UNIVERSITY OF CALIFORNIA SAN DIEGO

An overview of prehistoric fisheries studies in Taiwan

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by

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Abstract of the Thesis

An overview of prehistoric fisheries studies in Taiwan

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This MA thesis examines the existing body of knowledge of archaeology pertaining to ancient fisheries in Taiwan. Fish has been a main staple for coastal communities of Taiwan since the initial peopling of Taiwan during the Paleolithic period (30,000 BP) and remains an important economic resource in Taiwan today. In spite of the importance of fish as an economic resource, archaeologists have devoted little attention to prehistoric fisheries due to the lack of data. Moreover, prehistoric fisheries in Taiwan have undergone significant changes in the past due to the rapid and drastic environmental changes since the Last Glacial Maximum (LGM) ~23,000 BP and the location of Taiwan on the tectonically active boundary between the Eurasian Plate and the Philippine Sea Plate. To overcome this gap in knowledge, this thesis aims to comprehensively review the current advancements in the field of ichthyoarchaeology globally, and the (1) the geological history; (2) modern fisheries data; and (3) archaeological records of fish resource exploitation in the region. This review of the history of environmental, ecological, and cultural changes contributes to a comprehensive understanding of ancient fisheries in Taiwan. This information further sheds light on the range of pre-industrial ecological baselines of Taiwanese fisheries, and informs current and future conservation efforts, yielding vital insights into human adaptation amidst climate and environmental changes.

Abstract of the Thesis (Chinese)

概述台灣史前漁業的考古研究

by

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Master of Arts in Anthropology

University of California San Diego, 2024

Professor Guillermo Algaze, Chair

這篇論文探討現有對台灣史前漁業的研究。自距今約 3 萬年前的舊石器時代以來，魚類便是台灣沿海社群的主要食物來源。儘管如此，關於台灣史前漁業的研究相對甚少。此外，由於自末次冰期（約 23,000 年前）以來的快速且劇烈的海水面和環境變化，台灣的史前漁業也經歷了重大的改變。為彌補這一知識差距，本論文綜合回顧目前魚類考古學的發展及台灣史前漁業相關的（1）地質環境歷史；（2）現代漁業數據；以及（3）考古記錄。這一對環境、生態和文化變遷歷史的綜合性回顧有助於深入了解台灣的史前漁業及魚類生態環境。同時，它為我們應對當前氣候變遷和全球海水面上升所需的生態保育和漁業管理提供了寶貴的資料。

1. Introduction

Fish have been a main staple for coastal communities of Taiwan since the Upper Paleolithic period (30 ka Before Present, BP). Prehistoric fisheries in this region have undergone significant changes due to the rapid and drastic environmental changes since the Last Glacial Maximum (LGM) ~23 ka BP (Li *et al.*, 2014). These changes are observed in coastal sites globally and are seen as crucial factors in shaping subsistence strategies and maritime cultures worldwide (Bailey and Flemming, 2008; d'Alpoim Guedes *et al.*, 2016). Other factors that shaped prehistoric fisheries include different levels of social complexity, cultural-specific fishing behaviors and consumption patterns, as well as the implications of human predation on marine fish ecologies. Among them, overfishing has gained increasing public attention due to its relevance to modern societies (Pauly *et al.*, 2002). However, the evidence of overfishing is not straightforward. Current research highlights a multifaceted relationship between humans and fish, influenced by socio-ecological processes such as ecological resilience, sustainable pre-industrial fisheries, and conversely, intensive prehistoric fisheries and ecological vulnerability that have led to pre-industrial overfishing (Reitz *et al.*, 2022; Reitz, 2001). The interworking of these processes will leave distinct patterns of socio-ecological traces in the form of artifactual, biological and zooarchaeological remains within the archaeological context. Under such circumstances, a clear understanding of the complex underlying mixture of human actors and environmental factors is crucial to understanding prehistoric fisheries. These dynamics have not been extensively explored in the Taiwanese rchaeological literature due to a variety of factors. First, the scarce data of fish remains retrieved and analyzed in archaeological contexts; second, the impact of active environmental changes on the visibility of fish remains and maritime adapted sites; third, challenges posed by submerged paleocoastlines along Taiwan's west coast (as discussed further below). (Chen *et al.*, 2004; Chen, 2018; Liao, 2006; Liao, 2020; Yang, 2017; Yang, 2016).

To overcome the knowledge gap caused by scarce data and complex environmental history, in what follows I review various aspects of prehistoric fisheries in Taiwan in this thesis. This thesis is separated into five sections. Section 1 is the introduction, Section 2 is a general review of the study of prehistoric fisheries in archaeology, in Section 3 I present the background information for the study of prehistoric fisheries in Taiwan, Section 4 is the review of existing archaeological literature on ancient fisheries in Taiwan, and Section 5 is the summary of this thesis. Finally, I will conclude by a review of future research directions outlining how the field could move forward to achieve a more complete and nuanced understanding of ancient fisheries in Taiwan.

2. Background to the study of prehistoric fisheries

In 2022, seafood accounted for at least 20% of the average animal protein intake for 3.3 billion people (40% of the global populations) (FAO, 2022). Currently at an average per capita of 20.4 kg, annual global fish consumption is projected to continue rising over the next decade, playing an increasingly important role in human diet (OECD and FAO, 2023). A fishery is defined as an activity leading to harvesting of fish (FAO, 2014) that encompasses the people involved, targeted fish, fishing ground, fishing techniques, fishing vessels, and the purpose of the activities. The study of ancient fisheries is a crucial research topic in the field of archaeology, as fish meat, eggs, and oil are important sources of nutrition for coastal, islandic and even inland populations during prehistoric times and some scholars even see it as the most stable and reliable food source (Reinman, 1967; Reitz *et al.*, 2008). Formerly considered as a subsistence strategy of marginal significance, fishing is increasingly seen as a crucial component of human maritime adaptations that shape human evolutionary trajectories, migratory patterns, subsistence practices, and even the types of socio-cultural complex institutions that can emerge at particular locations (Erlandson, 2001; Sampson *et al.*, 2023).

