program STRUCTURE (Jacobs unpublished data) suggests that an additional sub-unit that includes the Santa Ynez River, Jalama Creek, Cañada Honda, and Cañada de Cojo appears merited. However, the lack of occupancy data between Cañada del Cojo and Gaviota Creek precludes precise definition of this unit. For the purpose of this study, we assigned all sites between Santa Ynez River and Cañada del Alegria to sub-unit *CO3.* Further sampling of the Hollister Ranch coastline and genetic analysis is needed before any recommendations of sub-unit reassessment for this region can be given. Given the limited amount of data from this coastline, it is difficult to appropriately place the numerous small sites here in an appropriate metapopulation framework as the boundary between *CO3 and CO4* is not well established

CO4: This sub-unit is comprised of all populations between Gaviota Creek and Rincon Creek. Microsatellite analysis suggests additional sub-units in this region may be warranted, however further investigation is needed before a precise definition of this unit can be recommended. The metapopulation behavior of this sub-unit is of particular interest as a number of sites have an established earlier history of extirpation including Refugio Creek, Devereaux Slough, Goleta Slough, Sycamore Creek, Andre Clark Bird Refuge, Arroyo Paredon, Carpinteria Creek and Rincon Creek (Lafferty et al. 1999ab). These extirpations all occurred coincidently with the 1970s drought and recolonization of many sites is evident as founder effects in genetic data (Jacobs et al. 2005, Jacobs unpublished). These observations serve as evidence for coincident climate driven extirpations in the region. Subsequently, this sub-unit has experienced a significant number of impacts since listing, including the extirpation of Arroyo Hondo (2007), Tecolote Canyon (2014), Winchester/Bell Canyon (2014), and Devereaux Slough (2014). In addition, the recent extirpation of Rincon Creek (2107), and the heavy impacts and population reductions in Arroyo Paredon and Carpinteria Creek from the Thomas fire. These may have severe long-lasting impacts on this sub-unit's metapopulation dynamics. Continued sampling of all sites within this sub-unit, in addition to genetic analysis, is needed before any recommendations of sub-unit reassessment for this region can be given.

L.A./Ventura Recovery Unit (Eucyclogobius newberryi)

Counties: Los Angeles, Ventura

LV1: The genetic structure of the L.A./Ventura Recovery Unit using microsatellite analysis in the program STRUCTURE (Jacobs unpublished data) suggests that an additional sub-unit that includes Malibu Lagoon and Topanga Creek appears merited. Since no tidewater gobies preserved in a fashion suitable for DNA extraction were collected from Malibu Lagoon prior to their extirpation in the late 1980's, we are unable to determine if this population historically experienced connectivity with any of the sites to the north (it is derived from an artificial recolonization from the Ventura River). The recent population in Topanga Creek was first documented in 2001 and appears to have been colonized from Malibu Lagoon. In addition, the distance between Malibu Lagoon and Sycamore Creek, the nearest neighbor to the north, is >30km and would require dispersing around the rocky headlands of Point Dume. Based on this available data, we recommend that the populations in sub-unit *LV1* should include the Ventura River, Santa Clara River, Ormond Beach/J Street Drain, Calleguas Creek – Mugu, and Sycamore Canyon.

LV2: Based on microsatellite analysis, distance to nearest neighbor to the north, and geomorphology of the Malibu Coast (see above), we recommend that Malibu Lagoon and Topanga Creek should be defined as a separate sub-unit *LV2.*

South Coast Recovery Unit (Eucyclogobius kristinae)

Counties: San Diego

SC1-SC2: The South Coast Recovery Unit experiences a very high rate of extirpation/colonization (Lafferty et al. 1999b), which could explain the low genetic variation found in this recovery unit based on mitochondrial sequencing and microsatellite analysis. Separating San Mateo Creek and San Onofre Creek from the sites in *SC2* in the recovery plan was in large part due to the distance between San Onofre Creek and Las Flores Creek (<15km), its nearest neighbor to the south. However, available data and field observations suggest that San Onofre Creek and San Mateo Creek have effectively communicated with sites to the south and are effectively part of *SC2* metapopulation. First, the maximum dispersal distance of approximately 13km employed here, determined by microsatellite assignment tests of the Central Coast Unit in 2008 (Jacobs unpublished data), makes dispersal between San Onofre Creek and Las Flores much more plausible. Second, in 2017 a few juvenile and sub-adult tidewater gobies were documented in Las Flores Creek for the first time since 2012. At that time, tidewater gobies were only present in San Onofre Creek, Hidden Lagoon, and Cockleburr Canyon Lagoon. The most likely site the Las Flores gobies colonized from would be Hidden Lagoon, approximately 2km to the south. However, based on field observations of all the systems on Marine Corps Base Camp Pendleton, our understanding is that San Onofre Creek was the only system that had breached prior to this colonization event. In fact, San Onofre had a significant breaching event in

February 2016 in addition to breaching in 2017. From a genetic analytical perspective, it is difficult to address the potential genetic distinction between *SC1 & SC2* due to lack of genetic variation in the region. Therefore, until additional markers are developed, and further genetic analysis is conducted on this recovery unit, we are assuming that it is possible that these two sub-units can function as a single metapopulation. For this study they will be modeled as a single unit *SC2*. Continued sampling of all sites within this sub-unit, in addition to further genetic analysis, is needed before any recommendations of sub-unit reassessment for this region can be given.

Research Methods

Coastal Surveys

To address the lack of continuous rangewide annual occupancy data, we (Spies and Jacobs) conducted three years (2014, 2015, and 2017-18) of occupancy surveys and habitat assessments in 122 estuaries, spanning from Sonoma County south to San Diego County (Fig. 2-1), which provided enough information to establish a baseline for continued work across the region. All localities with records of tidewater gobies since 1990 were included in these coastwide surveys except the nine sites located on Hollister Ranch, Santa Barbara County. Additionally, all credible presence/absence data from museum records, USFWS annual collection reports, or personal communication from permitted biologist since 1990 were included in our analyses.

Occupancy surveys for tidewater gobies occurred in water depths <1.5m and between 05:00am and 07:00pm (PST) using either a 3.7m X 1.5m beach seine with a 3.2mm mesh or a 4.5m X 1.5m beach seine with 3.2mm mesh. Direct observation using seine nets is the preferred collection method when conducting tidewater goby occupancy surveys in all sites coast wide, however, in some cases where surveys are needed in deeper pools or in heavy vegetated areas a 0.5m X 1.0m 1-man push net with 1.6mm mesh was used (Strawn 1954). In order to accurately estimate detection probability in all localities, a replicate seining protocol based on habitat size (area in hectares) was developed and implemented beginning in 2015. A “small site” (< 2ha) was surveyed with a minimum of 5 seine pulls (10 if possible), a “medium site” (2-50ha) was surveyed with a minimum of 10 seine pulls, and a “large site” (> 50ha) was surveyed with a minimum of 20 seine pulls. Each seine pull was approximately 3m-15m in length, starting from the deepest (outer) point moving towards the shore (shallowest). A universal coastwide surveying protocol is important in order to standardize annual survey efforts from multiple collectors, calculate site-specific detection probability, and to better estimate seasonal and temporal populations trends. Additional observations on tidewater goby demographics, physical and biological habitat characterization, and water quality were taken during these surveys but are not included in the database at this time. In the future it may be advisable to include both direct and eDNA observations of tidewater goby in MVA approaches, but at present, only direct observations are used in this database. We believe eDNA is a promising tool and considered including eDNA observations in this database but determined that methodology was not sufficiently developed for our database purposes. Statewide eDNA sampling across both tidewater goby species (Sutter and Kinziger 2019; Martel et al. 2020) generated unusual results in some cases, which were not confirmed with direct observations in the field. One concern in these contexts is the ease of contamination of eDNA samples in field excursions, where sampling is done in the same vehicle and with the same clothing potentially contaminating the water collected. Another potential issue is non-specific primer binding, especially in sites with wastewater contamination provides a huge array of potential templates. This is especially of concern for the application of primers developed for the northern tidewater goby to the southern tidewater goby. Given these concerns it would be good to sequence some of the amplified templates to confirm that the products are tidewater goby and which tidewater goby they derive from. Such confirmation would allow for the more certain use of the currently available tidewater goby specific eDNA primers (Schmelzle and Kinziger 2016).

Site Characterization

Estuary characterization data was compiled from the NHDPlusHR geodatabase (Moore et al. 2019) and an inventory of west coast estuaries from The Nature Conservancy (Heady et al. 2014). The TerminalPathID, found within the NHDPlusHR geodatabase, is a unique value that is applied to all features within a drainage area and represents the LevelPathID of the most downstream feature (Moore et al. 2019). TerminalPathID was used to group drainage areas from the coastal lagoons and estuaries in the NHDPlusCatchment data from the NHDPlusHR geodatabase. Individual estuaries in some drainage areas were not captured in the NHDPlusHR geodatabase and was supplemented by data from the Nature Conservancy. Duplicate entries of the same estuary were removed. The Catchment Area was calculated in ESRI ArcGIS Desktop ArcMap 10.7.1 in square kilometers. The Max Elevation was calculated in cm from the 3D Elevation Program (3DEP) raster data included in the NHDPlusHR geodatabase. The Mean Slope, in degrees, of the rivers and tributaries was calculated from the max elevation and the distance from the river mouth at sea level.

Permit history

This research was conducted under the approval of the Department of Defense (Vandenberg AFB) and permitted support of California State Parks, National Parks Service, U.S. Fish and Wildlife Service (recovery permit #TE-43944A-0), and the CA Department of Fish and Wildlife (permit #SC-10750).

Project personnel: *Brenton T. Spies, Camm C. Swift, Daniel E. Stofka, Chris Dellith, Marcus Lin, David K. Jacobs*

CLASS III. DATA SET STATUS AND ACCESSIBILITY

A. Status

Latest update: 15 May 2022

Latest Archive date: 15 May 2022

Metadata status: Up to date as of 15 May 2022

Data verification: Up to date as of 15 May 2022

B. Accessibility

Storage location and medium: The dataset, description, and relevant material are housed within ScholarWorks, the California State University System's shared institutional repository and managed by CSUCI's Broome Library. ScholarWorks is powered by Samvera Hyrax 2.9.6 and materials and backups are hosted using AWS.

Contact person: Brenton T. Spies, Department of Ecology and Evolutionary Biology, University of California, Los Angeles, 610 Charles E. Young Dr. East, CA 90095-7239, USA, brenton.spies@gmail.com

Copyright restrictions: None.

Proprietary restrictions: None

Costs: None, the authors believe that scientific data collated for the purpose of conservation and management of an endangered species should be free for scientific use. We would appreciate researchers citing this paper if using these data.

CLASS IV. DATA STRUCTURAL DESCRIPTORS

A. Data Set File

Identity: TWG_HISTORIC_ANNUAL_RECORDS_BINARY_MAR2022

Size: Please contact authors for updated data set

Format and storage mode: comma-separated values (.csv)

Header information: See column descriptions in section B

Alphanumeric attributes: Mixed

Special characters/fields: None. All character and numeric fields are complete and follow descriptions in Table 2-1.

Authentication procedures: Will be added by Elizabeth Blackwood, Digital Archivist, at the CSUCI Broome Library.

Identity: TWG_HISTORIC_ANNUAL_RECORDS_MAR2022

Size: Please contact authors for updated data set

Format and storage mode: comma-separated values (.csv)

Header information: See column descriptions in section B

Alphanumeric attributes: Mixed

Special characters/fields: None. All character and numeric fields are complete and follow descriptions in Table 2-1.

Authentication procedures: Will be added by Elizabeth Blackwood, Digital Archivist, at the CSUCI Broome Library.

Identity: TWG_SITE_CHARACTERIZATION_MAR2022

Size: Please contact authors for updated data set

Format and storage mode: comma-separated values (.csv)

Header information: See column descriptions in section B

Alphanumeric attributes: Mixed

Special characters/fields: None. All character and numeric fields are complete and follow descriptions in Table 2-1.

Authentication procedures: Will be added by Elizabeth Blackwood, Digital Archivist, at the CSUCI Broome Library.

Identity: TWG_OCCUPANCY_SURVEY_DATA_MAR2022

Size: Please contact authors for updated data set

Format and storage mode: comma-separated values (.csv)

Header information: See column descriptions in section B

Alphanumeric attributes: Mixed

Special characters/fields: None. All character and numeric fields are complete and follow descriptions in Table 2-1.

Authentication procedures: Will be added by Elizabeth Blackwood, Digital Archivist, at the CSUCI Broome Library.

B. **Variable information**

C. **Data anomalies:** Missing information was classified as "NA".

See Tables 2-1, 2-2, 2-3, and 2-4 below

See Figures 2-2 and 2-3 below

CLASS V. SUPPLEMENTAL DESCRIPTORS

A. Data Acquisition

Data forms or acquisition methods: All credible presence/absence data not generated directly by authors was acquired from primary/secondary literature, museum records, USFWS annual collection reports, or personal communication from permitted biologist since 1857 were included in this database.

Location of completed data forms: The original data sets can be accessed as Supporting Information to this Data Paper release in Ecology and through ScholarWorks at CSU Channel Islands, Broome Library. Updated versions of these data sets are stored on the principle investigators personal computers and are backed up to the cloud and to an external hard drive.

Data entry verification procedures: The authors reviewed the data jointly. BTS reviewed all data twice.

B. Quality assurance/quality control procedures: All data sets included in this Data Paper were reviewed by each author at least once (Spies multiple times) and approved for publication by the U.S. Fish & Wildlife Service. All occupancy data was independently reviewed by all major contributing scientist and researchers since listing in 1994.

C. **Related Materials:** A separate repository of digitized historic photos, occupancy records, and fields notes including all of Dr. Camm Swift's work related to the tidewater goby will be created and available open access through ScholarWorks at the CSU Channel Islands Broome Library at a later date.

D. **Computer programs and data-processing algorithms:** Microsoft Excel Version 16.61 was used to create each dataset. Estuary characterization data was compiled from the NHDPlusHR geodatabase (Moore et al. 2019), ESRI ArcGIS Desktop ArcMap 10.7.1, and 3D Elevation Program (3DEP).

E. **Archiving**

Archival procedures: Dataset and supporting material are archived both by the researchers and by the California State University (ScholarWorks). The ScholarWorks platform serves as both a search interface and archival storage platform, providing regular scheduled backups and curation based on filetype. System administrators at both the Systemwide Digital Library Services and local campus libraries follow standard archival best practice.

Redundant archival sites: The researchers will maintain redundant copies of the data and supporting materials. These copies are housed on local machines and in cloud storage platforms.

F. **Publications and results:** This data set was created and used to inform the quantitative framework developed to complete a metapopulation viability analysis (MVA) for both tidewater goby species. This project is directed towards implementing aspects of the tidewater goby recovery plan in coordination with, and funded by, the US Fish & Wildlife Service (USFWS) through a Section 6 Cooperative Agreement awarded to the University of California, Los Angeles on May 15, 2015.

Spies BT, Boughton DA, and Jacobs DK (2022). Modeling metapopulation viability and persistence of the endangered tidewater gobies (genus *Eucyclogobius*) on the California coast. (*In Review)*

G. History of data set usage

Data request history: Data has been requested by numerous researchers, state, federal, non-profit, NGO, and private agencies and consultants working or interested in tidewater goby occupancy records, habitat characteristics, and specimen collections.

Review history: None

Questions and comments from secondary users: None

ACKNOWLEDGMENTS:

BTS was supported by research and teaching fellowships by the University of California, Los Angeles Department of Ecology and Evolutionary Biology and by the U.S. Fish and Wildlife Service Cooperative Agreement Award (F15AC00320). Additional research funding from the UCLA La Kretz Center for California Conservation Science, National Parks Service, and California State Parks supported our rangewide occupancy surveys. Special thanks to Cat Darst and Eric Morrisette for all their support and guidance. Cami Pawlak and Patrick Wilson helped with database input and figure creations. This project would not have been possible without the many years of tidewater goby documentation by numerous biologists at sites across California, particularly Kevin Lafferty, Douglas Rischbieter, Rosi Dagit, Rosemary Thompson, Ramona Swenson, Jerry Smith, Don Alley, Greg Goldsmith, Carl Page, Darren Fong, Daniel Chase, Michael Rouse, Andrew Kinziger, Tom Taylor, Gage Dayton, Jeff Hagar, and Dan Holland.

Table 2-1. Description of the fields related with the binary (presence "1" and absence "0") tidewater goby historic annual records database

TWG_HISTORIC_ANNUAL_RECORDS_BINARY_MAR2022

Variable Name	Variable Definition	Units	Data Type	Range of Numeric Values	Example
Recovery_Unit_No	Recovery Unit Number	N.A.	Integer	1-6	5
Recovery_Unit	Recovery Unit Name	N.A.	Character	N.A.	L.A./Ventura
County	County in California, USA	N.A.	Character	N.A.	Los Angeles
Location_Name	Location or site name of a single TWG population	N.A.	Character	N.A.	Malibu Lagoon
Manag_Unit_No	Management Unit number.	N.A.	Character	N.A.	LV2
Manag_SubUnit_No	Management Sub-Unit number	N.A.	Integer	1-10	2
Manag_Site_No	Management Site Number	N.A.	Character	N.A.	LV 1h
Coastal_Order_Pop_No	Coastal order population number	N.A.	Character	N.A.	LV2 04
Coastal_Order_Site_No	Coastal order site number	N.A.	Character	N.A.	LV2 04a
Total_Records	Total number of annual occupancy records for each location/site	N.A.	Integer	0-30	30
Total_Presence	Total number of annual occupancy records of "presence" for each location/ site	N.A.	Integer	0-27	18
Percent_Occupied	Percent Occupied = Total_Records/Total_Presence x100	%	Numeric	0-100	60.0%
Site_Occup_Swift_1988	Sites found to be occupied by TWG in Swift et. al 1988. 0=absent, 1=present	N.A.	Integer	0-1	0
Site_Occup_Rec_Plan_05	Sites found to be occupied by TWG in the 2005 Recovery Plan (USFWS 2005). 0=absent, 1=present	N.A.	Integer	0-1	1
New_Sites_2005–Present	New sites where TWG have been discovered since 2005	N.A.	Integer	0-1	N.A.
Extirp_Sites_2005-Present	Sites where TWG extirpations have been documented since 2005	N.A.	Integer	0-1	N.A.
Sites_No_Occup_Record	Sites surveyed for TWG but have no records of occupancy	N.A.	Integer	0-1	N.A
Occ_1857	First year (1857) TWG documented on record. 0=absent, 1=present	N.A.	Integer	0-1	N.A.
Occ_1857 – Occ_2022	Annual range of TWG occupancy records (1857- 2022). 0=absent, 1=present. This data is represented in 109 columns for each year a TWG record has been recorded.	N.A.	Integer	0-1	0, 1, or N.A.
Occ_2022	Most recent year (2022) TWG documented on record. 0=absent, 1=present	N.A.	Integer	0-1	0

Table 2-2. Description of the fields related with the non-binary (presence “1”, absence “0”, both “0/1”) tidewater goby historic annual records database TWG_HISTORIC_ANNUAL_RECORDS_MAR2022