The study of ancient fisheries is termed ichthyoarchaeology or archaeoichthyology. Though mollusks, crustaceans, and marine mammals are important species encompassed within the wide scope of fisheries, this thesis focuses on target species within the focus of ichthyoarchaeology. Ichthyoarchaeology studies ‘fish,’ as defined in ichthyology, that consists of three major groups: superclass Agnatha (jawless fishes), class Chondrichthyes (cartilaginous fishes), and superclass Osteichthyes (bony fishes) (Parenti and Weitzman, 2024). Ichthyoarchaeology integrates zooarchaeological, material, bioarcheological, ethnographic, historical, ecological, and modern fisheries data to understand long-term human-fish interactions based on interdisciplinary approaches. These data are crucial to understanding prehistoric fishing techniques, cultural preferences, trade and exchange, regional interactions, maritime cultures, fish ecology, environmental and cultural changes (Morales-Muñiz and Llorente-Rodriguez, 2020). Recently, the emerging field of marine historical ecology has expanded the scope of ichthyoarchaeology to address current environmental and ecological issues (see section 2.4.5). Additionally, studies of prehistoric fisheries are crucial to understand prehistoric maritime adapted populations as fishing behaviors are embedded in the broader marine social-ecological framework (Fuller *et al.*, 2017). When examined under this theoretical framework, fishing is not limited by its economic importance but exerts a profound influence on various dimensions of prehistoric human existence, including social structures, cultural ideologies, technological innovations, sedentary settlements, migratory movements, and trade and exchange. For this reason, the study of fisheries helps archaeologists to understand the 'complexity' of fisher-hunter-gatherers that vastly differs from the canonical agriculturalist complex societies (Moseley, 1975; Sampson *et al.*, 2023).

The significance of studying maritime resource use in archaeology stems from the antiquity of fish exploitation in human history. Archaeological evidence shows that fish was exploited by early hominins ca. 1.95 million years ago (ma) in East Turkana, Africa (Braun *et al.*, 2010; Stewart, 1994) during the Early Pleistocene (2.6-0.781 ma), and by both early hominins and anatomically modern humans (AMH) during the Middle Pleistocene (781-126 ka) and Late Pleistocene (126-11.7 ka) (Steele, 2010). Early evidence of routine exploitation of marine fishes by AMH is found at the Blombos Cave in South Africa by 100,000-72,000 BP (van Niekerk, 2011), in East Timor, Southeast Asia by 42,000 BP (O'Connor *et al.*, 2011), and in the Pacific Islands by 40,000 BP (Lambrides and Weisler, 2016). The relatively scarce evidence of early fishing is in stark contrast to the more abundant and extensively studied early evidence of hunting. Scholars have mixed views on this issue, as some argue that early fishing prior to the Holocene sea level rise (~15 ka) might have been opportunistic, serving as an alternative resource during periods of scarcity (Stewart, 1994; Fagan, 2017, p.18; Steele, 2010, p.10771). Others note further that much of the evidence regarding marine adaptation and coastal settlements predating the Holocene is currently submerged due to eustatic sea level rise following the end of the Last Glacial Maximum (LGM) around 20 ka (Erlandson, 2001; Bailey and Flemming, 2008; Braje, 2018; d'Alpoim Guedes *et al.*, 2016, p.263), a similar threat of archaeological site degradation currently faced in low-lying coastal areas due to global sea level rise (Anderson *et al.*, 2017). However, some scholars also emphasize the absence of maritime or fishing-related artifacts in early inland sites and coastal sites that are unaffected by sea level rise (Potter *et al.*, 2017). Nonetheless, it is likely that by 15 ka, fishing had already become a crucial source of food for coastal or riverine communities and that it later became important to agricultural populations as well. It remains a crucial aspect of economic and social lives today.

2.1 Data recovery methods

Fish elements that are commonly found in archaeological assemblages include fish bones, otoliths (fish ear bones), scales, fin spines, and teeth. Each of these elements exhibits distinct sizes and frequencies per fish species and undergoes unique taphonomic processes influenced by different environmental conditions. To enhance the accuracy of the analysis of fish remains, researchers emphasize the importance of comprehending site- and element-specific taphonomic processes and employing appropriate recovery methods to achieve a higher accuracy of fish remain analysis (Lambrides and Weisler, 2016). Though some argued that smaller sieve sizes (3 mm and 1 mm) do not help to increase recovery rates (Vale and Gargett, 2002), there is an increasing evidence showing that smaller sieve sizes matter in controlling species richness (Zohar and Belmaker, 2005). Currently, most ichtyoarchaeologists have reached a consensus of practicing sieving of 3-1 mm fractions, with screen sizes smaller than 1.6 mm being the most ideal for fish remains recovery as larger (>1.6 mm) screen sizes often result in the loss species abundance and diversity (Lambrides and Weisler, 2016, p.281; Jones *et al.*, 2016, p.85; Salls, 1988, p.242). In other cases, a larger size fraction will result in high precision in sites with fisheries targeting larger fishes, but this can only be determined after a thorough analysis of both smaller and larger size fractions is employed to determine that the presence of smaller species is not missing (Sanchez, 2019, p.20). The definition of fine-grained analysis is further challenged compared to high resolution marine biological studies, where marine sediments are generally wet-sieved at a screen size of 250 µm for fish remains to reconstruct past fish assemblages (Tunnicliffe *et al.*, 2001; O'Connell and Tunnicliffe, 2001), and at 100 µm for retrieving samples for aDNA ecological studies (Muschick *et al.*, 2023); and land bulk sediments are wet-sieved at 2 mm, 500, 250, 104 and 63 µm fractions in paleontology studies (Lin *et al.*, 2019; Cramer *et al.*, 2017).

Upon retrieval, fish remains are typically identified based on morphological comparisons with reference collections, often requiring identification at taxonomic levels lower than the family level (Lambrides and Weisler, 2016). Once identified, fish species counts can be used to estimate abundance and diversity fluctuations across time and space. They can also be employed to infer harvested size or age, biogeography, and fishing techniques (Barrett, 2019). In addition, differential use of fish remains quantification and diversity estimate such as NISP and MNI are employed based on sample size and research questions. Generally, a small sample size (<500) makes the use of NISP preferable and vice versa (Morales-Muñiz and Llorente-Rodriguez, 2020, p.5489). Alternatively, a more refined quantification method based on minimum number of elements (MNE) and minimal animal unit (MAU) was employed to account for element-specific preservation conditions and cross-assemblage comparisons. For an exhaustive examination of the advantages and disadvantages associated with various quantification methods pertinent to ichthyoarchaeology, refer to van Niekerk's (2011) doctoral dissertation (Chapter 5).