Variable Name	Variable Definition	Units	Data Type	Range of Numeric Values	Example
Recovery_Unit_No	Recovery Unit Number	N.A.	Integer	1-6	5
Recovery_Unit	Recovery Unit Name	N.A.	Character	NA	L.A./Ventura
County	County in California, USA	N.A.	Character	NA	Los Angeles
Location_Name	Location or site name of a single TWG population	N.A.	Character	NA	Malibu Lagoon
Manag_Unit_No	Management Unit number.	N.A.	Character	NA	LV2
Manag_SubUnit_No	Management Sub-Unit number	N.A.	Integer	1-10	2
Manag_Site_No	Management Site Number	N.A.	Character	NA	LV 1h
Coastal_Order_Pop_No	Coastal order population number	N.A.	Character	NA	LV2 04
Coastal_Order_Site_No	Coastal order site number	N.A.	Character	NA	LV2 04a
Total_Records	Total number of annual occupancy records for each location/site	N.A.	Integer	0-30	30
Total_Presence	Total number of annual occupancy records of “presence” for each location/ site	N.A.	Integer	0-27	18
Percent_Occupied	Percent Occupied = Total_Records/Total_Presence x100	%	Numeric	0-100	60.0%
Site_Occup_Swift_1988	Sites found to be occupied by TWG in Swift et. al 1988. 0=absent, 1=present	N.A.	Integer	0-1	0
Site_Occup_Rec_Plan_05	Sites found to be occupied by TWG in the 2005 Recovery Plan (USFWS 2005). 0=absent, 1=present	N.A.	Integer	0-1	1
New_Sites_2005–Present	New sites where TWG have been discovered since 2005	N.A.	Integer	0-1	NA
Extirp_Sites_2005-Present	Sites where TWG extirpations have been documented since 2005	N.A.	Integer	0-1	NA
Sites_No_Occup_Record	Sites surveyed for TWG but have no records of occupancy	N.A.	Integer	0-1	NA
Occ_1857	First year (1857) TWG documented on record. 0=absent, 1=present	N.A.	Character	0, 1, 0/1	NA
Occ_1857 – Occ_2022	Annual range of TWG occupancy records (1857- 2022). 0=absent, 1=present. This data is represented in 109 columns for each year a TWG record has been recorded.	N.A.	Character	0, 1, 0/1	0, 1, 0/1
Occ_2022	Most recent year (2022) TWG documented on record. 0=absent, 1=present	N.A.	Character	0, 1, 0/1	0/1

Table 2-3. Description of the fields related with the tidewater goby site characterization database

TWG_SITE_CHARACTERIZATION_MAR2022

Variable Name	Variable Definition	Units	Data Type	Range of Values	Example
Recovery_Unit_No	Recovery Unit Number	N.A.	Integer	1 – 6	5
Recovery_Unit	Recovery Unit Name	N.A.	Character	NA	L.A./Ventura
County	County in California, USA	N.A.	Character	NA	Los Angeles
Location_Name	Location or site name of a single TWG population	N.A.	Character	NA	Malibu Lagoon
Manag_Unit_No	Management Unit number.	N.A.	Character	NA	LV2
Manag_SubUnit_No	Management Sub-Unit number	N.A.	Integer	1 – 10	2
Manag_Site_No	Management Site Number	N.A.	Character	NA	LV 1h
Coastal_Order_Pop_No	Coastal order population number	N.A.	Character	NA	LV2 04
Coastal_Order_Site_No	Coastal order site number	N.A.	Character	NA	LV2 04a
DMS_Lat_N	Degrees, minutes, seconds (DMS) latitude (N)	dms deg	Numeric	32°55'57.84" – 41°55'14.26"	34°02'00.71"
DMS_Long_W	Degrees, minutes, seconds (DMS) longitude (W)	dms deg	Numeric	117°15'29.11" – 124°17'49.97"	118°40'58.55"
Decimal_Lat_N	Decimal degrees (DD) latitude (N)	dec deg	Numeric	32.9327333 – 41.9206278	34.0335306
Decimal_Long_W	Decimal degrees (DD) longitude (W)	dec deg	Numeric	117.2580861 – 124.2972139	118.6829306
NHDPlusFlowline TerminalPathID	NHDPlus flowline terminal path ID number	N.A.	Character	NA	500001000082
Catchment_Area	Catchment area	*SqKm*	Numeric	0.08 – 20402.74	272.1892999
Catchment_Mean_Slope	Catchment mean slope	deg	Numeric	0.21 – 87.42	18.5967044
Catchment_Max_Elev	Catchment maximum elevation	cm	Numeric	712.00 – 335765.00	94675.00
Min_Habitat_Size	Minimum wetland habitat size of perceived suitable TWG habitat	*Ha*	Numeric	0.00 – 5000.00	6.00
Max_Habitat_Size	Maximum wetland habitat size of perceived suitable TWG habitat	*Ha*	Numeric	0,10 – 5000.00	10.00
Dist_Near_Neighbor_N	Distance to nearest northern neighbor site	km	Numeric	NA	13.25
Dist_Near_Neighbor_S	Distance to nearest southern neighbor site	km	Numeric	NA	5.75
Det_Prob_Seine_Total	Total number of seine hauls completed at each site during the 2017/18 field season to estimate detection probability	N.A.	Integer	1 – 20	10
Det_Prob_Seine_TWG	Total number of seine hauls with TWG present at each site during the 2017/18 field season to estimate detection probability	N.A.	Integer	1 – 18	6
Det_Prob_Percent	Detection Probability Percentage. Det_Prob_Seine_TWG / Det_Prob_Seine_Total x 100	%	Numeric	0.00 – 100.00%	60%

Table 2-4. Description of the fields related with the coastwide tidewater goby occupancy survey historic annual records database

TWG_OCCUPANCY_SURVEY_OBSERVATIONS_MAR2022

Variable Name	Variable Definition	Units	Data Type	Range of Values	Example
Recovery_Unit_No	Recovery Unit Number	N.A.	Integer	1-6	5
Recovery_Unit	Recovery Unit Name	N.A.	Character	NA	L.A./Ventura
County	County in California, USA	N.A.	Character	NA	Los Angeles
Location_Name	Location or site name of a single TWG population	N.A.	Character	NA	Malibu Lagoon
Manag_Unit_No	Management Unit number.	N.A.	Character	NA	LV2
Manag_SubUnit_No	Management Sub-Unit number	N.A.	Integer	1-10	2
Manag_Site_No	Management Site Number	N.A.	Character	NA	LV 1h
Coastal_Order_Pop_No	Coastal order population number	N.A.	Character	NA	LV2 04
Coast_Order_Site_No	Coastal order site number	N.A.	Character	NA	LV2 04a
DMS_Lat_N	Degrees, minutes, seconds (DMS) latitude (N)	dms deg	Numeric	32°55'57.84" - 41°55'14.26"	34°02'00.71"
DMS_Long_W	Degrees, minutes, seconds (DMS) longitude (W)	dms deg	Numeric	117°15'29.11" - 124°17'49.97"	118°40'58.55"
Decimal_Lat_N	Decimal degrees (DD) latitude (N)	dec deg	Numeric	32.9327333 - 41.9206278	34.0335306
Decimal_Long_W	Decimal degrees (DD) longitude (W)	dec deg	Numeric	117.2580861-124.2972139	118.6829306
Coll_Date	Collection date	dd-mon-yy	Numeric	NA	31_MAR_84
Coll_Month	Collection month	mon-yy	Numeric	NA	Mar_84
Coll_Year	Collection year	yyyy	Integer	1857-2020	1984
Coll_Method	Collection method	N.A.	Character	NA	seine
Coll_Start_Time	Collection start time	24hr	Numeric	0000-2359	0800
Coll_End_Time	Collection end time	24hr	Numeric	0000-2359	1600
Coll_Season	Collection season	N.A.	Character	NA	summer
Coll_No	Collection number	N.A.	Character	NA	BTS-17-001
TWG_Coll_Repos	Number of TWG specimens collected and preserved in repository at UCLA	# of TWG	Integer	0-52	40
Collector_Initials	Collectors initials (see reference list in section ?)	N.A.	Character	NA	BTS
Present_Absent	TWG occupancy status (Present or Absent)	N.A.	Character	Present/Absent	Present
Seine_Haul_Total	Total number of seine hauls completed	# seine hauls	Integer	0 - 199	10
Seine_Haul_TWG	Total number of seine hauls with TWG present	# seine hauls	Integer	0 - 18	6
TWG_Coll_Total	Total number of tidewater gobies (abundance) collected	# of TWG	Integer	0 – 10,000	150
TWG_Pop_Status	TWG population status	N.A.	Character	NA	Abundant
TWG_Age_Class	TWG age class	N.A.	Character	NA	Adult
Collection_Det_Prob	Detection probability for each survey. Seine_Haul_TWG / Seine_Haul_Total X 100	%	Numeric	0.00 – 100.00%	60%

Figure 2- 1. Updated tidewater goby rangewide distribution map with Recovery Unit boundaries and recommended Sub-Unit amendments (U.S. Fish & Wildlife Service 2005). Sub-Units with proposed amendments include GB10, CC2, CO2, CO3, LV1, SC1, and SC2. Sub-Units CO4 and LV2 are new additions, and Sub-Units GB11 and CC3 have been merged with GB10 and CC2, respectively.

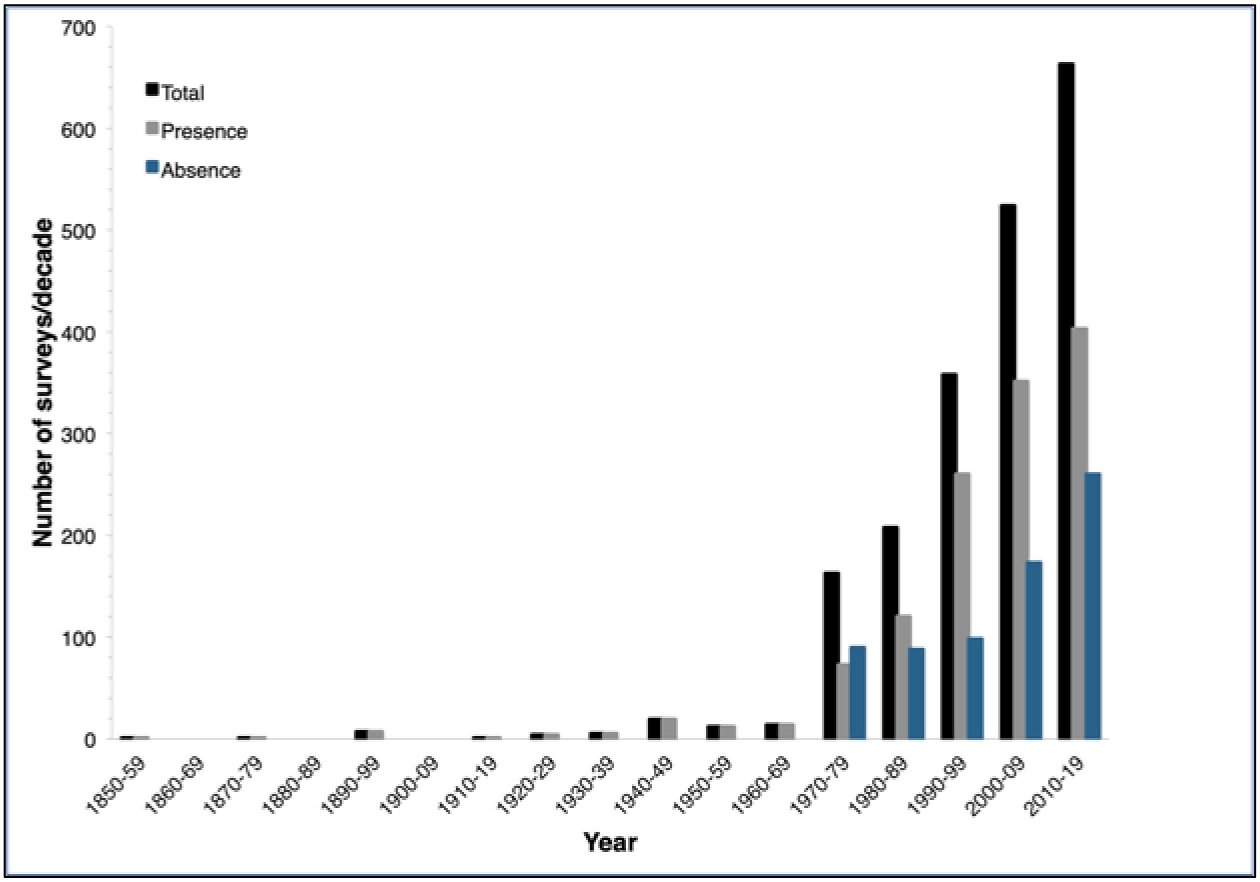

Figure 2-2. Number of surveys by decade. Note the dramatic recent increase in surveys, as well as the profound lack of observations of absence from sites in earlier records. These are concerning relative to possible biases that undercount the frequency of extirpation. Such concerns restrict metapopulation analysis to data from the most recent decades where such biases are reduced but may not be entirely eliminated.

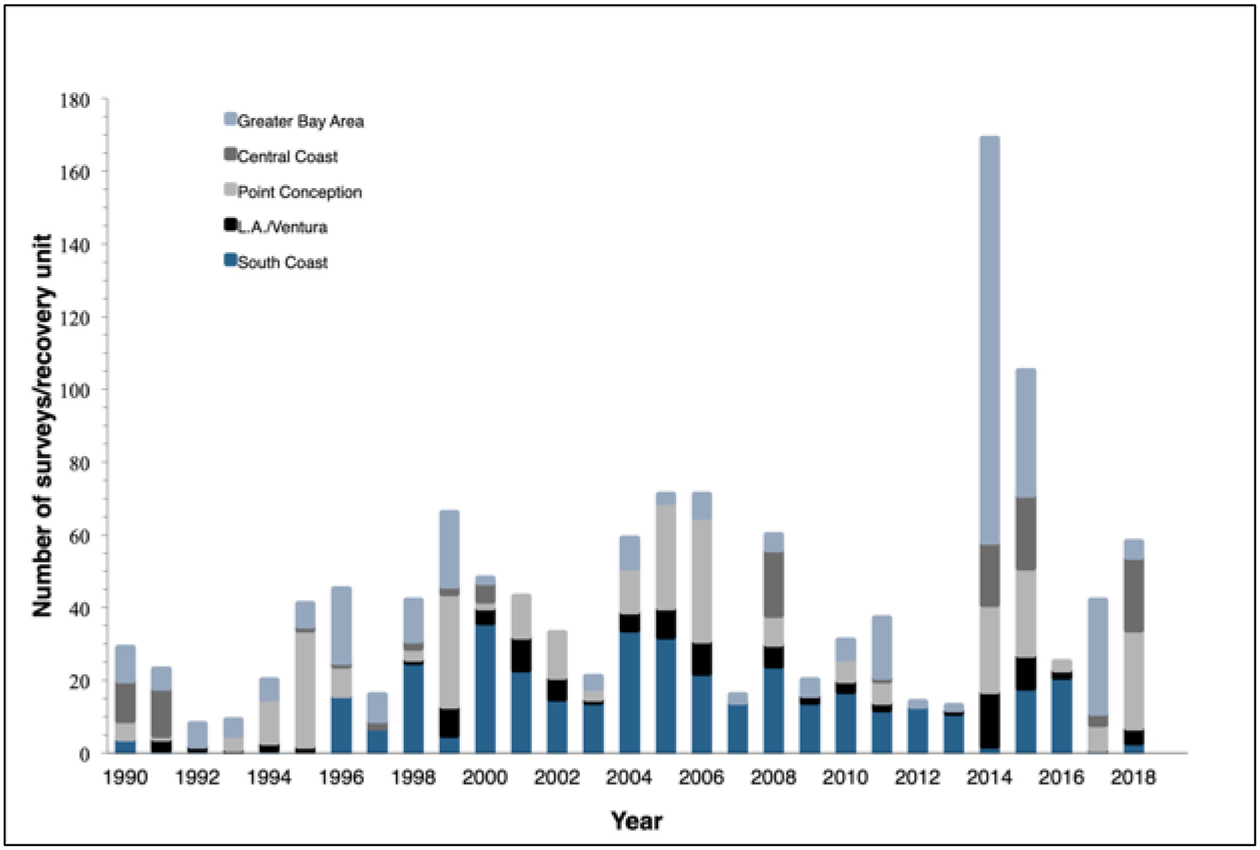

Figure 2-3. Tidewater goby occupancy surveys since 1990 by management unit. Note that sampling is by no means homogenous. The South Coast Recovery Unit is overrepresented for much of the time period due to mandated biannual sampling in this area. In addition, there is a significant contribution from the Greater Bay Area Recovery Unit in the last few years due to more regular sampling and the large number of sites to sample in this region. This variation in sampling is important as these are the data that inform the extirpation recolonization processes in the model as a whole. So, this lack of uniformity of observation could impart a bias to the overall model.

References

Ahnelt H, Go¨schl J, Dawson MN, Jacobs DK (2004) Geographical variation in the cephalic lateral line canals of *Eucyclogobius newberryi* (Teleostei: Gobiidae) and its comparison with molecular phylogeography. Folia Zoologica 53:385–398

Barlow, M (2002) Phylogeographic structure of the tidewater goby, *Eucyclogobius newberryi* (Teleostei: Gobiidae), in the San Francisco Bay area and Ventura County: Implications for Conservation Management. A thesis submitted in partial satisfaction of the requirements for the degree Master of Arts in Biology, University of California at Los Angeles.

Cooper SD, Lake PS, Sabater S, Melack JM, Sabo JL (2013) The effects of land use changes on streams and rivers in Mediterranean climates. Hydrobiologia 719:383−425

Cousins M, Stacey MT, Drake JL (2010) Effects of seasonal stratification on turbulent mixing in a hypereutrophic coastal lagoon. Limnology and Oceanography 55:172–186

Dawson MN, Stanton JL, Jacobs DK (2001) Phylogeography of the tidewater goby, *Eucyclogobius newberryi* (Teleostei, Gobiidae), in coastal California. Evolution 55(6):1167 1179.11

Dawson MN, Louie KD, Barlow M, Jacobs DK, Swift CC (2002) Comparative phylogeography of sympatric sister species, *Clevelandia ios* and *Eucyclogobius newberryi* (Teleostei, Gobiidae), across the California Transition Zone. Molecular Ecology 11:1065−1075

Earl DA, Louie KD, Bardeleben C, Swift CC, Jacobs DK (2010) Rangewide microsatellite phylogeography of the endangered tidewater goby, *Eucyclogobius newberryi* (Teleostei: Gobiidae), a genetically subdivided coastal fish with limited marine dispersal. Conservation Genetics 11:103–114

Ellingson RA, Swift CC, Findley LT, Jacobs DK (2014) Convergent evolution of ecomorphological adaptations in geographically isolated Bay gobies (Teleostei: Gobionellidae) of the temperate North Pacific. Molecular Phylogenetics and Evolution 70:464–477

Hà BA, Buckner JC, Sim JY, Dolby GA, Holland D, Swift CC, Spies BT, Jacobs DK. Hydrologic Control of Metapopulation Dispersal in the Endangered Northern Tidewater Goby (*Eucyclogobius newberryi*) on the California Coast. Manuscript in preparation

Heady WN, O'Connor K, Kassakian J, Doiron K, Endris C, Hudgens D, Clark RP, Carter J, and Gleason MG. An Inventory and Classification of U.S. West Coast Estuaries. The Nature Conservancy, 2014, p. 88.

Jacobs DK, Louie KD, Earl DA, et al. (2005) Genetics of *Eucyclogobius newberryi* in Mission Creek Santa Barbara: A Regional Metapopulation Analysis Using Mitochondrial Control Region Sequence and Microsatellites. *Final Report Prepared for US Army Corps of Engineers* 19.

Jacobs DK., Stein ED, and Longcore T (2011) Classification of California Estuaries Based on Natural Closure Patterns: Templates for Restoration and Management. *Southern California Coastal Water Research Project* 619.a:72.

Kinziger AP, Hellmair M, McCraney WT, Jacobs DK, Goldsmith G (2015) Temporal Genetic Analysis of the Endangered Tidewater Goby: Extinction-Colonization Dynamics or Drift in Isolation? *Molecular Ecology* 24 (22):5544–60.

Lafferty KD, Swenson RO, Swift CC (1996) Threatened Fishes of the World: *Eucyclogobius newberryi* Girard, 1857 (Gobiidae*). Environmental Biology of Fishes 46 (3).*

Lafferty KD, Swift CC, Ambrose RF (1999a) Extirpation and Recolonization in a

Metapopulation of an Endangered Fish, the Tidewater Goby. *Conservation Biology* 13 (6):1447–53.

Lafferty KD, Swift CC, Ambrose RF (1999b) Postflood Persistence and Recolonization of Endangered Tidewater Goby Populations. *North American Journal of Fisheries Management* 19 (2):618–22.