Moving beyond identification and quantification, icthyoarchaeological assemblages can be further analyzed using growth-size and age analysis, stable isotope analysis, aDNA and trace element analysis (Disspain, Ulm and Gillanders, 2016; Barrett, 2019; Lambrides and Weisler, 2016; Orton, 2016).

Growth-size and age analysis captures the chronological variations in fish size, demographics, and biological behaviors. Stable isotope analysis, in turn, is useful to understand changes of fish trophic levels (δ15N) (Disspain, Ulm and Gillanders, 2016), water chemistry (δ18O) (Andrus *et al.*, 2002; Reitz, 2001; Colaninno, 2012), diet and geographic affinity (δ13 C) (Ainis *et al.*, 2021). Stable isotope and morphometric analyses provide information help to answer specialized research questions on marine ecological structures, paleoenvironmental reconstruction, and fishing behaviors independent of other sources of data, (Ainis *et al.*, 2021, p.114). ADNA analysis helps to understand changes of genetic diversity and population dynamics of important economic and cultural species such as the Pacific herring (*Clupea pallasii*) and the Eastern Pacific Gray Whale (Eschrichtius robustus) prior to human overfishing (Moss *et al.*, 2016; Alter *et al.*, 2012). These methods are essential in fisheries studies, providing nuanced insights into past fish assemblages that complement species identification and quantification data. Additionally, they offer bio-ecological information relevant across various disciplines and hold significant potential for utilizing 'orphaned' fish remains in collections.

In tandem, these aforementioned lines of data are crucial to identifying changes in fish populations in response to natural and anthropogenic impacts. Most notably, fish abundance, size, and mean trophic levels reduction due to anthropogenic fishing, sometimes termed as the 'shifted baseline' (Izzo *et al.*, 2016; Pinnegar and Engelhard, 2008), can be identified by comparing archaeological and modern fisheries data (Lin *et al.*, 2022; Wing and Wing, 2001), a major research theme in ichthyoarchaeology that will be further discussed below. Other anthropogenic impacts such as environmental modifications can also be identified. For instance, the extensive damming of the Colorado River has led to significant shifts in the biology and demographics of fish populations compared to prehistoric fish records in Baja California based on similar approaches (Ainis *et al.*, 2021).

Other than discarded subsistence refuse, fish remains are sometimes found in archaeological sites as bone or teeth tools and ornaments. An example is the points made of stingray spines and sawfish rostrums (*Anoxypristis cuspidata*) from the Nanguanli East site in Taiwan (4200-4700 BP) (Tsang *et al.*, 2006). Recently, micro-usewear analysis have shown that perforated shark teeth, commonly identified as ornamental objects by archaeologists, are used as cutting tools in Indonesia (7000-5000 BP) (Langley *et al.*, 2023), and as wood and leatherworking tools in Brazil (500-700 BP) (Gilson *et al.*, 2023). In addition, the use of fish remains as personal ornaments is seen in the Mesolithic Upper and Lower Danube regions (~7835 BP), where the teeth of freshwater carp (Rutilus meidingeri) are used with other mammal teeth and freshwater shells as ornamental burial objects. Other examples include a perforated otolith necklace found in a Chumash site in California (3900-2900 BP) (Huddleston and Barker, 1978), and perforated shark teeth necklace in in Neolithic Taiwan (4200-4700 BP) (Tsang and Li, 2018). Tools and ornaments made of fish remains shed light on the wider functional and symbolic role of fish within past populations. Objects such as fishhooks, beads, and ornaments made of other marine faunal are such as marine and freshwater shells, marine mammal bones are commonly found in association with ichthyoarchaeological assemblages (Lauriers *et al.*, 2017; Heizer, 1949). They serve a similar role in helping us to understand the importance of fishing in the wider social network (Fuller *et al.*, 2017).

2.2 Complementary data

In addition to fish remains, complementary data such as bioarcheological evidence, fishing tools, fishing vessels, ethnographic and historic records are crucial to understanding the evolution of ancient fisheries. Bioarcheological evidence such as human diet composition that is studied based on stable isotope analysis provides indirect evidence of fishing subsistence that is independent of marine zooarchaeological and artifactual assemblage. For example, carbon and nitrogen stable isotope analysis of human and faunal bone collagen of the Middle to Final Jomon period (~5,000-2,300 BP) show clear signs of two coastal populations that had distinct marine diets that primarily constitute high trophic level marine fishes and marine shellfish respectively (Kusaka *et al.*, 2010). Other bioarchaeological evidence includes pathological evidence for maritime oriented subsistence activities. One prominent example is the external auditory exostoses (EAEs) or the surfer’s ear, a skeletal anomaly of human ears that is caused by long exposure to cold water during aquatic activity such as diving. For example, EAE is widely recognized among populations in certain latitudes occupying mid-latitudes (30-45°N and S) and wet low-latitudes coastal areas (Trinkaus and Wu, 2017, pp.14–15; Katayama, 1998), such as at the underwater site of Atlit Yam, Israel (~8000 BP) (Hershkovitz and Galili, 1990). A When combined, the co-occurrence of a marine fish-based diet inferred from human bones and a high occurrence of EAE provide an robust alternative to understand the prehistoric marine diet and fishing methods of populations of the Nonome shellmound of the Final Jomon Japan (~3000 BP) (Saeki *et al.*, 2016). A case of EAE is observed in Liangdao, Taiwan (8320-7434 BP) (Institute of Anthropology, National Tsing Hua University, 2015, pp.29–30), which will be further discussed in the next section.