Martel CM, Sutter M, Dorazio RM, Kinziger AP (2020) Using Environmental DNA and Occupancy Modelling to Estimate Rangewide Metapopulation Dynamics. *Molecular Ecology*. https://doi.org/10.1111/mec.15693.\

McCraney WT, Goldsmith G, Jacobs DK, Kinziger AP (2010) Rampant Drift in Artificially Fragmented Populations of the Endangered Tidewater Goby (*Eucyclogobius newberryi*). *Molecular Ecology* 19 (16):3315–27.

Moore RB, McKay LD, Rea AH, Bondelid TR, Price CV, Dewald TG, and Johnston CM (2019) User's Guide for the National Hydrography Dataset plus (NHDPlus) High Resolution. Report, 2019–1096, p. 80, https://doi.org/10.3133/ofr20191096. USGS Publications Warehouse.

Rich A, Keller EA (2013) A Hydrologic and Geomorphic Model of Estuary Breaching and Closure. *Geomorphology* 191 (C):64–74.

Schmelzle MC, Kinziger AP (2016) Using Occupancy Modelling to Compare Environmental DNA to Traditional Field Methods for Regional-scale Monitoring of an Endangered Aquatic Species. *Molecular Ecology Resources* 16(4)895-908

Spies BT, Boughton DA, and Jacobs DK (2022) Modeling metapopulation viability and persistence of the endangered tidewater gobies (genus *Eucyclogobius*) on the California coast. (*In Review)*

Sutter M, Kinziger AP (2019) Rangewide Tidewater Goby Occupancy Survey Using Environmental DNA. *Conservation Genetics* 20(3):597–613.

Swenson RO (1999) The Ecology, Behavior, and Conservation of the Tidewate Goby, *Eucyclogobius newberryi*. *Environmental Biology of Fishes* 55 (1–2): 99–114.

Swenson RO, McCray AT (1996) Feeding Ecology of the Tidewater Goby. *Transactions of the American Fisheries Society* 125 (6): 956–70.

Swift CC, Nelson JL, Maslow C, Stein T (1989) Biology and Distribution of the Tidewater Goby, *Eucyclogobius newberryi* (Pisces:Gobiidae) of California. *Natural History Museum of Los Angeles County, Contributions in Science, No 404 Pp 19* 404.

Swift, CC, Spies BT, Ellingson RA, Jacobs DK (2016) A New Species of the Bay Goby Genus *Eucyclogobius*, Endemic to Southern California: Evolution, Conservation, and Decline. *PloS One* 11 (7): e0158543.

US Fish and Wildlife Service (2005) Recovery Plan for the tidewater goby (*Eucyclogobius newberryi*). U.S. Fish and Wildlife Service, Portland, Oregon. Vi+199 pp.

Valiela I, Kinney E, Bulbertson J, Peacock E, Smith S (2009) Global Losses of Mangroves and Salt Marshes. In: Global Loss of Coastal Habitats Rates, Causes and Consequences. In: CM Duarte (ed) Global Loss of Coastal Habitats: Rates, Causes and Consequences. Fundación BBVA, Madrid, Spain, pp. 107–14.

CHAPTER 3

Modeling Metapopulation Viability and Persistence of the Endangered Tidewater Gobies (Genus *Eucyclogobius*) on the California Coast

Brenton T. Spies, David A. Boughton, and David K. Jacobs

PROJECT BACKGROUND

This project is directed towards implementing aspects of the tidewater goby recovery plan in coordination with, and funded by, the US Fish & Wildlife Service (USFWS) through a Section 6 Cooperative Agreement awarded to the University of California, Los Angeles on May 15, 2015. We have developed a quantitative framework to complete a metapopulation viability analysis (MVA) for the endangered tidewater gobies in the genus *Eucyclogobius*. Modeling tidewater goby metapopulation dynamics and estimating future persistence is an essential component in constructing long-term management plans rangewide throughout the California Coast.

This preliminary work and report demonstrate the effectiveness of a Bayesian approach to provide a flexible method to generate metapopulation viability analyses for the northern tidewater goby (*Eucyclogobius newberryi*) and the newly described southern tidewater goby (*Eucyclogobius kristinae*). *E. kristinae* has been recently described as a distinct species in the genus *Eucyclogobius* but is currently being managed as a component of *E. newberryi* under the Endangered Species Act until a separate Species Status Assessment and Recovery Plan have been developed. In this report, we briefly review the general biology, conservation status, habitat impacts, and metapopulation dynamics of the northern and southern species of tidewater goby. In addition, we have provided a detailed summary of the MVA model framework, including limitations, required corrections, and future amendments that need to be addressed in order to meet the recovery criterion envisioned in the recovery plan.

INTRODUCTION

Species Background

The tidewater gobies (family Gobionellidae), *Eucyclogobius newberryi* (Girard 1856) and *Eucyclogobius kristinae* (Swift et al. 2016) are small annual fish species endemic to California (Figure 3-1). Individuals of these species seldom exceed 55mm in standard length (SL) and are considered benthic microcarnivores that primarily feed on aquatic invertebrates such as amphipods, ostracods, and chironomid larvae (Swift et al. 1989; Swenson and McCray 1996). Tidewater gobies inhabit low-flow, shallow, brackish zones of coastal streams, marshes, estuaries, and lagoons throughout the California coast. The northern tidewater goby's range spans from the Smith River in Del Norte County to Topanga Creek in Los Angeles County (Swift et al. 2016). The historic range of the southern tidewater goby spanned from Aliso Creek in Orange County to Agua Hedionda in San Diego County; however, its current range has been reduced by over 50% to a <30km stretch of coastline on Marine Corps Base Camp Pendleton (Swift et al. 2016).

The vast majority of the coastal wetlands inhabited by the tidewater goby are partially or completely isolated from marine tidal influence due to the intermittent formation of sandbars at the estuary mouths (Jacobs et al. 2011; Behrens et al. 2015). This phenomenon, unique to only a few Mediterranean regions throughout the globe, imposes a pattern of distinct populations subject to extirpation and colonization that is discussed in more detail below (see section titled Metapopulation Dynamics). This report examines more closely how these dynamics affect viability, connectivity, and long-term persistence of tidewater goby metapopulations throughout the California coast.

Listing History and Management

In this section we summarize the events leading up to the listing of the tidewater gobies under the Endangered Species Act, recent efforts to downlist these species, and recent progress on achieving the steps to recovery proscribed in the recovery plan.

The tidewater goby, then considered a single species, has been federally listed as endangered since 1994 under the Endangered Species Act of 1974. Evidence for the endangerment of this species is loss and degradation of suitable habitat, resulting from coastal development and land use practices such as: conversion of coastal wetlands to marinas, highway and railroad bridge construction, freshwater diversions, flood control, grazing, agriculture, introduction of non-native predators, and artificial breaching of seasonal lagoons (Lafferty et al. 1996; USFWS 2005).

The tidewater goby was first identified as a candidate species Category 2 in 1982, with a recovery priority number of 7C (on a scale of 1 to 18), per criteria published in the Federal Register (USFWS 1983; USFWS 2005). This number indicates a species with moderate threats and a high potential for recovery. The letter C indicates some degree of conflict between the species' recovery efforts and economic development (USFWS 2005). The tidewater goby was then identified as a Category 1 candidate species in 1991 and was added to the Federal endangered species list on March 7, 1994 (USFWS 1994). Critical habitat was designated on November 20, 2000 (USFWS 2000). On June 24, 1999, the Service proposed a rule to remove the northern populations of the tidewater goby from the endangered species list (USFWS 1999). However, the proposed rule was withdrawn on November 7, 2002 (USFWS 2002).

On December 7, 2005 a recovery plan for the tidewater goby was finalized (USFWS 2005). According to the recovery plan, two major recovery criteria must be met prior to any downlisting, or delisting, of the tidewater gobies. The first criterion is that a metapopulation viability analysis (MVA) based on scientifically credible presence/absence monitoring over a 10-year period must indicate that each of the six recovery units (Figure 3-2) is viable (Recovery Action 2.11, USFWS 2005). To be considered viable for downlisting, individual sub-units (metapopulations) within each of the six recovery units must be projected to have either a 75% or better chance of persistence for a minimum of 100 years. As specifically stated in the USFWS Recovery Plan (2005), the target is for at least 5 sub-units in the North Coast Unit, 8 sub-units in the Greater Bay Unit, 3 sub-units in the Central Coast Unit, 3 sub-units in the Conception Unit, 1 sub-unit in the Los Angeles/Ventura Unit, and 2 sub-units in the South Coast Unit to individually have a 75% chance of persisting for 100 years. For the species to be downlisted (change of status from endangered to threatened), each of the six recovery units must meet these criteria. For example, if the three sub-units in the Central Coast Recovery Unit were determined to have probabilities of 86%, 79%, and 95% that they would persist for 100 years, and a management plan was in place for all three, that recovery unit would meet the downlisting criteria. The five other recovery units would also need to similarly meet their criteria for downlisting of the species to be considered (USFWS 2005).

For both species to be delisted (removal from endangered species list due to complete recovery), a metapopulation viability analysis must project that all recovery units are viable, as in downlisting criterion one described above, except that the target for sub-units is a 95% probability of persistence for 100 years. Each recovery unit must meet this criterion in addition to those required for downlisting (USFWS 2005). The second criterion states that individual management plans need to be developed for each sub-unit based on long-term conservation and management needs for each population. To date, there are no management plans for any sub-unit or recovery unit on record.

A 5-year review for the tidewater was completed on September 28, 2007 by USFWS, which recommended the downlisting of the species from endangered to threatened status (USFWS 2007). This downlisting recommendation was believed to be warranted in the 5-year review due to 1) laws and regulations at the time reduced large and small-scale habitat loss and alterations throughout the coast, and 2) tidewater gobies are more resilient to severe drought events than believed at the time of listing (USFWS 2007). Although tidewater gobies had been documented in more sites by 2007 then at the time of listing, this is largely because many new sites were surveyed between 1994-2007 that had never been surveyed prior to listing, which does not necessarily indicate resiliency to extreme drought events. Although more populations, in general, should mean greater resilience to environmental disturbance, it is unclear how much more resilient additional populations would make each species, on a local or regional scale, without explicitly quantifying extinction and colonization dynamics. To accurately determine whether tidewater gobies are resilient to extreme drought, an analysis of persistence of populations over the course of a drought and/or an assessment of recolonization of extirpated populations after the end of the drought are recommended. These analyses are likely sensitive to the number of extant populations, as well as their dispersal connectivity with the estuaries that were extirpated, but will provide a better understanding of drought resiliency compared to those discussed in the 2007 5-year review (USFWS 2007)

The 5-year review states that drought can greatly reduce tidewater goby abundance, productivity, and survival and recognizes that with the limited information available, it is difficult to determine the impact these factors are having or may have on the long-term survival of the tidewater goby (USFWS 2007). Furthermore, additional ongoing threats were listed in the 5-year review, including limited loss and alteration of habitat resulting from development projects, pollution, agriculture, cattle grazing, flood control, freshwater withdrawal, predation and competition with native and non-native species, and anthropomorphic breaching of coastal lagoons (USFWS 2007). Potential impacts from extreme events that have recently caused extirpations or significant reductions in population abundance, such as post-wildfire debris runoff, El Nino flooding, and high wave events, were not discussed in the 5-year review or subsequent reports.

On March 13, 2014, USFWS issued a proposed rule to reclassify the tidewater goby as a threatened species under the Endangered Species Act after a 12-month finding indicated that downlisting the tidewater goby to threatened was still warranted despite the continued ongoing threats listed above. However, the finding is inconsistent with the criteria for downlisting described in the recovery plan (2005) and reviewed above. Specifically, it included no formal analysis on the impacts of climate change and drought on tidewater goby population extirpations and recolonization dynamics (i.e metapopulation dynamics) (USFWS 2014). In addition, the requests and actions suggesting downlisting did not consider the genetic subdivision of the populations that engendered the management unit structure and did not estimate viability of units as specified by USFWS (2005). In part, this appears to be because **A)** insufficient data have been assembled over too few years that include both presence and absence observations of populations, preventing quantitative assessment of meta population processes as required by the recovery plan, **B)** meta-population viability analysis pertinent to the management unit and sub-unit structure have therefore not been conducted, and **C)** management plans have not been developed for the management units. Thus, we conclude the ecological criteria for downlisting have not been met.

In this work we describe progress on point “**A**” above and develop analytical methods to conduct the appropriate metapopulation viability analysis of point “**B**”. To date, there has been no progress made on point “C” since the development of management plans relies on the completion of points **A** and **B**.”. As developed in detail below, once these steps are finalized it will then be possible to quantitatively assess down-listings on a unit-by-unit basis for the northern tidewater goby (*Eucyclogobius newberryi*) and the southern tidewater goby (*Eucyclogobius kristinae*), consistent with the criteria outlined in USFWS (2005). This report focuses on the development of methods to estimate metapopulation viability “criteria one” (USFWS 2005), in hopes that management agencies can use the findings from this report to facilitate the development of management plans “criteria two” (USFWS 2005). We hope that when fully elaborated the metapopulation viability methods presented in preliminary form here can guide viability assessment and resulting development of management actions, such that recovery and downlisting of management units becomes possible.

Spatial Structure

Genetic data show that the tidewater gobies are subdivided into regional clades, which are further subdivided into long-isolated entities referred to as subclades (Dawson et al. 2001; 2002). Different regional clades exhibit distinct metapopulation processes within them (discussed in Earl et al. 2010). Local populations persist for long periods in many instances in the North Coast Unit (McCraney et al. 2010; Kinziger et al. 2015), while evidence of extirpation and recolonization supports rapid population turnover in the GBA, CCU and LA/V Units based on observations of extinction and recolonization from Lafferty et al. (1999a&b) and our database herein. These interpretations are supported by microsatellite population genetic studies in the CCU (Ha et al. in prep), the Conception, and the LA/Ventura units (Jacobs et al. 2005; Jacob's lab unpublished data).

The southernmost clade is especially divergent (Ellingson et al. 2014), is recognized as a separate species (Swift et al. 2016), and exhibits what appear to approach Levin's type metapopulation processes within the clade, where all population sites are subject to extirpation (Levins 1969, 1970). Lineage separation occurring in excess of a million years ago is based on Bayesian assessment of divergence time using a suite of nuclear and mitochondrial sequence in a phylogenetic context (Ellingson et al. 2014). These lineages show consistently much greater differences relative to other clades within *Eucyclogobius* in mitochondrial sequence (Dawson et al. 2001; 2002) and microsatellite analysis (Earl et al. 2010). Morphologic distinction of the southern tidewater goby was first evident from differences in the lateral line canals of the head (Ahnelt et al. 2004). Counted lateral line attributes, fin rays, and measured characters as determined by discriminant function analysis and generalized linear models also demonstrate the morphologic distinction of the genetically distinct southern entity, leading to its description as a separate species *E. kristinae*, the Southern Tidewater Goby (Swift et al. 2016). Observations of extirpation of all populations of *E. kristinae* (tidewater goby database – Spies & Jacobs in prep) suggest that it is now operating as a Levin's type metapopulation, where all populations are at significant risk of extinction, only a few populations are extant at any given time, and sufficient recolonization to balance extirpations is necessary for long-term persistence. Unfortunately, there is little genetic variation present (via microsatellite data - Jacobs Lab unpublished) to inform us about the metapopulation processes from a genetic standpoint.

The southern tidewater goby has the characteristics of a critically endangered species: it has been reduced from nine to four lagoonal populations on Camp Pendleton, Northern San Diego County since 2010, only three of which are currently considered stable (Swift et al. 2016, Spies & Jacobs pers. comm.). This >55% metapopulation decline is likely due to a variety of factors such as introduction of non-natives, mobilization of fire debris runoff into lagoons from the 2014 Tomahawk fire, and repeated drought conditions causing some systems to completely desiccate. The stability of the three remaining habitats is currently at risk from severe drought and strong winter flooding, further increasing the risk of complete extinction of this newly described species.

Metapopulation Viability

The tidewater gobies are the only vertebrates that are known to be exclusively associated with, and adapted to, closing estuarine systems in California. Coastal lagoon formation, opening vs. closure, as well as the aquatic habitat available during closure, has been found to strongly correlate with distinct aspects of the hydrologic cycle (Rich and Keller 2013). Tidewater gobies clearly respond to hydrology. The degree of closure strongly influences salinity, water quality, and tidal processes (Cousins et al. 2010, Jacobs et al. 2011, Cooper et al. 2012). This unique habitat preference requires the tidewater goby to tolerate highly variable conditions, including salinities ranging from 0-41 ppt, and temperatures from 9-25° C (Swift et al. 1989; Swenson 1999). Opening or "breaching" is usually a function of streamflow (Rich & Keller 2013), which is driven by seasonal precipitation. Isolation, or closure, occurs when a sand bar or raised beach berm impounds systems of variable salinity during periods of lowered "summer" streamflow. These lagoonal dynamics are a product of the Mediterranean climate that characterizes California and provide a unique study system of exceptional scientific interest for modeling metapopulation dynamics.

Colonization

This fish has an unusual evolutionary dynamic associated with limitations on dispersal related to the intermittent mouth closure. In addition to closure, lack of marine dispersal of larvae and small juveniles is likely accentuated by intolerance of these early life stages to marine salinity (Hellmair and Kinziger 2014). Dispersal appears exclusive to the adult stage, following hydrologic opening of lagoons during wet years (USFWS 2005; Earl et al. 2010). Thus, tidewater goby reproduction requires closed estuarine habitat, while opening is necessary for dispersal and recolonization of vacant estuaries (Swift et al. 1989; Kent and Marliave 1997; Lafferty et al.1999a&b; Dawson et al. 2002). Dispersal of the tidewater goby is associated with high stream-flow events (Lafferty et al. 1999a&b), which cause breaching of the estuary mouth, permitting dispersal (Earl et al. 2010). Breaching events occur most frequently during winter months, when reproduction is limited and larvae are generally absent. As confirmed by genetic differentiation, marine larval dispersal appears to be extremely limited if it occurs at all (Barlow 2002, Dawson et al 2002, Earl et al. 2010). Larval tidewater gobies are typically restricted to their lagoonal habitats during summer peak reproductive months when the estuary mouth is typically closed (Lafferty et al. 1999a&b, Swenson 1999). Thus, dispersal appears limited to adult movement over sandy substrate following breaching events (Earl et al. 2010).

Extirpation

The seasonally and episodically closed nature of the preferred estuary/lagoon habitat of tidewater gobies predisposes them to local extirpation (Lafferty et al. 1999a&b). However, the majority of tidewater goby extirpations documented over the past few decades have been due to number of anthropogenic causes, such as loss or degradation of habitat from agriculture or urban development that impact estuarine hydrologic processes, and the introduction of non-native predators such as the green sunfish *(Lepomis cyanellus)*, largemouth bass *(Micropterus salmoides*), and the yellowfin goby (*Acanthogobius flavimanus*). Additional causes of extirpation that have been documented include high-flow events, post-fire debris runoff, native predators, and site desiccation usually due to drought. Extirpation events resulting from site desiccation have been documented in the field in a few small systems along the California coast over the past few decades and can also be observed using aerial photography (Jacobs et al. 2005). Initial studies by Lafferty et al. (1999a&b) used field surveys and museum collection records to better understand some aspects of the metapopulation process of tidewater gobies. From these observations it is apparent that it is critically important to sample the systems in conjunction with assessment of the hydrologic state of the system. In particular, the available data indicate that there is a relationship between regional multiyear drought and extirpation across multiple systems. This in turn suggests the development of approaches and interactive models that can treat a range of variables and that can be adjusted to address the complex dynamics of the system is essential for appropriate persistence assessment and improved management unit downlisting. The ability for any model, or approach, to include the potential to change with climate is critical. The effort reported here can be seen as the first step in that process.

METHODS

A metapopulation is commonly defined as a group of two or more spatially separated populations of the same species, which have the potential to recolonize from one another once extirpated (e.g., Hanski 1994). The absence of thorough population surveys that properly assess occupancy status and turnover is the primary reason a metapopulation viability analysis has not been conducted for any tidewater goby sub-unit. This occupancy data discrepancy continues to get better each year with more frequent and expansive rangewide survey efforts being conducted and reported. However, there are still major data gaps in parts of the coast where survey efforts are infrequent and/or inadequate (see Coastal Survey section below). With the available presence/absence data in hand, an MVA was developed using a hierarchal Bayesian model approach to a stochastic patch occupancy metapopulation model (Risk et al. 2011). This type of model allowed us to assess the viability of individual metapopulations, providing an informed prediction on the likelihood of extinction and colonization based on occupancy status. Bayesian approaches are becoming more commonly used to assess population viability of endangered species, especially for species where missing occupancy data or false-negatives are a concern (Sjögren-Gulve and Hanski 2000, Heard et al. 2013). An advantage of such occupancy models is the ability to utilize presence/absence data over large spatial and temporal scales.

In this approach, the detection probability of a species has to be explicitly modeled to avoid the bias of false-absences, in which the species occurs but was not detected during a survey. This approach can also be expanded to include a number of habitat covariates such as patch area, hydrologic dynamics, and the presence of invasive species. However, the "basic" metapopulation model is based primarily on presence/absence data through time, and dispersal distance between populations. In this report we describe coastal surveys used to develop the required dataset and outline the development of the basic metapopulation model. Once the final MVA is completed, the model will have the potential to predict the improvements or decline in expected persistence of a sub-unit given particular management actions. Thus, it can serve as a critical tool to inform management action and restoration effort. A more detailed analysis that includes habitat covariates and population connectivity through genetic analysis can generate a far more expansive evaluation that will provide managers with a model that more accurately represents the latitudinal variation in extinction and colonization, providing a greater understanding of a particular system, metapopulation, or an entire recovery unit.

Study Region

Metapopulation viability analyses were completed for five of the six recovery units, encompassing a total of 20 sub-units defined according to genetic differentiation and geomorphology (Fig. 3-2; USFWS 2005). The number of sample sites within each sub-unit varied from one to twenty-two, with a total of 101 sites and 89 distinct populations used in this study. Distinct sample sites that are known to regularly connect hydrologically or are located within the same watershed with little to no barriers were analyzed as a single population (e.g., Chorro Creek and Oso Creek in Morro Bay). Sub-units with only one known locality were not analyzed in this study as they are, by definition, not metapopulations. We plan to conduct individual population viability analyses (PVA) for these sub-units at a later date, and results will be included in our final report. To date, there are 165 known localities within the six recovery units that are currently, or have been historically, occupied by tidewater gobies. At this time, only the South Coast Recovery Unit has 10-years of continuous presence/absence surveys, a criterion for MVA development listed in the recovery plan.

Coastal Surveys

To address the lack of continuous rangewide annual occupancy data, we (Spies and Jacobs) conducted three years (2014, 2015, and 2017-18) of occupancy surveys and habitat assessments in 122 estuaries, spanning from Sonoma County south to San Diego County, which provided enough information to establish a baseline for continued work across the region. All localities with records of tidewater gobies since 1990 were included in these coastwide surveys except the nine sites located on Hollister Ranch, Santa Barbara County. Due to the limited number of records on this stretch of coast since listing, only Cañada de Santa Anita and Cañada de Alegria were included in this analysis. These two sites were chosen because of their consistent, but limited, occupancy status when surveyed and were present when last surveyed in 2005. Cañada del Cojo, previously on Hollister Ranch property and now managed by The Nature Conservancy, was also included in this model. Additionally, all credible presence/absence data from museum records, USFWS annual collection reports, or personal communication from permitted biologists since 1990 were included in our analyses.

In the future it may be advisable to include both direct and eDNA observations of tidewater goby in MVA approaches, but at present, only direct observations are used in this study. Statewide eDNA sampling across both tidewater goby species (Sutter and Kinziger 2019; Martel et al. 2020) generated unusual results in some cases, which were not confirmed with direct observations in the field. One concern in these contexts is the ease of contamination of eDNA samples in field excursions, where sampling is done in the same vehicle and with the same clothing potentially contaminating the water collected. Another potential issue is non-specific primer binding, especially in sites with wastewater contamination provides a huge array of potential templates. This is especially of concern for the application of primers developed for the

Northern Tidewater goby to the southern tidewater goby. Given these concerns it would be good to sequence some of the amplified templates to confirm that the products are tidewater goby and which tidewater goby they derive from. Such confirmation would allow for the more certain use of the currently available tidewater goby specific eDNA primers (Schmelzle and Kinziger 2016).

****The North Coast Recovery Unit was not included in this report due to recent studies out of the Kinziger Lab at Humboldt State University that suggest that this unit does not appear to function as a traditional metapopulation, rather individual isolated populations with little to no dispersal that have been self-sustaining for decades (Kinziger et al. 2015). Individual population viability analyses for sites located in the North Coast Recovery Unit will be explored in the future but will not be included in this study.*

Sub-Unit Reassessment

The tidewater goby recovery plan designated six recovery units, encompassing a total of 26 sub-units or metapopulations (USFWS 2005). These management units were determined by the best available data on genetic differentiation of the species into regional clades based on mitochondrial sequencing (Dawson *et al*. 2001; Barlow 2002), in combination with variation in morphological differences in the degree and frequency of reduction of the supraorbital canal (Ahnelt *et al.* 2004). Genetic data were augmented by geomorphology. Headlands genetically isolate populations (e.g. Dawson et al. 2001), so headlands and rocky coasts were inferred to similarly limit dispersal in areas where genetic data were not densely sampled (USFWS 2005). However, after the recovery plan was published in 2005, we collected more field observations and genetic data. These include generation of microsatellite primers and confirmation of the coastwide patterns (Earl et al. 2010) described in the Recovery Plan (USFWS 2005). More detailed microsatellite studies have been performed specifically for the Central Coast Unit (Ha et al. in prep), as well as for the Conception, LA/Ventura, and South Coast (*E. Kristinae*) Units (Jacobs Lab unpublished). Detailed microsatellite work has also been published on the North Coast Unit (McCraney et al. 2010; Kinziger et al. 2015)). These largely support the previous inferences of evolutionarily significant management units and sub-units (USFWS 2005). They also provide a better understanding of the genetic substructure of tidewater gobies, as well as their maximum dispersal distance. This information facilitates our efforts to reconstruct metapopulation dynamics of the five focal recovery units in this study. These efforts include documentation of newly occupied sites, as well as sites that have been recently extirpated. The new evidence strongly suggests the need for reassessment of sub-unit structure and designation within these five recovery units. The appropriate association of populations into sub-units is essential to valid modeling of metapopulation dynamics that provides the best supported assessment of long-term persistence. Therefore, this MVA study will model sub-units based off their recovery plan designation (Model 1), and our suggested sub-unit reassessment criteria (Model 2). The previous inferences of recovery unit and sub-unit structure were largely supported, with exceptions as described below, where we recommend specific sub-unit amendments by recovery unit (Table 3-1 & 3-2).

Greater Bay Recovery Unit (Eucyclogobius newberryi)

- ***GB1-GB9:*** No recommended changes to any sub-units at this time. However, recent multi-year absences in Lagunitas Creek and Tomasini Creek in Tomales Bay (2016-present), in addition to documentation of gobies in Tunitas Creek (2015), Yankee Jim Gulch (2015), Gazos Creek

(2015), and Schwan Lagoon (2017), suggest that there is still a significant amount of uncertainty on the genetic structure and metapopulation dynamics of these sub-units that requires further investigation (Table 3-1).

- ***GB10-11:*** Based on the close proximity of the sites found within these two sub-units (<5km from nearest neighbor), in addition to gobies documented in Watsonville Slough (2014), Moro Cojo Slough (2007), Elkhorn Slough (2016), and Old Salinas River Irrigation Channel (2017), our recommendation is to combine these sub-units and label as ***GB10***, as they appear to be close enough to be regularly and frequently connected. However, a detailed understanding of the genetic structure and connectivity between these populations, as well as a detailed survey and assessment of any potential additional habitat in the Salinas Valley area, is needed to be confident of this ecological connectivity (Table 3-1).

Central Coast Recovery Unit (Eucyclogobius newberryi)

- ***CC1-CC2:*** Based on the close proximity Arroyo del Corral to Arroyo Laguna (<10km), in addition to genetic evidence that suggests that Arroyo del Corral has been extirpated and recolonized in the past (Jacobs unpublished data), our recommendation is to combine these two sub-units and define as ***CC1*** (Table 3-1).

- ***CC3:*** No recommended changes to this sub-unit at this time. However, recent documentation of gobies in Willow Creek (2018), Morro Creek (2018), and Oso Creek – Morro Bay (2015) may require further investigation to better understand genetic structure and metapopulation dynamics within this sub-unit. For the purpose of simplicity, we recommend changing this sub-unit from CC3 to ***CC2*** (Table 3-1).

Conception Recovery Unit (Eucyclogobius newberryi)

- ***CO1:*** No recommended changes to this sub-unit at this time. However, recent documentation of gobies in Carpenter Creek (2018), Meadow Creek (2018), and Oso Flaco Lagoon (2018) may require further investigation to better understand genetic structure and metapopulation dynamics within this sub-unit (Table 3-2).

- ***CO2:*** The genetic structure of the Conception Recovery Unit using microsatellite analysis in the program STRUCTURE (Fig. 3-6) suggests that San Antonio Creek and Shuman Lagoon function as a separate, and genetically distinct, metapopulation. Our recommendation is to define this sub-unit as ***CO2*** (Table 3-2).

- ***CO3:*** The genetic structure of the Conception Recovery Unit using microsatellite analysis in the program STRUCTURE (Fig. 3-6) suggests that an additional sub-unit that includes the Santa Ynez River, Jalama Creek, Cañada Honda, and Cañada de Cojo appears merited. However, the lack of occupancy data between Cañada del Cojo and Gaviota Creek precludes precise definition of this unit. For the purpose of this study, we assigned all sites between Santa Ynez River and Cañada del Alegria to sub-unit ***CO3*** (Table 3-2). Further sampling of the Hollister Ranch coastline and genetic analysis is needed before any recommendations of sub-unit reassessment for this region can be given. Given the limited amount of data from this coastline, it is difficult to appropriately place the numerous small sites here in an appropriate metapopulation framework as the boundary between ***CO3*** *and* ***CO4*** is not well established

- ***CO4:*** This sub-unit is comprised of all populations between Gaviota Creek and Rincon Creek. Microsatellite analysis suggests additional sub-units in this region may be warranted, however further investigation is needed before a precise definition of this unit can be recommended. The metapopulation behavior of this sub-unit is of particular interest as a number of sites have an established earlier history of extirpation including Refugio Creek, Devereaux Slough, Goleta Slough, Sycamore Creek, Andre Clark Bird Refuge, Arroyo Paredon, Carpinteria Creek and Rincon Creek (Lafferty et al. 1999a&b). These extirpations all occurred coincidently with the 1970s drought and recolonization of many sites is evident as founder effects in genetic data (Fig. 3-6; Jacobs et al. 2005, Jacobs unpublished). These observations serve as evidence for coincident climate driven extirpations in the region. Subsequently, this sub-unit has experienced a significant number of impacts since listing, including the extirpation of Arroyo Hondo (2007), Tecolote Canyon (2014), Winchester/Bell Canyon (2014), and Devereaux Slough (2014). In addition, the recent extirpation of Rincon Creek (2017), and the heavy impacts and population reductions in Arroyo Paredon and Carpinteria Creek from the Thomas fire (Fig. 3-7) may have severe long-lasting impacts on this sub-unit's metapopulation dynamics. Continued sampling of all sites within this sub-unit, in addition to genetic analysis, is needed before any recommendations of sub-unit reassessment for this region can be given (Table 3-2).

L.A./Ventura Recovery Unit (Eucyclogobius newberryi)

- ***LV1:*** The genetic structure of the L.A./Ventura Recovery Unit using microsatellite analysis in the program STRUCTURE (Fig. 3-6) suggests that an additional sub-unit that includes Malibu Lagoon and Topanga Creek appears merited. Since no tidewater gobies preserved in a fashion suitable for DNA extraction were collected from Malibu Lagoon prior to their extirpation in the late 1980's, we are unable to determine if this population historically experienced connectivity with any of the sites to the north (it is derived from an artificial recolonization from the Ventura River). The recent population in Topanga Creek was first documented in 2001 and appears to have been colonized from Malibu Lagoon. In addition, the distance between Malibu Lagoon and Sycamore Creek, the nearest neighbor to the north, is >30km and would require dispersing around the rocky headlands of Point Dume. Based on this available data, we recommend that the populations in sub-unit ***LV1*** should include the Ventura River, Santa Clara River, Ormond Beach/J Street Drain, Calleguas Creek – Mugu, and Sycamore Canyon (Table 3-2).

- ***LV2:*** Based on microsatellite analysis, distance to nearest neighbor to the north, and geomorphology of the Malibu Coast (see above), we recommend that Malibu Lagoon and Topanga Creek should be defined as a separate sub-unit ***LV2*** (Table 3-2).

South Coast Recovery Unit (Eucyclogobius kristinae)

- ***SC1-SC2:*** The South Coast Recovery Unit experiences a very high rate of extirpation/colonization (Lafferty et al. 1999b), which could explain the low genetic variation found in this recovery unit based on mitochondrial sequencing and microsatellite analysis. Separating San Mateo Creek and San Onofre Creek from the sites in ***SC2*** in the recovery plan was in large part due to the distance between San Onofre Creek and Las Flores Creek (<15km), its nearest neighbor to the south. However, available data and field observations suggest that San Onofre Creek and San Mateo Creek have effectively communicated with sites to the south and are effectively part of ***SC2*** metapopulation. First, the maximum dispersal distance of approximately 13km employed here, determined by microsatellite assignment tests of the Central

Coast Unit in 2008 (Fig. 3-3), makes dispersal between San Onofre Creek and Las Flores much more plausible. Second, in 2017 a few juvenile and sub-adult tidewater gobies were documented in Las Flores Creek for the first time since 2012. At that time, tidewater gobies were only present in San Onofre Creek, Hidden Lagoon, and Cockleburr Canyon Lagoon. The most likely site the Las Flores gobies colonized from would be Hidden Lagoon, approximately 2km to the south. However, based on field observations of all the systems on Marine Corps Base Camp Pendleton, our understanding is that San Onofre Creek was the only system that had breached prior to this colonization event. In fact, San Onofre had a significant breaching event in February 2016 in addition to breaching in 2017. From a genetic analytical perspective, it is difficult to address the potential genetic distinction between ***SC1 & SC2*** due to lack of genetic variation in the region. Therefore, until additional markers are developed, and further genetic analysis is conducted on this recovery unit, we are assuming that it is possible that these two sub-units can function as a single metapopulation. For this study they will be modeled as a single unit ***SC2***. Continued sampling of all sites within this sub-unit, in addition to further genetic analysis, is needed before any recommendations of sub-unit reassessment for this region can be given (Table 3-2).

Discrete-Time Metapopulation Model

For the metapopulation model, we modified the general approach laid out by Risk et al. (2011) in two ways: 1) We adjusted assumptions to more closely represent the sampling procedures and ecology for tidewater gobies, and 2) We implemented it as a hidden-Markov model in the computer language Stan (Stan Development Team 2018b), which improves performance and speed of the estimation procedure.

The fundamental model uses the discrete state-space formulation, in which observations of presence y_t made at time t are modeled as solely conditional on a hidden state vector $\mathbf{z}_t$, which in turn is modeled as conditional on state in the previous time step $\mathbf{z}_{t-1}$. The former conditional probability $\Pr[\mathbf{y}_t|\mathbf{z}_t]$ is known as the observation model and captures assumptions about the sampling procedure, and the latter conditional probability $\Pr[\mathbf{z}_t|\mathbf{z}_{t-1}]$ is known as the process model and captures the form by which processes alter the state over time. Each individual entry $z_{i,t}$ in the state vector represents the state of population i at time t and can take one of two values: $z_{i,t} = 1$ for an occupied population site (an extant population), and $z_{i,t} = 0$ for a vacant population site.

Observation Model

For the observation model, the sampling procedure is a series of n_s replicated pulls of a seine at each sampling event s. Each sampling event is associated with a time t (year), a site j, and a population i. In general, most populations are sampled via a single site, but some have samples from multiple sites, sometimes in the same year. The number of seine pulls containing tidewater gobies is given as y_s, which is always $\leq n_s$. Detection occurs when $y_s > 0$, non-detection when $y_s = 0$.

A distinct feature of these sorts of data is the fundamental asymmetry that, barring false-positive errors in species identification, the detection of occupancy is always certain, but the detection of vacancy is always uncertain because detection is imperfect, and some non-detections are therefore not vacant. If not accounted for in the model, this asymmetry will over-represent the vacancies relative to occupancies, leading to biased estimates of population turnover. For example, if p_s is the probability of detecting the tidewater goby in a pull of the seine when the species is present, the probability of non-detection during n_s independent seine pulls is

$$\textbf{Eq. 1} \quad \Pr[y_s = 0] = Binomial(0 \mid n_s, p_s) = (1 - p_s)^{n_s}$$

Of course, when the species is absent $\Pr[y_s = 0] = 1$. These two equations form part of the observation model; also part of the model: the probability of detection when the species is present is *Binomial* ($y_s \mid n_s$, p_s), and when absent is 0. Underlying assumptions of the binomial distribution used in this model are that detections in different seine hauls are independent, and the total number of seine hauls was determined independently of detections.

These assumptions do not quite hold for some of the observations in the tidewater goby dataset, requiring a more elaborate "composite" observation model accounting for different sampling rules (Table 3-3). In some cases, seines were pulled until the species was detected, or until some fixed number of empty hauls (usually 10) was obtained. In this case the detection must be modeled as a negative binomial distribution, while non-detection can still be modeled by the binomial (Model 1 in Table 3-3). Many observations conformed to the assumptions of the binomial and could be modeled as above (Model 2 in Table 3-3), but a significant number of observations failed to report the number of hauls detecting tidewater goby (Model 3 in Table 3-3) and also sometimes the number of total hauls (Model 4 in Table 3-3). We should note that our Model 4 contains a slight simplification, in which we assume $n_s = 1$ rather than modeling it as a randomly distributed number between 1 and some plausible maximum number of seine hauls. This slightly inflates the probability that a non-detected population is occupied but we assume it to be a minor effect. Finally, the composite model includes a dummy "Model 5" for site-year combinations where no observations were made (Table 3-3), as well as provisions for multiplying together the probabilities for different sites in a given population in a given year. Each sample *s* was pre-assigned a model based on our knowledge of the approaches used to collect the data.

Finally, the individual sample probabilities p_s were treated as a random effect, modeled as

$$\textbf{Eq. 2} \quad logit(p_s) \sim Normal(\mu_p, \sigma_p)$$

where *logit*(*p*) is the log-odds *log*(*p*/(1-*p*)) as in logistic regression. This normal distribution is a hierarchical element of the model known as a hyperdistribution and seems vastly more realistic than assuming all samples to have the same detection probability. By making this assumption, detection probabilities that are poorly constrained (have relatively flat likelihood profiles) by the data can still be reasonably estimated, by "partial pooling" of information through the hyperdistribution (Gelman et al. 2004).