Fishing tools, including fishhooks, gorges, nets, weights, harpoons, barbed points (hooks or spears), needles and shuttles for net weaving, and fishing vessels are the most common categories of material evidence for ancient fisheries found in the archaeological context. While fishing tools are frequently abundant and well-preserved in archaeological sites, reconstructing past fishing behaviors based on material evidence poses considerable challenges (Morales-Muñiz, 2010; Salls, 1989; Bernal Casasola, 2010). This difficulty arises from the wide variability in fishing techniques and fish biology, as well as the substantial overlap among different fishing tools and methods (Thomas, 2010, p.153). Several common patterns of fishing techniques can be synthesized by integrating ethnographic, modern fisheries and archaeological data, offering valuable insights into prehistoric fishing practices inferred from tool usage in archaeological contexts (Morales-Muñiz, 2010; Bernal Casasola, 2010). Methods such as hand catch and ichthyotoxin (compounds that are toxic to fish), though rarely preserved in archaeological assemblages, represented common prehistoric fishing practices. Additionally, fishhooks, being highly versatile, could capture fish across various depths and locations, contingent upon the jaw anatomy of the targeted species (Morales-Muñiz, 2010, p.12). In addition, fish gorges serve similar functions but are swallowed whole by the fish, requiring the fishermen to cut open the fish to retrieve the tool, whereas fishhooks are easily retrievable and reusable (Salls, 1989, p.194). Spearfishing utilizing harpoons, points, and leisters emerged as particularly effective for targeting larger species among various fishing techniques. Moreover, traps and weirs, despite being passive fishing methods, proved highly cost-effective and productive in procuring medium to large-sized fishes from specific environments. Nets, known for their efficiency, often targeted gregarious fish in significant numbers, with set nets displaying lower selectivity but yielding a variety of fish in different sizes, whereas gill nets exhibited a higher selectivity towards a narrower size range. The presence of various forms of net sinkers, and numerous littorals and mid to small-sized taxa often indicates the utilization of net fishing techniques (Morales-Muñiz, 2010, p.42). Other common fishing methods utilize different tools, such as torch fishing, coral fishing, trident fishing, among others. For a specialized analysis focusing on the functional morphologies of fishing tools, refer to Bernal Casasola's review on fishing tools in Spain during the Roman and medieval period (2010).

Fishing vessels, mostly made of organic materials in prehistoric contexts, are less visible within the archaeological context but are of crucial importance to ancient fishing populations. Fishing and seafaring vessels hold great significance for maritime subsistence, transportation, trade and exchange activities, which are seen as the key to understanding social complexities in maritime societies (Gamble, 2002). The study of submerged shipwrecks offers rare opportunities to directly study past marine vessels and their relevance to fishing activities. For example, fishing vessels equipped with fishing gears and fish wells to harvest and transport fresh fish are found in Classical Rome (100~200 AD) (Boetto, 2010). Complementary evidence for fishing vessels includes the presence of deep pelagic fishes, deep sea fishing tools such as harpoons, island colonization, boat models and ceramic paintings of watercrafts (Carter, 2012), and ethnohistorical records. Some of the known examples of archaeological and pre-contact fishing vessels include the sailed reed boats in the Mesopotamia (~7000 BP) (Carter, 2012), single dugout canoes in China ~8000 BP (Huisheng *et al.*, 2016; Wu, 2021), Korea ~6800 BP (Kim and Seong, 2022), and Japan (~6900-5200 BP) (Habu, 2010), single and double outrigger in the Pacific Islands (~3500 BP) (Amesbury and Hunter-Anderson, 2008), as well as the Chumash plank canoe (*tomol*) in California by ~500 AD (Arnold and Bernard, 2005). These vessels are crucial in open-sea or offshore fishing, supplemented by the evidence of offshore fishes or mammals such as swordfish (*Xiphias gladius*) (Flores Fernandez and Olguín, 2023), tuna and mackerel (Scombridae) (Mylona, 2021; Andrews *et al.*, 2022) , dolphinfish (*Coryphaena hippurus*) (Amesbury, 2013), fur seals (*Callorhinus ursinus*) (Takase, 2019), and whales (Hennius *et al.*, 2023). Overcoming the limitation of archaeological data visibility, simulation models, experimental archaeology and ethnohistorical data provide valuable information to infer prehistoric fishing and seafaring activities using rafts, boats, and canoes made of various organic materials (Kaifu *et al.*, 2019; Kaifu *et al.*, 2022; Fauvelle and Montenegro, 2024).

As demonstrated by various case studies mentioned above, ethnohistorical and modern fisheries records can provide crucial evidence for studying prehistoric fisheries as they offer modern examples that allow us to infer past marine subsistence activities. However, these data should be used with caution in archaeological studies as it does not fully account for cultural and technological changes that occur over time. In addition, ethnohistorical data may sometimes contradict actual fishing behaviors in the more distant past. One common example is the overemphasis of ethnographic records on certain culturally esteemed species and the underrepresentation of economically significant species, as seen by the exaggerated importance of salmonids in California (Gobalet *et al.*, 2004, pp.825–826) and rainbow runner (*Elegatus bipinnulatus*) in Micronesia (Leach and Davidson, 1988, p.15) in ethnographic records when compared to archaeological fish assemblages. Discrepancies between prehistoric and contemporary fisheries are also evident; for instance, the Pacific tomcod, a presently abundant commercial species, is exceptionally rare in archaeological records, possibly indicating variations in prehistoric abundance or distribution, or the influence of cultural taboos, necessitating further analysis (Gobalet *et al.*, 2004, p.826). Additionally, ethnohistorical data might prove insufficient for studying archaeological findings lacking modern parallels. For instance, stone-bowl-like artifacts are frequently discovered along the submerged coasts and offshore areas of San Diego, suggesting a potential role in maritime activities. However, these tools are entirely absent from historical and modern ethnographic records, posing significant challenges for accurate interpretation (Hildebrand and York, 2022).

Despite their limitations, these sources of data complement ichthyoarchaeological data to help us study the multifaceted aspects of past fisheries and their impact on human societies. They are especially crucial to areas with sparse archaeological data, such as Taiwan (further discussed below). Hence, it is only by maximizing the often complementary, sometimes supplementary bodies of archaeological and ethnographic data can we arrive at a better-rounded interpretation of ancient fisheries and their impact on human societies.