Process model

As in Hanski (1994) and Risk et al. (2011), we assume that the occupancy state of individual populations evolves through time as

$$\textbf{Eq. 3} \quad P(z_{i,t} = 1) = z_{i,t-1}\phi_{t-1} + (1 - z_{i,t-1})\gamma_{t-1}$$

where z_t is 1 if the population site is occupied, and 0 if it is vacant. The parameter ϕ_t is the probability of population persistence between times *t* and *t*+1, and likewise the parameter γ_t is the probability of a vacant patch getting colonized. A Bayesian version of this model is described for the BUGS language by Kery and Schaub (2012, ch. 13), with the individual transitions $z_{i,t-1}$ to $z_{i,t}$ treated as Bernoulli samples (Binomial samples with sample size 1 each), which is a simple formulation but produces very slow convergence of the estimation procedure due to the explicit modeling of discrete states. Stan Development Team (2018, section 10.6) and Ito (2017) show how to rework the model as a hidden-Markov model with the discrete states integrated out, using what is known as "the forward algorithm." In the forward algorithm, the likelihood for occupancy is computed iteratively as

Eq. 4 $$L_{1,i,t} = L_{1,i,t-1}\phi_{t-1}q_{1,i,t} + L_{0,i,t-1}\gamma_{t-1}q_{1,i,t}$$

and

$$L_{0,i,t} = L_{1,i,t-1}(1-\phi_{t-1})q_{0,i,t} + L_{0,i,t-1}(1-\gamma_{t-1})q_{0,i,t}$$

where the first line is the likelihood for occupancy at time *t*, the second line is the likelihood for vacancy at time *t*, and the $q_{z,i,t}$ represent the composite observation probabilities described in Table 3-3. These intermediate likelihoods are computed by forward iteration to obtain the final log-likelihood used in estimation, $log(L_{1,i,T} + L_{0,i,T})$, where *T* is the last year in the dataset. To begin the iteration, likelihoods for the first year are modeled as

$$\textbf{Eq. 5} \quad L_{1,i,1} = \psi_{i,1} q_{1,i,t}$$

and

$$L_{0,i,1} = (1 - \psi_{i,1}) q_{0,i,t}$$

where $\psi_{i,1}$ is the probability of occupancy in year 1, modeled as uniformly distributed between 0 and 1. Stan Development Team (2018, section 10.6) gives a fuller description of the forward algorithm and how it can be implemented in Stan.

Colonization and extinction processes

Similarly to Hanski (1994) we model an index of dispersal pressure to a population as

$$\textbf{Eq. 6} \quad S_{i,t-1} = \sum_{j=1}^{j=I} \psi_{j,t-1} M_{i,j} e^{-D_{i,j}/\alpha}$$

where *i* indexes the focal population receiving immigrants, and *j* indexes the other populations that serve as potential sources of immigrants. In the above equation,

$\psi_{j,t-1}$ is the probability of occupancy, calculated from the estimated colonization and persistence probabilities produced by the forward algorithm,

$M_{i,j}$ is an indicator where $M_{i,j} = 1$ for populations within the same metapopulation (sub-unit), and $M_{i,j} = 0$ for populations in different metapopulations (by convention, we set $M_{i,i} = 0$ to prevent dispersal from a population to itself).

D_{im} is the measured distance between the two populations, and

α is the mean dispersal distance for dispersing fish, and is treated by the model as an estimated parameter, possibly with an informative prior.

In words, $S_{i,t}$ is an index of dispersal pressure summed across nearby populations, where $S_{i,t}$ = 1 represents dispersal pressure from one nearby population at distance zero. The exponential term represents a situation in which the distribution of dispersal distances declines exponentially with distance, as would be produced by a constant risk of mortality per distance traveled during dispersal. The dispersal index is converted into a colonization probability using the equation

$$\textbf{Eq. 7} \quad \gamma_{i,t-1} = \frac{S_{i,t-1}}{S_{i,t-1} + \delta_{t-1}}$$

where δ_{t-1} is an estimated parameter allowed to vary randomly between years, but constrained to be greater than 0:

$$\textbf{Eq. 8} \quad -log(\delta_t) \sim Normal(\mu_\delta, \sigma_\delta)$$

This formulation is modified from similar formulations in Hanski (1994) and Risk et al. (2011) by two simplifications. First, the squared terms in those publications have had their exponent 2 replaced by a 1, to represent dispersal in linear space (coastline) rather than 2-D space (landscape). Second, those publications assumed that the number of migrants produced by a population scaled with the area of the habitat patch occupied by the population. Here we assumed no such relationship and omitted the area term, as our observations of population size and inferences of habitat quality do not suggest a monotonic positive relationship with size. Consequently, we also have no *a priori* expectation the number of migrants will correlate with habitat size.

The persistence probability is modeled simply as

$$\textbf{Eq. 9} \quad logit(\phi_t) \sim Normal(\mu_\phi, \sigma_\phi).$$

Again, this differs from the formulations of Hanski (1994) and Risk et al. (2011) by omitting any effect of habitat patch size on persistence rate. Note that extinction probability for populations = 1 - ϕ_t.

The last two equations highlight a substantive feature of the model that is very important: the rates of colonization and extinction are allowed to vary randomly from year to year, with magnitudes (σ_δ and σ_ϕ) that are estimated from the dataset. As with the capture probabilities p_s, this is accomplished by defining probability distributions characterized by hyperparameters (μ_δ, μ_ϕ, σ_δ and σ_ϕ), which are then estimated as part of the overall estimation procedure.

Extinction Risk of Metapopulations

Once the model has been defined and the parameters estimated via Markov Chain Monte Carlo (MCMC,) the estimation of extinction risk is straightforward: γ_t and ϕ_t are randomly sampled from the posterior predictive distributions of the hyperparameters (μ_δ, μ_ϕ, σ_δ and σ_ϕ), and each metapopulation then uses these samples to iterate forward from time T to time T + 100 (i.e., 100 years into the future). These simulations were repeated 10,000 times to obtain a probability of persistence (= x persisting / n simulations) for each metapopulation.

Model Assumptions and Parameters

This MVA model was analyzed using a hierarchal Bayesian model approach to a discrete-time stochastic patch occupancy metapopulation model (Risk et al. 2011). Discrete time (time-step = 1 year) was chosen as no shorter than the generation time of the species (1 year) but no longer than the processes driving extinction and colonization (the annual hydrologic cycle). The South Coast recovery unit, however, has fairly consistent annual occupancy data with little seasonal variation dating back to 1998. Occupancy data used to inform the model began in 1990 and extends to the end of 2018. The maximum dispersal distance was set to 15km based on two criteria: 1) tidewater gobies collected in 2008 from the Central Coast Recovery Unit were found to have a maximum dispersal distance of approximately 13km determined by microsatellite assignment tests (Fig. 3-2 and 3-3) the distance between San Onofre Creek and Las Flores Creek in the South Coast Recovery Unit, which we propose in our sub-unit reassessment could possibly function within the same metapopulation structure, has an approximate dispersal distance of 14.5km. Although the max dispersal distance is set to 15km within sub-units, the model does not allow successful dispersal to occur at all between sub-units. Major assumptions for the model include: 1) density independence of extirpation rate, 2) population size and structure does not affect metapopulation dynamics, 3) habitat patch size does not affect metapopulation dynamics, 4) random dispersal and connectivity within metapopulations based on distance between patches, 5) imperfect detection, 6) no false presence in data, 7) metapopulation level density-dependance, and 8) detection history at each location is independent. This model was developed with the computer software R version 1.1.456.

MODEL LIMITATIONS

Occupancy Data

Effective understanding of occupancy and dispersal between populations are critical to metapopulation modeling. While the amount of occupancy surveys included in this study are abundant and far more comprehensive than most model study systems with metapopulation dynamics, the vast majority of populations and sub-units throughout the range have not been monitored regularly since listing in 1994, creating major data gaps and uncertainty in the model's persistence estimates. To date, only the South Coast Recovery Unit has met the 10-years of scientifically credible presence/absence monitoring recommended in the recovery plan (2005) that is needed to accurately model long-term persistence in each of the six recovery units. Furthermore, while developing our tidewater goby rangewide database (Spies & Jacobs in prep) and reviewing thousands of tidewater goby reports and records dating back to the 1970's, we found that most sub-units in the Greater Bay Area, Central Coast, and Conception Recovery Units have large data gaps since 1994 and prior to 2014, such as the Hollister Ranch coastline in Santa Barbara County, where eight of the nine localities where tidewater gobies have been documented have not been surveyed since 2005.

Our preliminary model on these matters is relatively unsophisticated, but amelioration of the situation may be possible with further modeling. However, the primary need going forward is for unbiased and continued collection of data with a standardized coastwide survey protocol when possible (see S1 text for proposed survey protocol). There's been a dramatic increase in sampling of all recovery units through time (Fig. 3-4 and 3-5), yet many past survey efforts have only reported when tidewater gobies were present in a system. Records of tidewater goby absence throughout the coast have been extremely limited until recently, with the first absence in our database (Spies & Jacobs in prep) recorded by Camm Swift in 1970. Such data are a fundamental need prior to any assessment of downlisting.

Habitat Covariates

The interaction of tidewater gobies and the nature of persistence in the lagoonal habitats are known *a priori* to be complex. Typically, metapopulation models assume that area is a consistently positive predictor of persistence, because they tend to support larger average population size, all else being equal. However, based on our experience the relationship between habitat size and persistence appears to be complex because all else is not equal. For example, larger lagoons are subject to larger numbers of invasive species and native predators, which are detrimental to tidewater gobies. In addition, larger lagoons are thought to breach more frequently, and stable water level and closed lagoon conditions are associated with successful reproduction in tidewater gobies. Conversely, small lagoons may have a lower risk of invasion, and also have less tidal driven variation in water level, but these habitats are at a substantially greater risk of desiccation. This suggests a hump-shaped relationship between lagoon size and population persistence, with intermediate sizes having the highest persistence. Other habitat attributes have additional effects that may or may not be related to size. In particular, submerged and emergent aquatic vegetation, such as *Ruppia maritima, Ruppia chirrosa, Zannichellia paustris, Stuckenia pectinata, Potamogeton pectinatus, Typha latifola, and Scirpus spp.,* provide protection from predators and high flow events. Thus, aquatic vegetation is a critical habitat characteristic that has been found to have very strong positive relationship with tidewater goby occurrence in lagoons and likely enhances persistence. Lastly, anthropogenic phenomena such as channelization, which limits escape from high flows, or upstream impoundment which limits scour, appear to negatively impact the temporal continuity of habitat at many localities.

*****None of the above factors have yet to be included in the predictions of persistence in the MVA model. Some of the more tractable variables such as habitat size and habitat quality, which will include the presence/absence of native and nonnative predators, water quality parameters, and critical habitat characteristics such as aquatic vegetation, will be integrated in further versions of the model.*

Dispersal

Interannual dispersal variation associated with precipitation and breaching (Fig. 3-3), regional variation in breaching frequency of lagoons along the California Coast, and variation in coastal substrate (Fig. 3-6) are all likely to influence dispersal in ways yet to be included in the model. Breaching of lagoons is required for dispersal and connectivity of tidewater goby populations within a sub-unit. Following breaching, dispersal is presumably dominated by nearshore movement of adult fish. Such demersal dispersal is likely to be influenced by the benthic habitat along the shore. Available data suggests that rocky headlands, rocky reef habitat, or kelp substrate limits dispersal between lagoons relative to soft sedimentary bottoms. Breaching is strongly correlated with significant precipitation events that drive streamflow (Jacobs et al 2011). This has been demonstrated using microsatellite analysis of the Central Coast Recovery Unit. In this case, microsatellite data demonstrated that dispersal was greater in a high rainfall year (2008) compared to a low flow rainfall year (1990) (Fig. 3-3). Rainfall events comparable in scale to that which caused dispersal along the Central Coast in 2008 occur in different frequencies in coastal regions throughout California.

A binary probability of whether or not there was dispersal due to breaching in management units in a given year has been estimated from rainfall using the historic record of precipitation from station data in each recovery unit (see calculations below) and from inferences based on assignment tests using genetic data that suggest that dispersal only occurs when a rainfall threshold is reached and multiple systems breach (Buckner et al. 2016; Ha et al. in prep). Furthermore, as a consequence of regional differences in frequency of rainfall events there appears to be a four-fold variation of dispersal frequency between management units. However, this factor has yet to be included in the MVA model.

Annual probability of sufficient breaching for dispersal from weather station precipitation data

• Greater Bay Area unit (51/59 years) = **0.86**

– Santa Cruz Main Station # 047916

– Watsonville Waterworks Supplemental Station # 049473

• Central Coast unit (26/59 years) = **0.44**

– Morro Bay Fire Station #045866

– San Luis Obispo, Poly #047851

• Conception unit (33/59 years) = **0.56**

– Santa Barbara Municipal #047902

– Santa Barbara Airport # 047905

• LA Ventura unit (21/59 years) = **0.36**

– Santa Monica Pier #04793

– Culver City # 042144

- South Coast unit (12/59 years) = **0.20**

– Oceanside Marina #046377

– San Diego Airport #047704

The criteria applied in the above determinations are that dispersal can occur if rainfall in any given month is over six inches, or if rainfall sums to over 10-inches in three contiguous months. These values are a little lower than the numbers associated with the genetically observed dispersal event in Central Coast Recovery Unit described above (Fig. 3-3). This assessment is limited to 59 years per recovery unit due to the limited availability of weather station data. Observations extend from 2018 to 1960, and are based on rainfall years, that begin October 1st and group the contiguous rainy months of the winter, rather than calendar years (e.g., 1960 is late 1959 early 1960).

*******This preliminary MVA model does not account for dispersal differences between years, nor does it account for differences in breaching dynamics between management units or any impact of coastal substrate thought to influence dispersal. Additionally, this preliminary model assumes a universal dispersal kernel coastwide that is based on dispersal during a single wet year (2008) in the Central Coast Recovery Unit. Given that dispersal is enhanced during wet years, this version of the model is likely to substantially overestimate connectivity and metapopulation persistence. Thus, the preliminary results reported here likely overestimate tidewater goby metapopulation persistence. We anticipate that metapopulation persistence will drop* *significantly, especially in the southern units, once appropriate modifications are included in the model.*

Climate Change

Climate change is likely to have a number of impacts on lagoon dynamics and tidewater goby metapopulations. In Mediterranean regions, such as California, climate variations are predicted to increase and continued climate change, resulting in warmer, often drier, and more variable precipitation with more intense drought and flood (Valiela et al. 2009, Klausmeyer and Shaw 2009, Berg & Hall 2015, Williams et al. 2015). These climate patterns have become more noticeable over the past decade, especially in the coastal zones of Southern and Central California. It is not clear how climate change will affect closed vs. open estuarine habitats along the coast of California, because variations in climate patterns over large latitudinal scales can have considerable effects on the overall size, function, and distribution of estuarine habitats (Scavia et al. 2002, Day et al. 2008). A rise in global temperature is expected to shift the evaporation/precipitation regime, causing increased evaporation at lower latitudes and increased precipitation in the higher latitudes (Roessig et al. 2005). This could cause longer durations of estuary closure in southern California, and more frequent opening conditions in northern California. It has been found that stream flow, not tidal patterns, are the primary cause of breaching in California estuaries (Jacobs et al. 2011). Warming will likely facilitate desiccation and invasion of non-native predators with negative impacts on small and large systems, respectively. Variation in precipitation is also thought to likely increase with more frequent large precipitation events (Berg & Hall 2015). Greater episodicity of precipitation should have implications for scour-maintenance of lagoon habitat, breaching frequency and desiccation of systems. However, none of these impacts have been assessed.

With the more variable and severe climate patterns predicted to occur over the next 100 years, it is possible the California coast could experience one or more droughts similar to or more extreme or of longer duration than the 2011-2017 drought. Additionally, the federal register document for reclassification states that sea-level rise and the hydrological changes associated with climate change are anticipated to have significant effects on tidewater goby habitat over the next several decades. Sea-level rise poses a substantial threat to the species, potentially causing more frequent inundation of systems by breaching of the sandbar. This would eliminate a substantial amount of suitable habitat designated for the tidewater goby and numerous other species adapted to these habitats. It is important to note that maintaining genetic diversity among populations is essential for long-term persistence of this species, as the unique genetic signatures found within this species contain the required raw genetic material needed for adapting to local conditions. This could prove to be critically important for these species in the face of climate change and sea-level rise. Inference regarding how regional climate change along the California coast may influence tidewater goby metapopulation processes can be incorporated into future versions of the model.

Extreme Events – fires, drought, El Niño flooding, high wave events

Extreme events by their nature occur episodically. Thus, regular observations cannot adequately sample these. Impacts from recent fires on coastal lagoons have shown that dramatic impacts over suites of systems can occur (Spies personal observations). Fires such as the Thomas fire, which affected multiple tidewater goby habitats in the same event (Fig. 3-7), and the relationship of these larger events to climate change is under active investigation. There is a significant likelihood of expansion in size and frequency of fires with changing climate. Increased frequency of large coastal fires such as the recent Thomas fire (Kolden and Abatzoglou 2018), which extirpated the Rincon Creek population and significantly reduced population sizes in Arroyo Paredon and Carpinteria Creek, would likely have significant impacts reducing probabilities of persistence of units due to their ability to impact multiple populations in the same event. How regional extreme events may simultaneously impact multiple sites in a metapopulation can be incorporated in future iterations of the model but are beyond the scope of this effort.

PRELIMINARY RESULTS

Preliminary results from both MVA models shows that many sub-units still do not have enough survey data to accurately estimate the appropriate extinction and colonization parameters necessary to model long-term metapopulation persistence. The model currently assumes the same parameters across all management units. This model assumption means that population turnover observed in data-rich units also applies to data-poor units. This represents a best estimate with available data, but a better estimate would arise if at least 10-years of data were available for all populations. Out of the 101 sites used in this study, only 34 sites have at least five years of continuous survey data reported, and just 14 sites have credible presence/absence surveys over a 10-year period since 1990, a criterion listed in the executive summary and section 2.11 of the tidewater goby recovery plan (USFWS 2005). In fact, 66 out of the 101 sites have less than 10 years of credible survey data in total since 1990, with 27 sites having been surveyed only five years or less. Thus, the availability of data and the consistency of survey efforts reported have not reached the criteria set out in the recovery plan and are still insufficient for appropriate metapopulation modeling.

From 1990-2018, the probability that an occupied site remains occupied the following year (Fig. 3-8) was estimated to average approximately 95-98% across all sites found within the five focal recovery units examined in this study. In other words, the estimated annual probability that an occupied site is extirpated during this time period is approximately 2-5%. While an annual probability of persistence estimated between 95-98% for all sub-units may seem high, this also means that out of the 101 sites modeled in this study, three to five are likely to be extirpated annually. Despite the low estimates of extirpation found in both MVA models, colonization estimates appear to be lower most years (Fig. 3-9). Since extirpation estimates appear to be consistently higher than colonization estimates, a slight continuous downward trend in occupancy is seen for each site and sub-unit from 1990-2018 (Fig. 3-10). These trends in extirpation, colonization, and occupancy are consistent throughout the five recovery units, however, the standard error is highly variable between sites and sub-units. This variation in standard error between sub-units appears to be due to the amount of annual occupancy data available for each sub-unit to inform the model. Evidence of this can be seen in Fig. 3-10, which shows the annual occupancy of Malibu Lagoon and San Onofre Creek. While both Malibu Lagoon and San Onofre Creek are two of the few populations with more than 20 years of occupancy data since 1990, San Onofre has a significantly lower standard error in annual occupancy because all but one site within the SC1 and SC2 sub-units also have 20 years or more of occupancy data. That is not the case with Malibu Lagoon, which only has two out of eight sites within its sub-unit with more than 20 years of occupancy data and four sites with ten years or less. This further supports the need for additional monitoring of all sites and sub-units to better inform the model in order to make more accurate assessments of long-term persistence before a downlisting decision is made.

Estimated probabilities of persistence for each management unit for 100 years forward beginning from 2018, based on recovery plan sub-unit categories (*MVA Model 1*), can be found in Table 3-4. Despite the likely overestimation of connectivity and persistence in the preliminary models due to the use of a universal coastwide dispersal kernel described above, 8/15 (53.3%) of sub-units in *MVA Model 1* did not meet the downlisting criteria of 75% or better chance of persisting for a minimum of 100 years listed in the recovery plan. Five sub-units (GB1, GB3, GB4, GB10, and CC1) were not included in the *MVA Model 1* analysis because each consist of only a single site and do not function as a true metapopulation by definition. Specific targets for downlisting are listed for each recovery unit in the executive summary section of the recovery plan and specify that 5 sub-units in the North Coast Unit, 8 sub-units in the Greater Bay Recovery Unit, 3 sub-units in the Central Coast Unit, 3 sub-units in the Conception Unit, 1 sub-unit in the Los Angeles/Ventura Unit, and 2 sub-units in the South Coast Unit must individually have a 75% chance of persisting for a minimum of 100 years (USFWS 2005). Although we did not conduct a MVA analysis for the North Coast Unit in this study, based on the recovery criteria previously described, only the Central Coast Recovery Unit met the listed downlisting criteria when modeled under *MVA Model 1* sub-unit categories (3/5 sub-units modeled in the Greater Bay Area Recovery Unit, 2/2 modeled sub-units in the Central Coast Recovery Unit, 1/3 sub-units in the Conception Recovery Unit, 0/1 sub-unit in the Los Angeles/Ventura Recovery Unit, and 1/2 sub-units in the South Coast Recovery Unit). It is important to note that most populations in the Central Coast Recovery Unit have been poorly monitored since listing. Currently there are only two sites with at least 10 years of annual occupancy data since 1990, with no sites meeting the criteria of 10-years of continuous survey data.

Persistence estimates based on our amended sub-unit category recommendations (*MVA Model 2*) can be found in Table 3-5. Similar to *MVA Model 1*, a significant amount of sub-units (6/16, 37.5%) did not meet the recovery downlisting criteria of 75% or better chance of persisting for a minimum of 100 years. In this model, four sub-units (GB1, GB3, GB4, SC1) consist of only one site and were not included in the analysis due to the same criteria described above for *MVA Model 1*. Out of 16 modeled sub-units in *MVA Model 2,* both the Central Coast Recovery Unit and the South Coast Recovery Unit met the downlisting criteria. Additionally, the number of sites within a metapopulation, or sub-unit, appears to have a strong influence on occupancy, colonization, and the probability of long-term persistence. The seven sub-units that met the 75% recovery downlisting criteria in *MVA Model 1* had an average of 9±5.41sites (min = 4; max = 22). Similar estimates were seen in the ten sites that met the 75% recovery downlisting criteria in *MVA Model 2* (8±4.22 sites; min=4, max=18). However, as stated numerous times throughout this document, preliminary results of persistence are heavily overestimated in both models because of a universal dispersal kernel that does not take into account region-specific precipitation and breaching dynamics. Nonetheless, the fact that 53.3% of sub-units in *MVA Model 1* and 37.5% of sub-units in *MVA Model 2* do not meet the downlisting persistence criteria, even with connectivity likely being overestimated in both models, means that multiple tidewater goby sub-units are still at risk. Since breaching frequency is strongly related to overall rainfall, suggesting lower connectivity in southern sub-units, overestimation of model connectivity explains assumptions of viability overestimates in the south coast. Continued monitoring of all populations is critical to further develop and inform this model before any downlisting decision is made.

CONCLUSIONS

The focus of this study was to develop the basic framework to complete a metapopulation viability analysis (MVA) for the federally endangered northern tidewater goby (*Eucyclogobius newberryi*) and the newly described southern tidewater goby (*Eucyclogobius kristinae*). The development of such a model for all six recovery units, based on scientifically credible presence/absence monitoring over a 10-year period, is one of two major downlisting criteria listed in the tidewater goby recovery plan along with individual management plans for each sub-unit based on long-term conservation and management needs for each population (Recovery Action 2.11, USFWS 2005). Developing the appropriate MVA model that provides best estimates of future persistence based on an accurate representation of a species metapopulation dynamics is an essential component in constructing long-term management plans for endangered and threatened species. Since the tidewater gobies are genetically sub-divided into regional clades, which are further subdivided into long isolated entities (Dawson et al. 2001, 2002), each clade (recovery unit) represents an ecologically distinct component of the species, and each sub-clade (management unit) exhibits independent metapopulation dynamics at ecological timescales (Lafferty et al. 1999a&b, Earl et al. 2010). After the development of our initial MVA, which used frequentist methods to a more traditional stochastic patch occupancy model (SPOM), we determined that the model did not accurately represent the metapopulation dynamics of each recovery unit based on the occupancy data in hand and required prior knowledge of tidewater goby regional metapopulation dynamics and structure to be built into the model. Therefore, the

MVA model framework described in this preliminary report was developed using a Bayesian hierarchical approach to a stochastic patch occupancy metapopulation model (Risk et al. (2011). Ecologists and management agencies are increasingly using Bayesian inference as a tool for estimating metapopulation viability and persistence when assessing status of threatened and endangered species. The benefits of a Bayesian approach compared to a frequentist approach for this study, is that it allows us to use prior knowledge available before the study was conducted, or an informative prior probability distribution, along with the likelihood estimates collected from survey data generated over the past decade, to generate a more accurate posterior probability distribution. Bayesian statistics also helps to address criticisms that can occur from more traditional population viability models that are often attributed to poor or insufficient occupancy data, imprecise parameter estimates, inability to validate models, and account for imperfect detection. This methodology allowed us to assess long-term persistence of each tidewater goby metapopulation in five of the six recovery units over a 29-year period (1990-2018), while integrating informative priors of tidewater goby metapopulation processes based on decades of published research and rangewide occupancy surveys dating back to the 1970's.

While this preliminary report and MVA analysis demonstrates the flexibility and effectiveness of modeling tidewater goby viability and persistence using a Bayesian model framework, this study illustrates the complex nature of tidewater goby metapopulation dynamics and suggests that further development of a more interactive model that can treat a range of variables and can be adjusted to the dynamics of each metapopulation sub-unit is essential for an appropriate downlisting assessment that reflects the recovery plan viability and persistence criteria. Furthermore, this study has identified a number of data restraints, required corrections, and future amendments that need to be addressed in order to meet the downlisting or delisting criterion envisioned in the recovery plan. As described in detail above, the critical model limitations identified in this study include:

- ***occupancy data*** *– the nature of presence/absence surveys has been inadequate and inconsistent since listing in 1994. The vast majority of populations, and all but one sub-unit, have not been thoroughly surveyed over a 10-year period based on recovery plan criteria. This is evident from the significant differences in estimated standard error between the sub-units in the South Coast Unit and all remaining sub-units modeled in this study. The need for more consistent and frequent sampling efforts of all populations based on a standardized survey protocol that reports both presence and absence is essential. This will allow for the model to continually update estimates of viability and persistence annually, providing an informative and flexible tool that all management agencies can use when constructing long-term management plans.*

- ***habitat covariates*** *– none of the central factors that relate to critical habitat, and that have been identified in the recovery plan as variables that could influence the presence/absence of tidewater gobies, have yet to be included in the MVA model. Some of the more tractable variables such as habitat size and habitat quality, which will include the presence/absence of native and nonnative predators, water quality parameters, and habitat characteristics such as aquatic vegetation, need to be integrated in further versions of the model in order to provide enhanced predictions of future persistence and viability.*

- ***dispersal/connectivity*** – *variation in dispersal between years or differences in breaching dynamics between management units or any impact of coastal substrate thought to influence dispersal has not been built into this version of the model. This preliminary model assumes a universal coastwide dispersal kernel that is based on dispersal during a single wet year (2008) in the Central Coast Recovery Unit. Given that dispersal is enhanced during wet years, this version of the model is likely to substantially overestimate connectivity and metapopulation persistence. Thus, the preliminary results reported here likely overestimate tidewater goby metapopulation persistence. We anticipate that metapopulation persistence will drop significantly, especially in the southern units, once appropriate modifications are included in the model*

- ***climate change*** – *there are numerous climate related factors that will likely have significant impacts on tidewater goby metapopulations such as hydrology and breaching dynamics of lagoonal habitat. Maintaining genetic diversity among populations is needed for adapting to local conditions is essential for long-term persistence of this species. This could prove to be critically important in the face of climate change and sea-level rise. Inference regarding how regional climate change along the California coast may influence tidewater goby metapopulation processes can be incorporated into future versions of the model.*

- ***extreme events*** – *the potential impacts of extreme natural events, such as wildfires, drought, high wave events, and El Niño flooding, can pose a significant threat to tidewater goby future persistence. However, due to the episodic nature of these events data is very limited. Nevertheless, how regional extreme events may simultaneously impact multiple sites in a* *metapopulation can be incorporated in future iterations of the model and is worth further investigation.*

However, despite the significant amount of work that is still required to develop a completed MVA model for both the northern and southern tidewater goby, this study was able to deliver preliminary results that can provide a better understanding of current estimates of occupancy, extirpation and colonization rates, and future probabilities of persistence for each sub-unit. The most informative preliminary results from this study that will help with current management decisions relating to downlisting include:

- *The high standard error estimated in all model parameters for all sub-units located outside the South Coast Recovery Unit provide clear evidence of inadequate occupancy data to inform the model.*

- *Annual rangewide extirpation rates were low, approximately 2-5% annually. However, extirpation rates were higher than colonization rates most years. These estimates show that out of the 101 sites used in this study, between two and five sites on average are extirpated each year.*

- *Average colonization rates were lower than extirpation rates for the majority of sub-units most years despite the lack of heterogeneity in dispersal and breeching frequency across recovery units in the current model. This model limitation is mainly due to lack of adequate sampling in most sub-units.*

- *Furthermore, even with overestimates of dispersal and colonization,* 8/15 (53.3%) sub-units in MVA Model 1, and (6/16, 37.5%) in MVA Model 2, did not meet the minimum probability of persistence downlisting criteria.

- *A slow continuous decline in occupancy from 1991 to 2017 was observed due to annual extirpation rates being higher than annual colonization rates for all sub-units most years.*

We hope that the preliminary results and analysis described in this report provide a clear and informative description of the MVA model framework and can help guide current and future management actions such that recovery and downlisting of all tidewater goby management units is possible.

Acknowledgments

This project was supported by the U.S. Fish and Wildlife Service, the Department of Ecology and Evolutionary Biology at the University of California, Los Angeles, the UCLA La Kretz Center for California Conservation Science, the CSU Chancellors Doctoral Incentive Program, and the International Women's Fishing Association. Special thanks to Cat Darst and Eric Morrisette for all their support, guidance, and extreme patience throughout the duration of this project, as well as the tidewater goby core team of Susie Tharatt, Arnold Roessler, Josh Hull, Gjon Hazard, and Bradd Bridges. Thank you to Chris Dellith, Kendra Chan, and Chris Kofron at the USFWS Ventura Office for their support with permits and sharing survey reports. Thank you to Daniel Stofka for your help with field collections and the development and management of the tidewater goby database. Cami Pawlak, Patrick Wilson, and Ryan Doyle helped with database input and figure creations. This project would not have been possible without the many years of tidewater goby documentation by numerous biologists at sites across California, particularly Camm Swift, Kevin Lafferty, Douglas Rischbieter, Rosi Dagit, Rosemary Thompson, Ramona Swenson, Jerry Smith, Don Alley, Greg Goldsmith, Carl Page, Darren Fong, Daniel Chase, Michael Rouse, Andrew Kinziger, Tom Taylor, Gage Dayton, Jeff Hagar, and Dan Holland. This research was conducted under the permitted support of California State Parks, National Parks Service, U.S. Fish and Wildlife Service (recovery permit #TE-43944A-0), and the CA Department of Fish and Wildlife (permit #SC-10750).

Table 3-1. Greater Bay Area (G.B.A) and Central Coast (C.C.) Recovery Unit study sites used in MVA model simulations, with corresponding latitude/longitude coordinates. Management unit categories are based on 1) Recovery Plan listing and 2) our recommended sub-unit amendments. Single asterisks (*) indicate sites within connected lagoonal systems that have been joined as individual populations in our metapopulation analysis. Double asterisks (**) indicate sub-units with different names under the "amended" MVA model category.

Recovery Unit		Site	Latitude (°N)	Longitude (°W)	Sub-Unit Recovery Plan	Sub-Unit Amended
Greater Bay Area (G.B.A)		Salmon Creek	38°21'18.00"	123°04'00.00"	GB1	GB1
		Estero Americano	38°18'34.76"	122°56'08.62"	GB2	GB2
		Estero de San Antonio	38°16'39.19"	122°56'54.11"	GB2	GB2
	*	Tomasini Creek - Tomales Bay	38°04'15.17"	122°48'47.43"	GB3	GB3
		Lagunitas/Papermill Creek - Tomales Bay	38°03'52.61"	122°48'18.86"	GB3	GB3
		Rodeo Lagoon	37°49'51.00"	122°31'48.00"	GB4	GB4
		Tunitas Creek	37°21'24.53"	122°23'58.66"	GB5	GB5
		San Gregorio Creek	37°19'16.18"	122°24'08.54"	GB5	GB5
		Pomponio Creek	37°17'56.76"	122°24'18.90"	GB5	GB5
		Pescadero Creek	37°15'50.00"	122°24'22.00"	GB5	GB5
		Bean Hollow Creek / Arroyo de los Frijoles	37°13'29.58"	122°24'24.92"	GB5	GB5
		Yankee Jim Gulch	37°11'34.76"	122°23'53.34"	GB5	GB5
		Gazos Creek	37°09'55.26"	122°21'41.70"	GB5	GB5
		Waddell Creek	37°05'33.00"	122°16'32.00"	GB6	GB6
		Scott Creek	37°02'26.30"	122°13'46.13"	GB6	GB6
		Laguna Creek	36°58'60.00"	122°09'10.00"	GB6	GB6
		Baldwin Creek	36°58'02.23"	122°07'24.67"	GB7	GB7
		Lombardi Creek	36°57'44.23"	122°06'46.01"	GB7	GB7
		Old Dairy Creek	36°57'17.51"	122°05'29.21"	GB7	GB7
		Wilder Creek / Meder Creek	36°57'13.05"	122°04'38.77"	GB7	GB7
		Younger Lagoon	36°57'03.45"	122°04'00.00"	GB7	GB7
		Moore Creek	36°57'01.87"	122°03'31.20"	GB7	GB7
		San Lorenzo River	36°57'53.00"	122°00'46.00"	GB8	GB8
		Schwan Lagoon	36°57'45.25"	121°59'48.59"	GB8	GB8
		Corcoran Lagoon	36°57'36.76"	121°59'03.46"	GB8	GB8
		Moran Lake	36°57'24.93"	121°58'39.50"	GB8	GB8
		Soquel Creek	36°58'18.58"	121°57'07.84"	GB9	GB9
		Aptos Creek	36°58'10.09"	121°54'23.28"	GB9	GB9
	*	Watsonville Slough	36°52'16.87"	121°49'06.30"	GB10	GB10
		Pajaro River	36°51'15.08"	121°48'36.05"	GB10	GB10
	*	Bennett Slough / Struve Pond	36°49'22.00"	121°46'39.00"	GB11	GB10**
		Elkhorn Slough	36°48'44.97"	121°46'28.30"	GB11	GB10**
		Moro Cojo Slough	36°47'44.40"	121°46'58.06"	GB11	GB10**
	*	Old Salinas River irrigation channel	36°46'16.27"	121°47'25.11"	GB11	GB10**
		Salinas River	36°44'52.49"	121°48'04.44"	GB11	GB10**
Central Coast (C.C.)		Arroyo del Corral	35°41'05.04"	121°17'10.56"	CC1	CC1
		Oak Knoll Creek / Arroyo Laguna	35°39'06.98"	121°13'10.61"	CC2	CC1**
		Arroyo Tortuga	35°38'50.25"	121°12'41.32"	CC2	CC1**
		Arroyo del Puerto	35°38'36.68"	121°11'20.57"	CC2	CC1**
		Broken Bridge Creek	35°38'32.09"	121°10'57.51"	CC2	CC1**
		Little Pico Creek	35°38'02.10"	121°09'48.59"	CC2	CC1**
		Pico Creek	35°36'57.33"	121°08'55.01"	CC2	CC1**
		San Simeon Creek	35°35'44.62"	121°07'31.99"	CC2	CC1**
		Santa Rosa Creek	35°34'00.20"	121°06'28.93"	CC2	CC1**
		Villa Creek	35°27'40.52"	120°58'12.19"	CC3	CC2**
		San Geronimo Creek	35°26'59.44"	120°54'27.32"	CC3	CC2**
		Cayucos Creek	35°26'55.50"	120°56'03.34"	CC3	CC2**
		Liitle Cayucos Creek	35°26'54.11"	120°54'13.58"	CC3	CC2**
		Willow Creek	35°25'41.74"	120°52'56.15"	CC3	CC2**
		Torro Creek	35°24'46.00"	120°52'23.00"	CC3	CC2**
		Morro Creek	35°22'35.00"	120°51'48.00"	CC3	CC2**
	*	Chorro Creek - Morro Bay	35°21'18.41"	120°49'28.57"	CC3	CC2**
		Oso Creek - Morro Bay	35°19'48.24"	120°49'04.29"	CC3	CC2**

Table 3-2. Conception (C.O), L.A./Ventura (L.V.), and South Coast (S.C.) Recovery Unit study sites used in MVA model simulations, with corresponding latitude/longitude coordinates. Management unit categories are based on 1) Recovery Plan listing and 2) our recommended sub-unit amendments. Single asterisks (*) indicate sites within connected lagoonal systems that have been joined as individual populations in our metapopulation analysis. Double asterisks (**) indicate sub-units with different names under the "amended" MVA model category.

Recovery Unit		Site	Latitude (°N)	Longitude (°W)	Sub-Unit Recovery Plan	Sub-Unit Amended
Conception (C.O.)		San Luis Obispo Creek	35°10'49.16"	120°44'15.54"	CO1	CO1
	*	Pismo Creek	35°08'09.73"	120°38'22.74"	CO1	CO1
	*	Carpenter Creek	35°07'42.55"	120°38'08.62"	CO1	CO1
	*	Meadow Creek	35°06'14.62"	120°37'40.79"	CO1	CO1
	*	Arroyo Grande	35°05'58.00"	120°37'45.00"	CO1	CO1
		Oso Flaco Lagoon	35°01'46.50"	120°37'29.05"	CO1	CO1
		Santa Maria River	34°58'11.50"	120°38'35.33"	CO1	CO1
		Shuman Creek	34°50'41.00"	120°35'44.00"	CO2	CO2
		San Antonio Creek	34°48'07.00"	120°37'06.00"	CO2	CO2
		Santa Ynez River	34°41'31.00"	120°36'03.00"	CO2	CO3**
		Cañada Honda	34°36'31.00"	120°38'12.00"	CO2	CO3**
		Jalama Creek	34°30'40.00"	120°30'06.00"	CO3	CO3
		Cañada del Cojo	34°27'12.48"	120°24'58.81"	CO3	CO3
		Cañada de Santa Anita	34°28'02.72"	120°18'23.27"	CO3	CO3
		Cañada de Alegria	34°28'09.28"	120°16'19.74"	CO3	CO3
		Gaviota Creek	34°28'18.00"	120°13'34.81"	CO3	CO4**
		Refugio Creek	34°27'46.00"	120°04'09.00"	CO3	CO4**
		Tecolote Canyon	34°25'56.06"	119°55'03.74"	CO3	CO4**
		Winchester / Bell Cyn.	34°25'46.44"	119°54'45.80"	CO3	CO4**
		Devereaux Slough	34°24'35.72"	119°52'46.95"	CO3	CO4**
	*	Los Carneros Creek - Goleta Slough	34°25'43.78"	119°51'29.24"	CO3	CO4**
	*	Tecololito Creek - Goleta Slough	34°25'52.38"	119°51'29.50"	CO3	CO4**
	*	Atescadero Creek - Goleta Slough	34°25'22.54"	119°49'17.03"	CO3	CO4**
	*	San Pedro Creek - Goleta Slough	34°25'31.83"	119°49'50.88"	CO3	CO4**
	*	San Jose Creek - Goleta Slough	34°25'32.92"	119°49'50.95"	CO3	CO4**
		Arroyo Burro	34°24'11.10"	119°44'34.86"	CO3	CO4**
	*	Mission Creek	34°24'45.14"	119°41'16.51"	CO3	CO4**
	*	Laguna Channel	34°24'48.41"	119°41'07.77"	CO3	CO4**
		Sycamore Creek	34°25'01.72"	119°40'00.93"	CO3	CO4**
		Andre Clark Bird Refuge	34°25'03.52"	119°39'48.20"	CO3	CO4**
		Arroyo Paredon	34°24'49.00"	119°33'33.00"	CO3	CO4**
		Carpinteria Creek	34°23'26.49"	119°31'10.30"	CO3	CO4**
		Rincon Creek	34°22'25.75"	119°28'36.82"	CO3	CO4**
L.A./Ventura (L.V.)		Ventura River Lagoon	34°16'30.24"	119°18'27.52"	LV1	LV1
		Santa Clara River	34°14'08.00"	119°15'25.71"	LV1	LV1
		Ormond Beach / J Street Drain	34°08'13.00"	119°11'00.00"	LV1	LV1
		Calleguas Creek - Mugu	34°06'45.36"	119°04'52.43"	LV1	LV1
		Sycamore Canyon	34°04'17.11"	119°00'52.95"	LV1	LV1
		Malibu Lagoon	34°02'00.71"	118°40'58.55"	LV1	LV2**
		Topanga Creek	34°02'19.56"	118°34'58.98"	LV1	LV2**
South Coast (S.C.)		San Mateo Creek	33°23'10.31"	117°35'38.32"	SC1	SC2**
		San Onofre Creek	33°22'51.97"	117°34'42.65"	SC1	SC2**
		Las Flores / Las Pulgas Creek	33°17'27.40"	117°27'50.24"	SC2	SC2
		Hidden Lagoon	33°16'31.97"	117°27'05.92"	SC2	SC2
		Aliso Canyon Lagoon	33°15'52.63"	117°26'32.08"	SC2	SC2
		French Lagoon	33°15'44.00"	117°26'26.00"	SC2	SC2
		Cockleburr Canyon Lagoon	33°15'01.39"	117°25'52.96"	SC2	SC2
		Santa Margarita River	33°13'55.00"	117°24'55.00"	SC2	SC2
		San Luis Rey River	33°12'10.62"	117°23'27.24"	SC2	SC2

Table 3-3. Elements of the composite observation model for a species detected in y_s out of n_s samples during site-visit *s*.