2.3 Data Limitations

The limitations of ichthyoarchaeology include retrieval biases, sample size, taphonomic processes, identification challenges, the lack of reference collections, and costs (Zohar and Belmaker, 2005; Morales-Muñiz and Llorente-Rodriguez, 2020; Colley, 1987; Colley, 1990). Sample size and representation is a major issue in ichthyoarchaeology, as faced by other archaeological studies. For instance, archaeological fish assemblage from a mass processing site of the Atlantic bluefin tuna in Spain that is dated to around 200 BC represent only a fraction of the actual assemblage due to processing and refuse behaviors, where most remains of fish were dumped or burnt on beaches (Andrews *et al.*, 2022, p.255). The incomplete nature of archaeological remains, strictly limited by prehistoric disposal patterns, taphonomic processes, and retrieval methods, requires critical assessment and interpretation if we are to reconstruct past fisheries (Andrews *et al.*, 2022, p.248). Among them, fine screening is the biggest issue faced in archaeology. As mentioned above, the ideal screen size for the retrieval of archaeological fish remains is <1.6 mm, where larger screen sizes are poorly representative of the actual assemblage. For example, by employing fine-grained screening (1-2 mm) for the first time at the well-studied coastal sites of Santa Cruz, California, Sanchez (2019, pp.81–83) was the first to identify net-based mass-harvesting of the Northern anchovy in the region and yielded fish remains 32 times (in NISP/liter) higher than previous excavations at the same site[1]. The common practice of 3 mm and 6 mm screen size in California that resulted in the loss of fish remains recovery is not uncommon, as fine-fraction screening is rarely practiced in most archaeological excavations due to costs and time constraints, especially in regions where salvage excavations dominate most archaeological excavations like Taiwan (Zorzin *et al.*, 2022). For example, a 3-mm screen size is generally practiced in the Caribbean (Wing and Wing, 2001) and the Pacific Islands (Lambrides and Weisler, 2016; Ono and Intoh, 2011) even for fisheries studies, resulting in the loss of data and an incomplete data that is not comparable with marine biology and paleontological data that are collected in finer mesh sizes (see above).

Moreover, species identification, especially to taxonomic levels lower than the family level, can be difficult due to the high diversity and low counts of species in certain archaeological assemblages. For example, Leach and Davidson (1988) have argued that a family-level identification is sufficient for a robust analysis on Micronesian ichthyoarchaeological assemblage that are have low counts and high species abundance. Fortunately, recent advancements of supplementary identification methods such as aDNA, Zooarchaeology by mass spectrometry (ZooMS) using peptide mass fingerprinting (PMF) or collagen fingerprinting help to overcome identification challenges, but they require specialized equipment and expertise. These techniques perform molecular analyses on fish samples, hence achieving high precision identification independent of factors such as sample size, morphology, fragmentation and the uneven frequencies and preservation of different body parts (Lambrides and Weisler, 2016, p.288; Orton, 2016). Most notably, aDNA analysis has been instrumental in identifying the Pacific salmon with high species abundance within the same genus in British Colombia that were previously challenging to differentiate based on skeletal morphology (Cannon, Yang, and Speller 2011, as cited in Orton 2016). In another example, mitochondrial DNA analysis was used to construct past effective population size of grey

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[1] At the site CA-SCR-15, the fish bone density was 0.04 NISP/liter in previous excavations with a >3.2 mm dry-screened recovery, where the new >2 mm wet sieved recovery resulted in 1.3 NISP/liter (Sanchez, 2019, p.81).

whales and cod, showing historic and modern population crashes due to overexploitation (Alter, Newsome, and Palumbi 2012; Ólafsdóttir et al. 2014, as cited in Orton 2016). More recently, the first application of ZooMS collagen fingerprinting methods in the Caribbean—a region where fish archaeology often has low taxonomic resolution due to high species diversity—increased the precision of taxa identification by 45% compared to previous studies (Harvey *et al.*, 2022). Despite the limitations posed by high costs and the size of existing fish molecular databases, these innovative techniques have been producing promising results and have great potential in future studies of fisheries (Lambrides and Weisler, 2016; Harvey *et al.*, 2022).

In addition, biased research interests have affected data representation in fisheries archaeology. For instance, limited attention given to the transition towards the High Middle Ages in the Mediterranean region has resulted in a dearth of information during this era (800-1000 AD), leading to a misinterpretation of diminished fish utilization (Andrews *et al.*, 2022, p.252), thus illustrating the realization that, in archaeology, "absence of evidence is not evidence of absence" (Andrews *et al.*, 2022, p.255). Another instance in the Mediterranean pertains to the disproportionate emphasis on amphorae, with research primarily focused on these cargo vessels in maritime archaeology, consequently resulting in a significant underrepresentation of data regarding fishing vessels during the Classical Period (Maarleveld, 2010). Additionally, the proper identification of fish remains requires long-term experience and extensive reference collections, which might be challenging to acquire. Finally, species identification can be challenging due to high species abundance in certain places, hence requiring an adjustment towards lower identification levels (Wing and Wing, 2001).

2.4 Common research themes in ichthyoarchaeology

There are a variety of comprehensive reviews of the field of ichthyoarchaeology. Some of these reviews focused on specific regions (Lambrides and Weisler, 2016; Barrett, 2019; Wing and Wing, 2001) while others highlight general themes and debates (Morales-Muñiz and Llorente-Rodriguez, 2020). These body of work underscores that ichthyoarchaeology encompasses a wide-ranging research themes, methodologies, and geographical contexts. This section aims to offer a general overview of common themes in ichthyoarchaeology that are relevant to Taiwanese archaeology to set the stage for the subsequent chapter's discussion on prehistoric Taiwanese fisheries. Four broad themes are explored: diet and subsistence reconstruction, ecological and environmental proxies, marine historical ecology, and socio-cultural complexity.