Model	Sampling Rule	Species Observed?	Pr[obs|occupied]	Pr[obs|vacant]
1	Until species detected, or fixed number of empty samples	Yes	$\text{Nbin}((n_s - y_s) \mid y_s, p_s)$	0
		No	$\text{Bin}(0 \mid n_s, p_s)$	1
2	Fixed number of samples, number of detections known	Yes	$\text{Bin}(y_s \mid n_s, p_s)$	0
		No	$\text{Bin}(0 \mid n_s, p_s)$	1
3	Fixed number of samples, number of detections not known	Yes	$1 - \text{Bin}(0 \mid n_s, p_s)$	0
		No	$\text{Bin}(0 \mid n_s, p_s)$	1
4	Neither number of samples nor number of detections known	Yes	$1 - \text{Bin}(0 \mid 1, p_s)$	0
		No	$\text{Bin}(0 \mid 1, p_s)$	1
5	No samples	No	1	1

Table 3-4. Persistence probabilities for each management unit for 100 years forward beginning from 2018, estimated from the metapopulation model based on recovery plan sub-unit categories. Each management unit is treated as an independent metapopulation, isolated from other management units. For each sub-unit, N is a crude measure of effective sample size for simulations (number of independent simulations), and Rhat is the potential scale reduction factor on split chains, which indicates when the MCMC procedure has converged onto a reasonable posterior estimate of the persistence probability (at convergence, Rhat=1).

MVA Model 1: Recovery Plan Sub-Unit Categories

MU	Persistence	SE	N	Rhat
GB1	NA	NA	NA	NA
GB2	0.1667	0.002332	25536	1.00
GB3	NA	NA	NA	NA
GB4	NA	NA	NA	NA
GB5	0.9001	0.002280	17292	1.00
GB6	0.2888	0.002852	25253	1.00
GB7	0.9503	0.002003	11768	1.00
GB8	0.8257	0.002815	18148	1.00
GB9	0.1187	0.001871	29869	1.00
GB10	NA	NA	NA	NA
GB11	0.1321	0.002029	27845	1.00
CC1	NA	NA	NA	NA
CC2	0.9675	0.001681	10908	1.00
CC3	0.9648	0.001764	20908	1.00
CO1	0.6584	0.003280	23267	1.00
CO2	0.4541	0.003264	12756	1.00
CO3	0.9735	0.001422	27845	1.00
LV1	0.6298	0.003328	21045	1.00
SC1	0.1230	0.002016	26526	1.00
SC2	0.9636	0.001765	11245	1.00

Table 3-5. Persistence probabilities for each management unit for 100 years forward from 2018, estimated from the metapopulation model based on recommended amendments to the Recovery Plan's listed Sub-Unit categories. Each management unit is treated as an independent metapopulation, isolated from other management units. For each Sub-Unit, N is a crude measure of effective sample size, and Rhat is the potential scale reduction factor on split chains (at convergence, Rhat=1).

MVA Model 2: Amended Sub-Unit Categories

MU	Persistence	SE	N_eff	Rhat
GB1	NA	NA	NA	NA
GB2	0.4642	0.003001	27610	1.00
GB3	NA	NA	NA	NA
GB4	NA	NA	NA	NA
GB5	0.9655	0.001290	20007	1.00
GB6	0.5727	0.003211	23739	1.00
GB7	0.9703	0.001253	18341	1.00
GB8	0.9260	0.001849	20062	1.00
GB9	0.4448	0.003084.	25972	1.00
GB10	0.7303	0.002814	24876	1.00
CC1	0.9827	0.0009231	19916	1.00
CC2	0.9805	0.001041	17675	1.00
CO1	0.8752	0.002213	22308	1.00
CO2	0.4117	0.002991	27072	1.00
CO3	0.7983	0.002683	22390	1.00
CO4	0.9875	0.0008399	19983	1.00
LV1	0.7758	0.002715.	23595	1.00
LV2	0.3042	0.002793	27132	1.00
SC1	NA	NA	NA	NA
SC2	0.9829	0.0009539	18437	1.00

Figure 3-1. (Top) northern tidewater goby (*E. newberryi*). (Bottom) newly described southern tidewater goby (*E. kristinae*). Photos by Brenton Spies.

Figure 3-2. Updated tidewater goby rangewide distribution map with Recovery Unit boundaries and recommended Sub-Unit amendments (U.S. Fish & Wildlife Service 2005). Sub-Units with proposed amendments include GB10, CC2, CO2, CO3, LV1, SC1, and SC2. Sub-Units CO4 and LV2 are new additions, and Sub-Units GB11 and CC3 have been merged with GB10 and CC2, respectively.

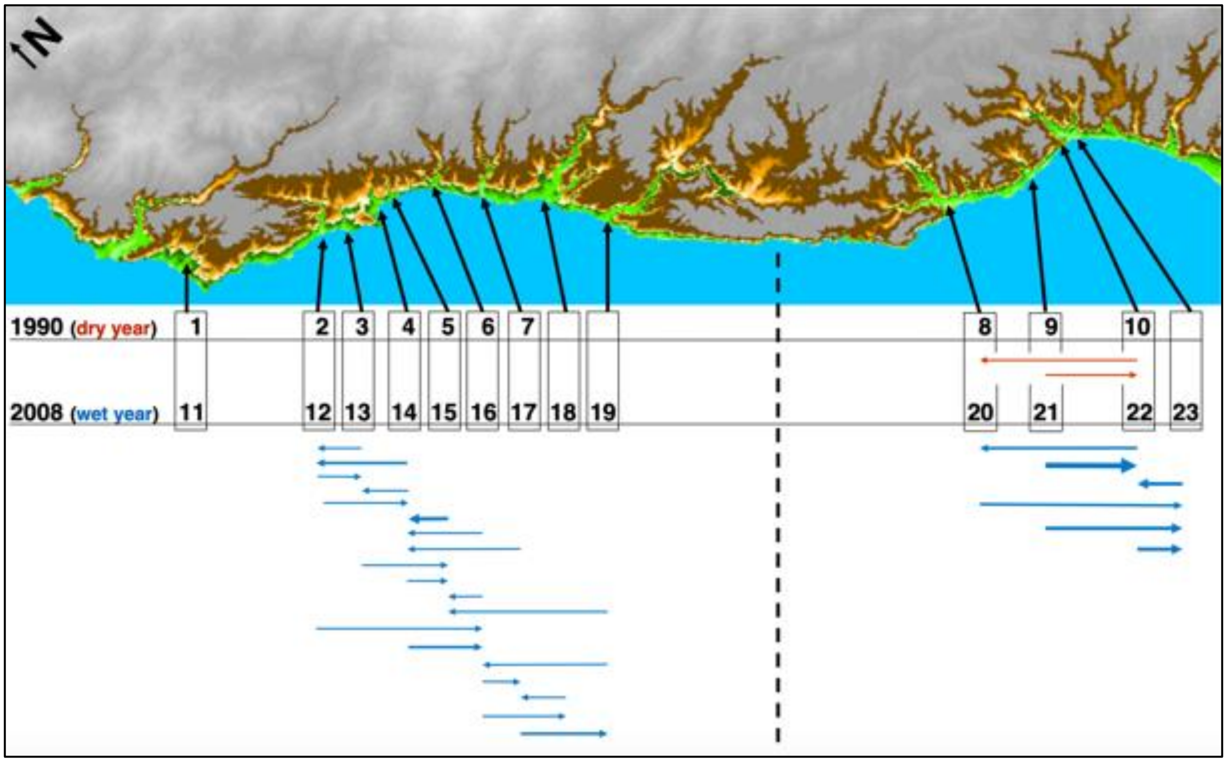

Figure 3-3. Pluvial dispersal of tidewater gobies (2008) vs. a dry year dispersal (1990): The above figure shows movement of fish between sets of small closing lagoons on the San Luis Obispo County coast, as determined from genetic assignment tests. The narrowest arrow indicates movement of a single individual, and broader arrows indicate movement of proportionally more fish. Movement is determined by an assignment test implemented in the program Arlequin (Excoffier et al 2005) and it is based on 19 microsatellite loci in 30 fish per sample in 2008 and 12-18 fish per 1990 sample. Statistical significance was assessed using a resampling protocol (Buckner 2016, Ha et al. in prep), given the difference in sample sizes between years. Samples were taken in February of 2008 following 7-inches of rainfall in January that breached lagoons, facilitating adult tidewater goby dispersal. 1989 and 1990 were very low rainfall calendar years (7.26inch & 6.83inch annual total precipitation respectively). The largest monthly precipitation in the two-year period was 2.08 inches in January of 1990. All rainfall records are from the Western Regional Climate Center and the Morro Bay fire station (045866)

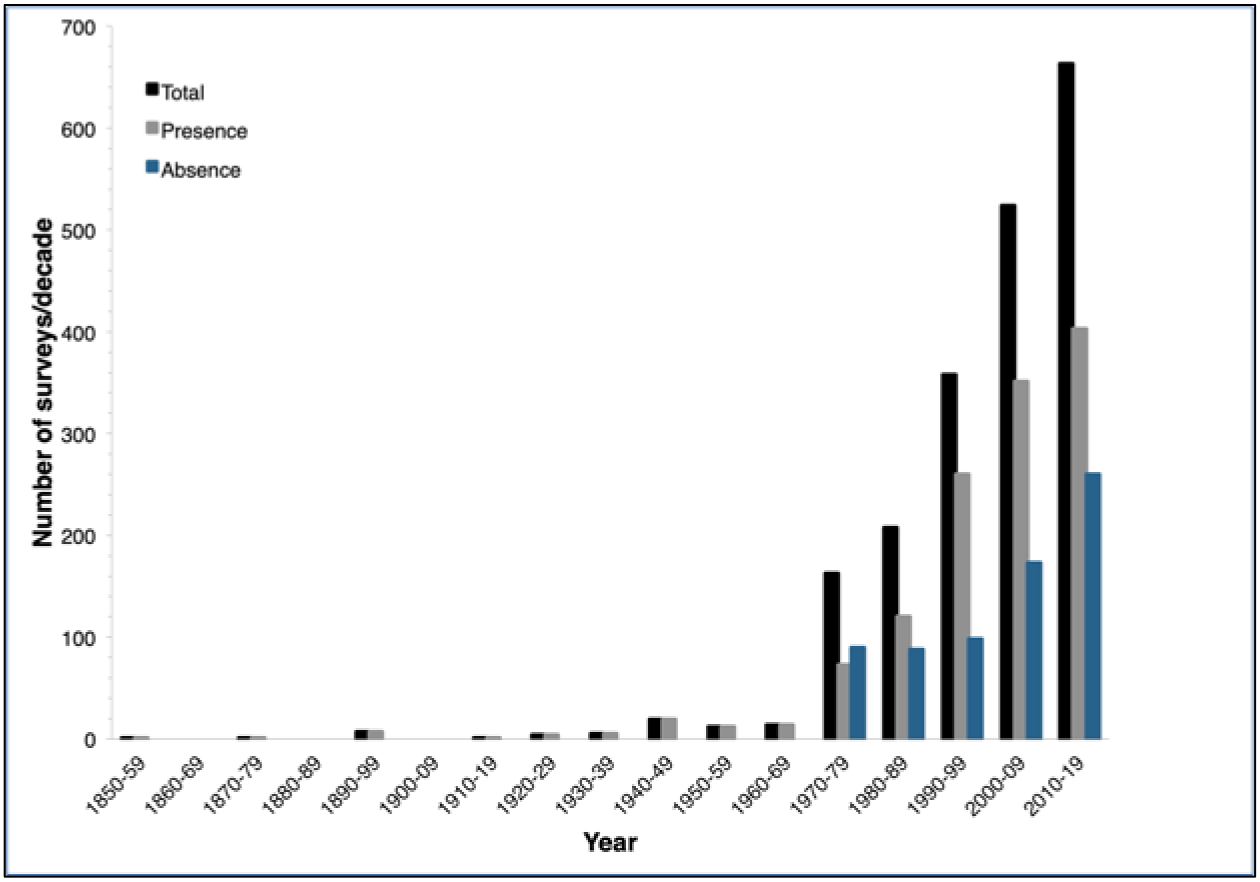

Figure 3-4. Number of surveys by decade. Note the dramatic recent increase in surveys, as well as the profound lack of observations of absence from sites in earlier records. These are concerning relative to possible biases that undercount the frequency of extirpation. Such concerns restrict metapopulation analysis to data from the most recent decades where such biases are reduced but may not be entirely eliminated.

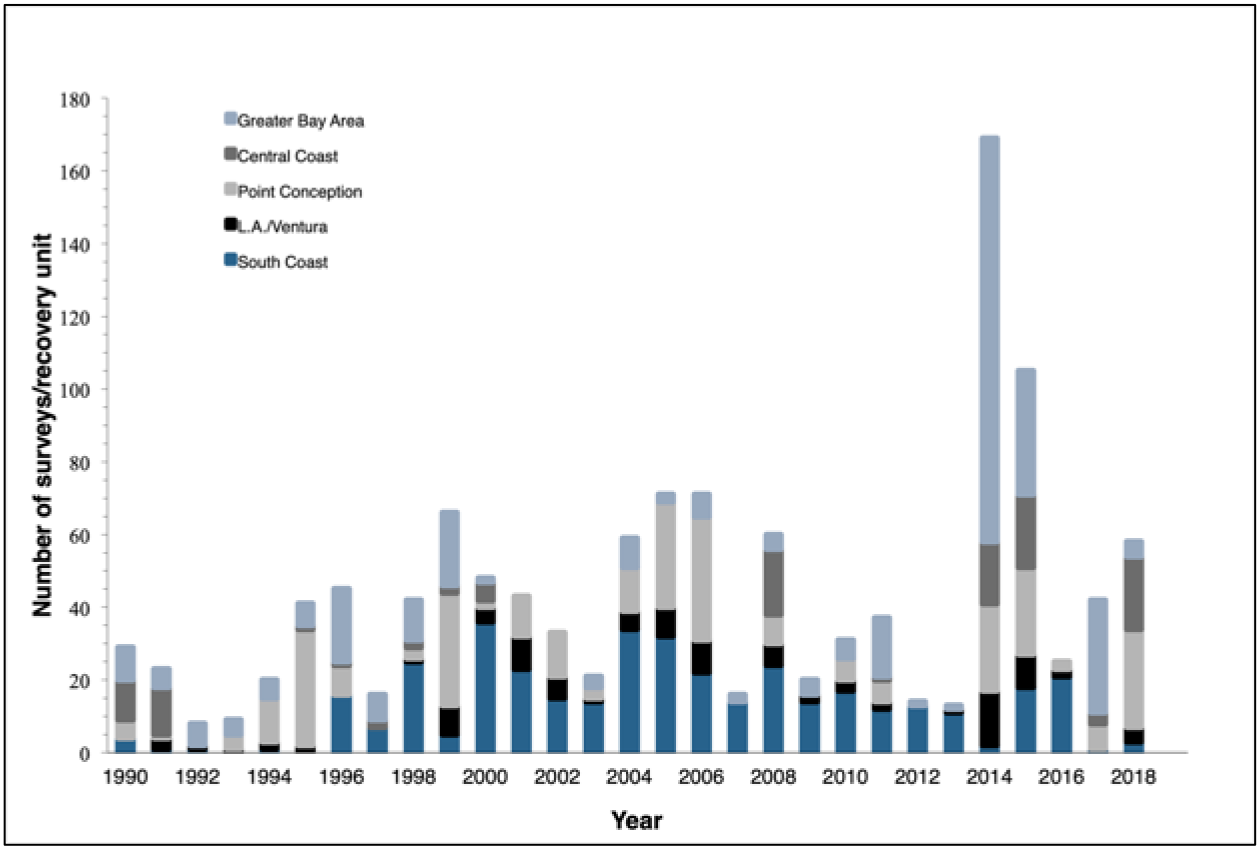

Figure 3-5. Tidewater goby occupancy surveys since 1990 by management unit. Note that sampling is by no means homogenous. The South Coast Recovery Unit is overrepresented for much of the time period due to mandated biannual sampling in this area. In addition, there is a significant contribution from the Greater Bay Area Recovery Unit in the last few years due to more regular sampling and the large number of sites to sample in this region. This variation in sampling is important as these are the data that inform the extirpation recolonization processes in the model as a whole. So, this lack of uniformity of observation could impart a bias to the overall model

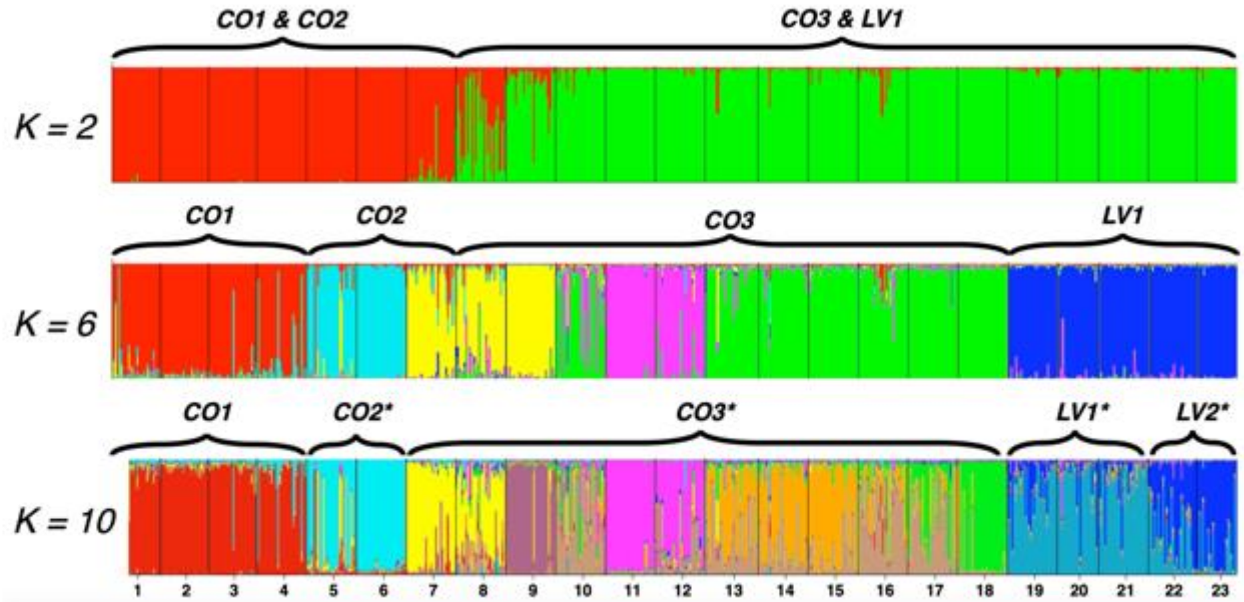

Figure 3-6. Genetic structure among tidewater goby populations in the Conception (C.O) and L.A./Ventura (L.V.) Recovery Units obtained using STRUCTURE on a data set of 680 individuals from 23 sites with 25-32 individuals per site using 11 microsatellite loci, with replicates averaged by CLUMPP (Jacobs et al. 2005; Jacobs Lab unpublished data). The number of clusters in each plot is indicated by the value of K on the left side of the figure. Vertical bars represent individuals (listed left to right in north–south order in each plot) and are made up of stacked columns proportional in height to the average membership to clusters. Localities are separated by vertical black lines. We varied K from 1 through 24 for the full data set, though we only show K=2, 6 and 10. Localities are coded from north to south: 1-San Luis Obispo Creek, 2-Pismo Creek, 3-Arroyo Grande, 4-Santa Maria River, 5-Shuman Creek, 6-San Antonio Creek, 7-Santa Ynez River, 8-Jalama Creek, 9-Cañada del Cojo, 10-Gaviota Creek, 11-Refugio Creek, 12-Tecolote Canyon, 13-Arroyo Burro, 14-Mission Creek, 15-Andre Clark Bird Refuge, 16-Arroyo Paredon, 17-Carpinteria Creek, 18-Rincon Creek, 19-Ventura River, 20-Santa Clara River, 21-Ormond Lagoon, 22-Malibu Lagoon, 23-Topanga Creek. Separation of sets of populations into sub-units at K=6 is significantly influenced by headlands and steeper stretches of shore which presumably limit dispersal. K=6 shows the previous subdivision of the Conception Unit into sub-units. K=10 (e.g *CO#*)* shows our current suggested subdivision. Note that an additional sub-unit (7-9) Santa Ynez, Jalama Creek, and Cañada del Cojo appears merited, but lack of sampling between Cañada del Cojo and Gaviota Creek precludes precise definition of this unit

Figure 3-7. (A-B) Arroyo Paredon, Santa Barbara County. (C) Carpinteria Creek, Santa Barbara County. (D) Rincon Creek, Ventura County. Photos taken on March 1, 2018 post Thomas fire debris flow. Note that the Thomas fire affected multiple systems simultaneously. Additional modeling effort will be required to account for the apparent increased frequency of large fire events and other episodic regional impacts that simultaneously affect multiple systems. Such dynamics are not considered within the current model framework.

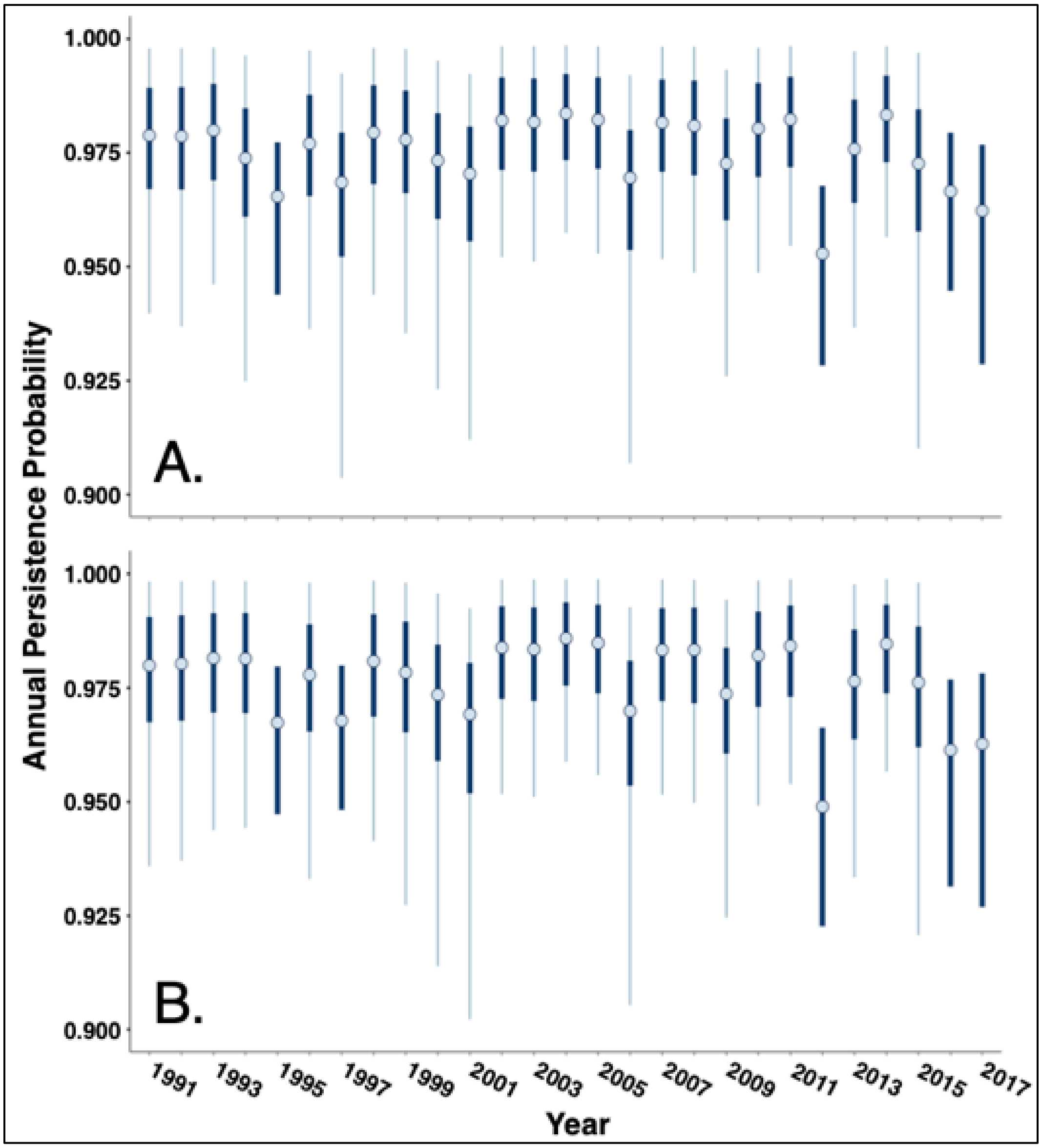

Figure 3-8. Persistence probability per population per year, modeled under (A) *MVA Model 1: Recovery Plan Sub-Unit Categories* and (B) *MVA Model 2: Amended Sub-Unit Categories* from 1990-2017. Persistence is the probability that an occupied site will remain occupied from year x to year x+1. Notice the little to no difference between MVA Model 1 and 2 results. The average annual persistence for all 101 sites from 1990-2017 was approximately 95-98%, which shows an annual extirpation rate between 2-5%.

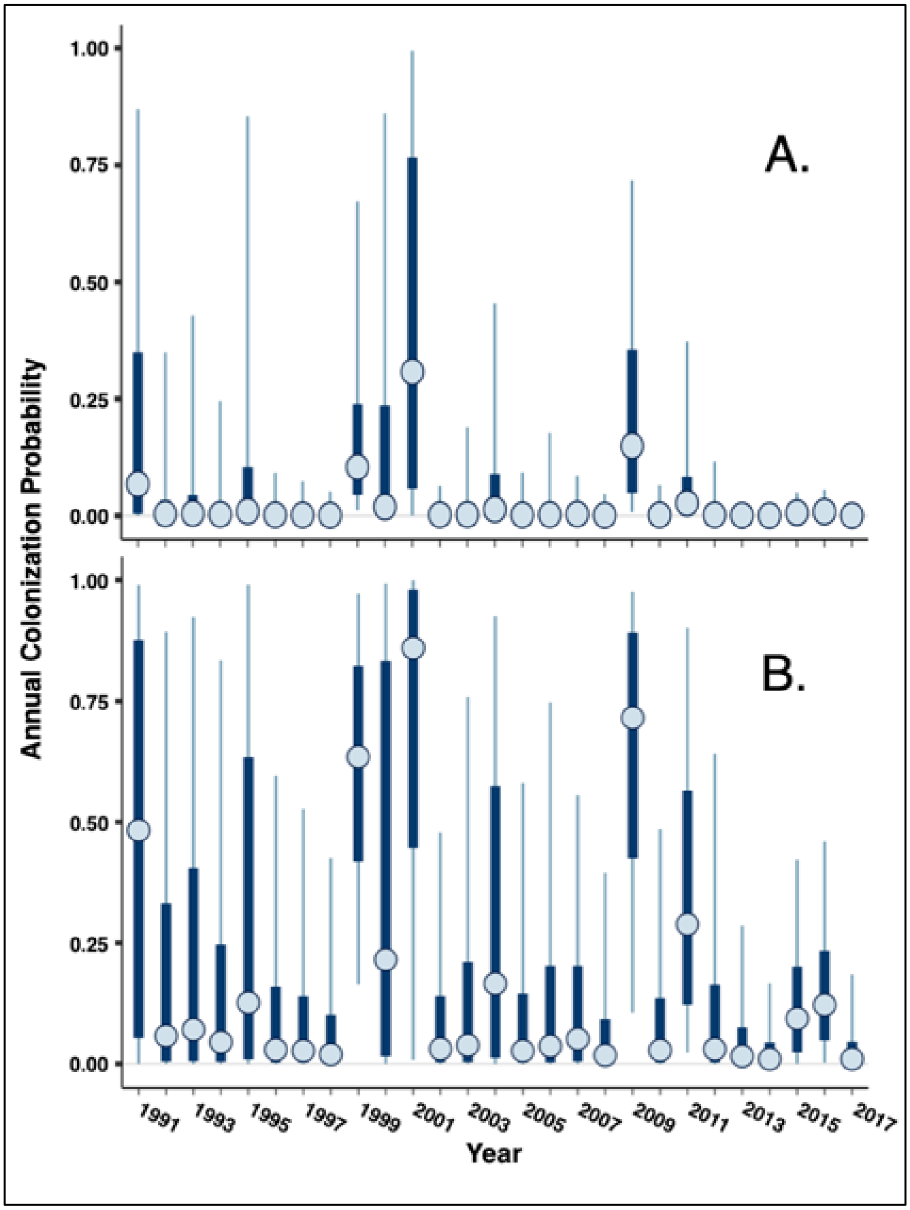

Figure 3-9. Annual colonization probability for (A) Malibu Lagoon and (B) San Onofre Creek (B) from 1990-2017. Colonization is the probability that an unoccupied site in year x becomes occupied in year x+1. Notice the significant difference in the average annual colonization rates and associated standard errors. The high amount of standard error that occurs in both sites, in addition to the overestimation of annual colonization in San Onofre Creek, further supports the integration of breaching dynamics based on precipitation into the model for more realistic dispersal and connectivity estimates, as well as continued coastwide occupancy surveys with consistent sampling protocols.

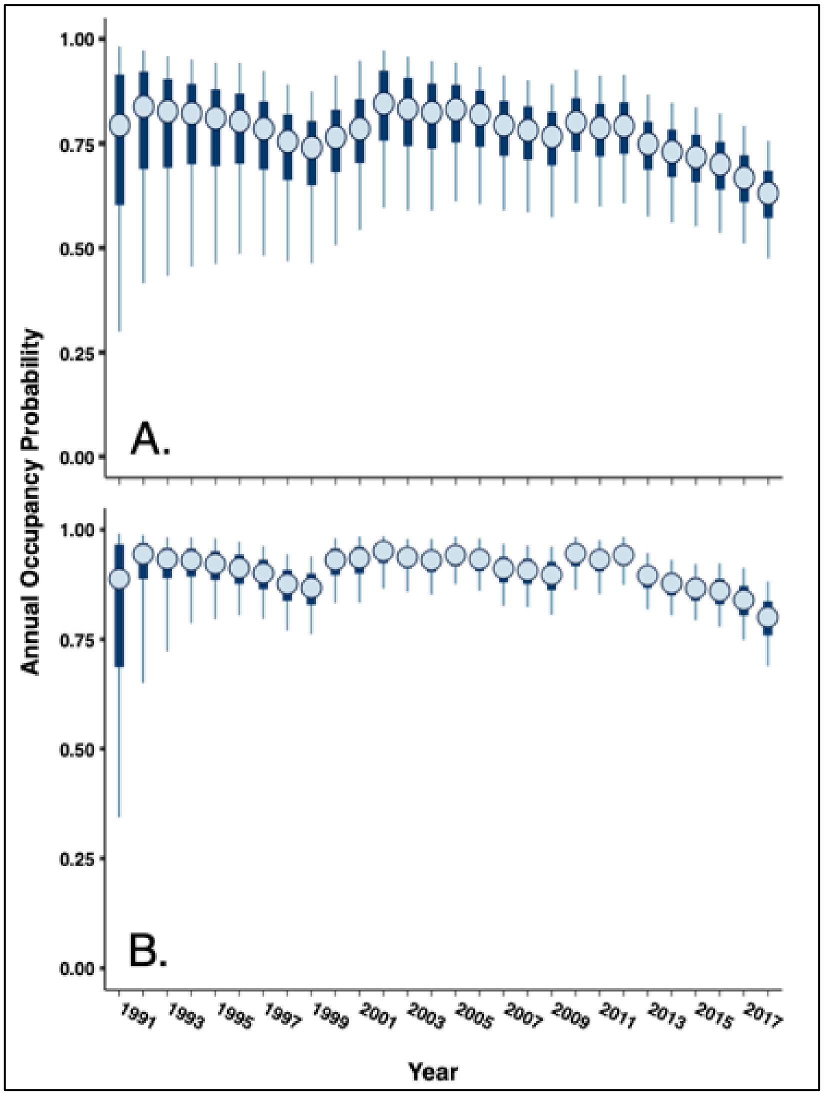

Figure 3-10. Annual occupancy probability for (A) Malibu Lagoon and (B) San Onofre Creek from 1990-2017. Occupancy is based on the fraction of sites occupied within a sub-unit in a given year. Notice the slow continuous decline in occupancy from 1991 to 2017 due to annual extirpation rates being higher than annual colonization rates for all sub-units most years. Furthermore, the lower standard error in annual occupancy for San Onofre Creek is likely due to the amount of consistent survey reports from all sites within the South Coast Recovery Unit since the annual occupancy probability for each site is dependent on the occupancy status of all sites within a sub-unit in a given year. Out of the nine sites in the South Coast Recovery Unit modeled in this study, eight have at least 20 years of occupancy data since 1990, where only two out of eight sites within the L.A./Ventura Recovery Unit meet the same criteria.

References

Ahnelt H, Go¨schl J, Dawson MN, Jacobs DK (2004) Geographical variation in the cephalic lateral line canals of *Eucyclogobius newberryi* (Teleostei: Gobiidae) and its comparison with molecular phylogeography. Folia Zoologica 53:385–398

Barlow, M (2002) Phylogeographic structure of the tidewater goby, *Eucyclogobius newberryi* (Teleostei: Gobiidae), in the San Francisco Bay area and Ventura County: Implications for Conservation Management. A thesis submitted in partial satisfaction of the requirements for the degree Master of Arts in Biology, University of California at Los Angeles.

Behrens, DK, Brennan M, Battalio B (2015) A Quantified Conceptual Model of Inlet Morphology and Associated Lagoon Hydrology. *Shore & Beach* 83(3):33–42

Berg N and Hall A (2015) Increased interannual precipitation extremes over California under climate change. Journal of Climate 28(16) pp.6324-6334.

Buckner JC, Sim JJ, Jacobs DK (2016) Hydrologic mediation of dispersal in tidewater gobies in the Midcoast. 41st Annual Meeting, CalNeva Chapter/Western Division, American Fisheries Society, at Reno, Nevada, USA

Cooper SD, Lake PS, Sabater S, Melack JM, Sabo JL (2013) The effects of land use changes on streams and rivers in Mediterranean climates. Hydrobiologia 719:383−425

Cousins M, Stacey MT, Drake JL (2010) Effects of seasonal stratification on turbulent mixing in a hypereutrophic coastal lagoon. Limnology and Oceanography 55:172–186

Dawson MN, Stanton JL, Jacobs DK (2001) Phylogeography of the tidewater goby, *Eucyclogobius newberryi* (Teleostei, Gobiidae), in coastal California. Evolution 55(6):11671179.11

Dawson MN, Louie KD, Barlow M, Jacobs DK, Swift CC (2002) Comparative phylogeography of sympatric sister species, *Clevelandia ios* and *Eucyclogobius newberryi* (Teleostei, Gobiidae), across the California Transition Zone. Molecular Ecology 11:1065−1075

Day JW, Christian RR, Boesch DM, Yáñez-Arancibia A, Morris J, Twilley RR, Naylor L, Schaffner L, Stevenson C (2008) Consequences of climate change on the ecogeomorphology of coastal wetlands. Estuaries Coasts 31:477–491

Dressler TL, Lafferty KD, Jerde CL, Dudley T (2020) Looking Where It’s Hard to See: A Case Study Documenting Rare *Eucyclogobius newberryi* Presence in a California Lagoon. Journal of Fish Biology 97 (2): 572–76

Earl DA, Louie KD, Bardeleben C, Swift CC, Jacobs DK (2010) Rangewide microsatellite phylogeography of the endangered tidewater goby, *Eucyclogobius newberryi* (Teleostei: Gobiidae), a genetically subdivided coastal fish with limited marine dispersal. Conservation Genetics 11:103–114

Ellingson RA, Swift CC, Findley LT, Jacobs DK (2014) Convergent evolution of ecomorphological adaptations in geographically isolated Bay gobies (Teleostei: Gobionellidae) of the temperate North Pacific. Molecular Phylogenetics and Evolution 70:464–477

Appendix

S1 Text: Tidewater Goby MVA Survey Protocol

(***) Indicates annual survey data critical for MVA model development

Basic Information

1) collector(s) name ***
2) date and time of collection ***
3) site name and city/county ***
4) GPS coordinates ***
5) weather conditions (outside air temp, sunny, cloudy, partly cloudy, etc.)
6) tidal height

Tidewater Goby Fish Surveys

1) Collection methods - seine net
    a. height, length, and mesh size of seine net (≤ 1/8" mesh preferred)***
    b. average depth of survey localities
    c. Small sites – minimum 5 seine pulls (10 if possible) ***
    d. Medium sites – minimum 10 seine pulls ***
    e. Large sites – minimum 20 seine pulls ***

**Note: seine nets are the preferred collection method when conducting tidewater goby surveys in all sites coastwide. This is important in order to standardize annual survey efforts from multiple collectors, calculate site specific detection probability for the MVA model, and to better estimate seasonal and temporal populations trends.*

2) Tidewater goby parameters

   a. Present or absent (each seine pull) ***

   b. Approximate number of gobies collected (each seine pull) ***

   c. Age/size classes (e.g. larvae, juveniles, adults) ***

   d. Gravid females present? ***

   e. Parasites, infection, disease (e.g. white microsporidia tissue infection)

3) Native & non-native fish species

   a. Present or absent (each seine pull) ***

   b. Approximate number of each species collected (each seine pull) ***

4) Additional collection methods to note

   a. Fish traps, dip net, one-man pushnet, etc.

Water Quality Parameters

1) Salinity – most important parameter ***

2) Temperature, dissolved oxygen (DO), pH, ORP, conductivity

Habitat Characteristics

1) Biological

   a. Algae or emergent vegetation present (*Ruppia* grass important to document)? ***

   b. Percent algal/vegetation cover ***

   c. Invertebrates present ***

   d. Reptiles/amphibians present ***

   e. Birds present

   f. Mammals present

2) Physical
    a. lagoon mouth open or closed? ***
    b. sediment type/grain size (e.g. fine sand, small cobble, anaerobic mud, etc.) ***
    c. mouth closure score 1-6 (see Jacobs et al. 2010)
    d. berm height
    e. evidence of recent wave wash-over/marine influence?

Photo Documentation

1) tidewater goby (when present) ***
2) tidewater gobies with signs of infection or disease (e.g. microsporidia, parasites) ***
3) all native fish species (especially other goby spp.) ***
4) all non-native species (fish, invertebrates, amphibians, etc.) ***
5) lagoon mouth clearly showing closed/open status with reference object for scale (stationary object or something of known height) ***

Example Photos