2.4.1 Diet and subsistence reconstruction

Archaeological fish data is crucial to understanding paleodiet and subsistence strategies. The integration of interdisciplinary data including modern fisheries data, ethnoarchaeology, ethnobiology, and material culture sheds light on crucial aspects of ancient fishing behaviors such as seasonality, fishing strategies, and target species. For instance, archaeological fish assemblage from the Middle Stone Age (MSA) Blombos Cave main site in South Africa (100-72 ka), provides valuable insights into one of the earliest examples of fish resource utilization worldwide. 453 NISP are identified into 17 species from 11 families, representing a diverse range and size of estuarine, nearshore, and offshore marine species, and are inferred to be captured by various methods such as scavenging, hook fishing, spearfishing, tidal traps, and net fishing (van Niekerk, 2011). In this case, high resolution identification and accurate quantification methods were essential to ensure accurate interpretation, a point emphasized in multiple sources of literature (see above). Other case studies of fishing subsistence reconstruction include the findings of the use of small-mesh size net fishing that is focused on medium to small forage fishes, Clupeids, such as the Pacific herring and sardines, at the middle Early Jomon (ca. 5700-5600 BP) Sannai Maruyama site (Komiya *et al.*, 2019) and at the pre-Contact to historical (2750 BP-1800 AD) sites from Point Reyes, California (Sanchez, 2019). This technique is proven highly efficient and sustainable for mass harvesting forage fish, as it avoids the capture of large-size spawning individuals that are mostly overfished in modern times (Sanchez, 2019, pp.26–32). On the other hand, stable isotope analysis of fish otoliths are commonly used to study fishing and occupational seasonality (Hufthammer *et al.*, 2010; Jew and Rick, 2014; Colaninno, 2012). Though less commonly used, fish teeth oxygen and strontium isotope ratios ($\delta^{18}O_{PO4}$ and $^{87}Sr/^{86}Sr$) can be used to study origins of fish provenance in Early Byzantine (450-650 AD) Turkey (Dufour *et al.*, 2007), and the presence of long-distance fish trade in Iron Age (2850-2750 BP) Southern Levant (Tütken *et al.*, 2020). When compared to other faunal and plant assemblages, changes in the ichthyoarchaeological assemblage highlight diachronic changes of the relative importance of fishing, hunting, and plant cultivation through time (Beresford-Jones *et al.*, 2018; Dalzell, 1998; Kappelman *et al.*, 2024).

2.4.2 Ecological and environmental proxies

By providing direct evidence to harvested fishes in the past, archaeological fisheries can act as important proxies for past environmental and ecological changes (Izzo *et al.*, 2016). Identified ichthyoarchaeological remains provide critical information on fish biogeography, biological behaviors, trophic levels, and water chemistry, which are crucial proxies to understanding past marine ecological structures, population dynamics, geographical distributions, migration and spawning behaviors, as well as past fishing environments, and sea surface temperature (Barrett, 2019; Izzo *et al.*, 2016; Disspain, Ulm, Izzo, *et al.*, 2016; Aguilera *et al.*, 2016). For example, changes of species composition in archaeological fish assemblages that reflect major changes in fish biogeography are indicators of coastal environmental and climatic change. Complementary data to past sea level and coastal environmental changes includes material remains or features related to ancient fishing that are good indicators of paleoshorelines such as fish tanks (Mourtzas, 2012) and fishing weirs (Tveskov and Erlandson, 2003; Fischer, 2007). Species information can be further converted into a canonical temperature proxy, the ‘Mean Temperature of the Catch’ (MTC) by referencing to modern fish biomass and preferred temperature. The application of MTC on archaeological fish assemblage results in a high resolution paleotemperature record comparable to historic and modern fisheries data. Hills et al. (2022) refer this as the ‘palaeothermometer’ of ancient fisheries, and provided a 5000-year long ancient MTC (aMTC) record that showed gradual broad ocean warming in the northeast Pacific based on archaeological fish remains in British Columbia, Canada.

Aside from species-derived information, utilizing stable isotope and geochemical data, age-growth data, and aDNA analysis obtained from fish remains serves as significant paleoenvironmental and paleoecological indicators. The incremental chemical signatures present in otoliths (inorganic) and fish bone collagens (organic) capture the isotopic footprints of past environment and ecology accumulated within fish over time. Different stable isotopes and geochemical datasets reflect unique bio- and geochemical signatures of various sources, hence shedding light on the highly diverse aspects of past environments. Some common stable isotope data used in ichthyoarchaeology include δ18O record obtained from otolith that act as an optimal proxy for changes of seasonality, paleo-sea surface temperature (SST) and hydrological processes (Andrus *et al.*, 2002; Sisma-Ventura *et al.*, 2015; Long *et al.*, 2021), as well as paleoclimate (Walker and Surge, 2006); fish bone δ13C, δ15N, and δ34S records, often used together, are good reflectors of past ecological structures, population dynamics, and fish biology or ontogeneticbehaviors (Disspain, Ulm, Izzo, *et al.*, 2016; Andrews *et al.*, 2023; Ainis *et al.*, 2021; Izzo *et al.*, 2016).The use of other geochemical data are less common but shed light on specialized topics on ancient fisheries. For example, otolith Sr/Ca and Ba/Ca elemental record is used to showed changes of fish life cycle and habitat in Southeastern Brazil (5820–4980 BP) (Lopes *et al.*, 2023).

2.4.3 Socio-cultural complexity

Ichthyoarchaeology contributes to our understanding of the socio-cultural complexities of past societies, especially through modes of subsistence, trade, and exchange. Increased evidence has shown that fishing can sustain high population densities and complex, (semi-)sedentary societies in areas with rich fisheries resources (Moseley, 1975). Once perceived as a marginal resource of food or adopted by ‘simple’ mobile hunter-gather-fisher societies in archaeology, prehistoric fishing is now considered as a source sufficient to support highly complex maritime fisher societies (Sampson *et al.*, 2023). In addition, fishing is a culturally mediated subsistence activity that is interconnected with the wider socio-cultural networks and subsistence activities such as hunting and farming (Aswani, 2020; Beresford-Jones *et al.*, 2018; Raymond, 1981).

Fisheries resources have played a key economic role in sustaining socio-cultural complexities by producing surplus food, which has led to population growth and long-distance maritime trade. For example, ancient fisheries are proven to be the main diet source to some highly complex societies such as the Ancient Aleuts and Chumash people in the Pacific coast of the North America, and the Lapita culture in the Pacific Islands (Fagan, 2017; Sampson *et al.*, 2023). High marine productivity and intensive exploitation in these regions have ensured the constant supply of food to feed large coastal populations and sustain complex socioeconomic structures that parallel agricultural societies. However, in stark contrast with sedentary farming activities, maritime societies are highly mobile and often engage in frequent maritime trade and migration, such as the highly mobile Pacific Islanders that are sometimes referred as 'sea nomads' (Bellina *et al.*, 2021). In other cases, marine fish serve a supplementary role in human diets but were crucial in long distance maritime trade and regional socioeconomic interactions. For example, dried fish is an essential source of food during long-distance maritime voyages and a crucial commodity to maritime and terrestrial trade. Prominent examples of dried fish trades include the intensive fishing and trading of gilthead seabream (*Sparus aurata*) in the Southern Levant since the Late Bronze Age (3550-3200 BP) (Guy *et al.*, 2018), and cod and herring during the High Middle Ages (AD1050 to 1350) in Europe (Barrett, 2016).

In addition, the manufacturing and maintenance of seaworthy watercrafts and specialized fishing tools that require intensive labor investment have resulted in increased social stratification to regulate, manage, and organize fishing resources and harvests (Arnold, 1995; Cassidy, 2021). This increase in labor management and resource distribution has, in turn, increased fishing efforts and fish catch, forming a positive feedback loop for higher maritime social complexity. As evident from these examples, prehistoric fisheries have played a significant role in the increasing complexity of socioeconomic structures via increased population density, maritime trade, and social stratification. Other factors that shaped the socioeconomic role of ancient fisheries to past societies include environmental changes (Toso *et al.*, 2021; Tushingham *et al.*, 2016; Lewis *et al.*, 2020), long distance migration, such as the vast exchange network in the Pacific Islands (Dalzell, 1998), aquaculture and fish preservation techniques that enhance food stability and facilitate fish trade (Fitzpatrick, 2020; Alessandri *et al.*, 2019; Hudson and Fernández, 2023), and the increased use of terrestrial resources through direct plant cultivation or exchange (Beresford-Jones *et al.*, 2018; Zangrando, 2009; Pezo-Lanfranco and Colonese, 2024). In addition to its role as a source of food, archaeological and ethnohistorical data have shown that fish and fishing hold significant socio-cultural significance to maritime societies. A prominent example is the cultural selection of toxic diodontids (porcupinefish) and tetraodontids (pufferfish) that are common among fishing populations across East Asia, Southeast Asia, and Pacific Oceania (Boulanger *et al.*, 2023; Li, 2002). During the Lapita period (3400-2400 BP), diodontids were frequently harvested and consumed across the Pacific Islands. However, there is a change in fish consumption patterns as diodontids were almost absent in most post-Lapita sites in Micronesia, where cultural taboos on diodontids are still observed among modern populations (Dalzell, 1998). Complementing the archaeological record are ethnoarchaeological records that shed light on the non-material sociocultural role of fishing activities in fisher societies. For example, ethnohistorical data have shown that major socio-cultural events are centered around major fishing seasons and daily fishing activities in fishing villages that require high labor investment and contain significant symbolic values (Linares Matás and Lim, 2024). The evidence presented underscores the significance of studying ancient fisheries beyond their economic and ecological functions, thereby contributing towards our comprehensive understanding of past human existence.

2.4.4 Human-fish interactions

Human-fish interactions represent the complex relationship between human fishing behaviors and fish populations mediated by wider socio-ecological processes. Currently, modern human-fish interactions are exemplified by the overwhelming pressure of anthropogenic activities on marine ecosystems including overfishing, pollution, habitat loss, biological invasion, disease, and the impact on fish of anthropogenically induced climate changes (He and Silliman, 2019; Halpern *et al.*, 2008; Steneck and Pauly, 2019; Pauly *et al.*, 2002; Cheung *et al.*, 2013). This dire state of marine ecosystem prompted marine biologists, ecologists, and modern fisheries experts to examine older historical, archaeological, and paleontological records in understanding past human-fish relationships in the search to solve current and future ecological crises (Dillon *et al.*, 2022; Dietl and Flessa, 2011; Dillon *et al.*, 2022; Lotze and McClenachan, 2020; Leonhard and Agiadi, 2023).

Among them, archaeological records are increasingly used by marine biologists to show the antiquity of the impacts of overfishing on past fish populations or the 'shifted baselines' (Jackson *et al.*, 2001; Pauly *et al.*, 2002; Steneck and Pauly, 2019). However, archaeological evidence of prehistoric overfishing, most notable in fish abundance and size reduction, is less equivocal than cited by fish scientists. In fact, the most known cases of prehistoric overfishing are evidenced by large marine mammals such as sea otters, sea cows and sea turtles, and marine invertebrate such as oysters, abalones, and sea urchins that fall outside the definition of 'fish' as mentioned earlier. The implications of prehistoric fishing on fish populations are multifaceted, with conflicting evidence showing both significant and minimal anthropogenic impacts across different time and space. A good example of this complication is the archaeological evidence of 'fishing up the food web' in the Channel Islands, California (10,000-1500 BP), and evidence of 'fishing down the food web' at the coast of Maine (4500-30 BP) and in the Caribbean (1800-30 BP) (Steneck and Pauly, 2019). The multitude of human-fish interactions highlights the interrelatedness of socio-ecological processes that are constructed by multiple actors of human, fish, and environment (Balée, 2006; Redman *et al.*, 2004; Reitz *et al.*, 2009). In addition to the complexity of past human-fish interactions, the issue of equifinality in zooarchaeology should also be considered as different processes might result in apparently similar 'signatures' observed in archaeological assemblages (Gifford-Gonzalez, 2018, pp.64–65). In this case, archaeological interpretations should be made with extreme caution as both natural and cultural processes can either be the cause or result of changes observed in zooarchaeological assemblages. To accurately identify the underlying causes that shaped past fisheries, multiple lines of evidence should be assessed, and unicausal interpretations should be avoided.

Though it is important to note that it is impossible to generalize the multiple-causal relationship between fishing and fish populations, due to the limitation of space, this section briefly reviews several case studies of prehistoric human-fish interactions under three general trends to facilitate later comparative analysis with Taiwanese ancient fisheries. The three general trends include prehistoric fisheries that are mainly caused by (1) cultural or anthropogenic factors, (2) non-anthropogenic factors, and (3) the presence of a relatively stable fishery due to sustainable practices or ecological resilience.

Anthropogenic factors

Diachronic changes observed in ichthyoarchaeological assemblage might be attributed to significant changes in fishing behaviors, socio-cultural factors, and anthropogenic fishing pressure. Technological changes such as the use of fishhooks, fishing nets, and seaworthy vessels can result in significant changes of target fish size and species compositions. The most common example is the increase of pelagic species through time due to the advancement of seafaring vessels that allow fishing in deeper waters, a critical topic related to human dispersals in the past (Cassidy, 2021; Sutton, 2017). Another example that is the introduction of the morphologically standardized single-piece shell fishhooks (O'Connor *et al.*, 2017) that are mostly associated with the capturing of deep pelagic fish, is thought to have significant increased fishing efficiency and resulted in fishing intensification in Japan (~23,000 BP) (Fujita *et al.*, 2016), Timor, Kisar, and Indonesia of the Wallacean Archipelago (~23,000-11,000 BP) (O'Connor *et al.*, 2011; O'Connor *et al.*, 2019; Langley *et al.*, 2023; O'Connor *et al.*, 2017), Mexico (~11,300 BP) (Des Lauriers *et al.*, 2017), Chile (~7000 BP) (Llagostera, 1992), southern and central California (~2500 BP) (Rick *et al.*, 2002). Other examples include the increased fishing efficiency by the use of fishing nets in central California (~AD 700) (Sanchez, 2019, p.51). In addition, socio-political and other cultural changes might result in changes in fish assemblages (see section 2.4.3). For instance, long-lasting fisheries changed significantly due to drastic socio-political events such as the drastic halt of a 3000-year-old deep sea fishery in the Mariana Islands due to Spanish colonization (1668 AD) (Amesbury, 2013), and the drastic decline of dolphinfish consumption after salted dolphinfish was being replaced by frozen tuna and bonito fish in the 1920s due to the invention of refrigerator in Japan (Osamu, 2013).

Other than causing changes in fish catch, anthropogenic activities might alter wild fish populations, such as overfishing and environmental alterations. The most pronounced examples of prehistoric overfishing mostly targeted large marine mammals, such as the local extinction of sea cow and sea otter in the Northern Pacific by around 11 ka BP and 2500 BP respectively (Jackson *et al.*, 2001). However, local extinction of fish populations is less observed in prehistoric fisheries. The presence of prehistoric overfishing is identified based on the decrease of mean trophic levels detected in fish species composition and stable isotope data derived from fish and human remains in the Penobscot Bay, Maine (5000-400 BP) (Bourque *et al.*, 2008), Puerto Marqués, Mexico (5500-2300 BP) (Kennett *et al.*, 2008), Puerto Rico (500-1100 AD) (Pestle, 2013), and the Bahamian Archipelago (1020-270 BP) (Schulting *et al.*, 2021). More pronounced evidence such as the declines of mean trophic levels, mean size, and estimated biomass is observed in the Caribbeans (1850-560 BP) (Wing and Wing, 2001). Though these case studies show a similar trend of the decrease of fish trophic levels, the underlying factors that caused overfishing, such as increased population size, exploitation intensification, technological changes, are highly varied and in most cases, 'localized' in nature (Kennett *et al.*, 2008, p.119; Bourque *et al.*, 2008, p.180; Schulting *et al.*, 2021, p.29). In addition to its smaller scale, there is not a 'universal' pattern of overfishing in ichthyoarchaeology as observed in large marine mammals. For example, in the case studies mentioned earlier, the underlying factors that caused prehistoric overfishing are highly varied, ranging from the extirpation of nearshore cod in Maine that led to the increased importance of low trophic species, to the extirpation of nearshore prey (low trophic level) species that has caused the distribution shift of higher trophic pelagic species in Mexico. Its small scale and complex underlying factors make overfishing in ichthyoarchaeology hard to be determined. On top of that, it is hard to clearly identify human predation pressure as the underlying factors that can result in a regional decrease in trophic level are often complex and are always also intertwined with natural processes.

Non-anthropogenic factors

Natural processes such as coastal environmental changes caused by natural sea level fluctuations, ocean productivity variability, environmental changes, and climatic oscillations can pose significant impacts on marine ecosystems, hence altering fish resource availability that is crucial to human fisheries. Common examples include natural climatic oscillations of the El Niño/Southern Oscillation (ENSO), the Pacific Decadal Oscillation (POD) and the North Atlantic Oscillation (NOA), and episodic climatic phenomena such as the Little Ice Age (~AD 1350-1800) that directly and indirectly affect marine resource availability (Chavez *et al.*, 2003; Rothschild, 1995; Field *et al.*, 2011; Ottersen *et al.*, 2004; Finney *et al.*, 2010). The impacts of natural climatic fluctuations on prehistoric fisheries are evidenced by the transition from an anchovy- to sardine-dominated fishery in Peru (~AD 1500) due to higher ENSO frequencies (Sandweiss *et al.*, 2004); as well as the fluctuations of in fish size, abundance, and composition in response to the warming of the Medieval climatic anomaly or the Medieval Warm Period (~AD 1000-1300), and the cooling of the 'AD 1300 event' and the Little Ice Age (Maschner *et al.*, 2008; Lécuyer *et al.*, 2021; Holland-Lulewicz and Thompson, 2024; Nunn, 2000; Ono and Intoh, 2011).

Moreover, sea level fluctuations that change coastal environments, most notable by significant changes in species composition or relative abundance that reflect biogeographical changes. Case studies that support these observations include changes in ancient fisheries caused by post-LGM sea level rise (after ~8650 BP) in the southwestern Baltic Sea (Schmölcke *et al.*, 2006), sea level decline after the early Holocene rapid sea level rise in Argentina (3100-1350 BP) (Zangrando *et al.*, 2016) and sea level decline caused by high sedimentation of terrestrial rivers in southwestern Taiwan (1400-300 BP) (Lin *et al.*, 2022) (further discussed below). Other natural processes that shaped ancient fisheries include episodic climatic events (Finney *et al.*, 2002), fluctuations in marine productivity (Bas *et al.*, 2023), natural regime shifts of marine ecosystems (Fitzhugh *et al.*, 2022), changes in precipitation rate and climate (Prestes-Carneiro *et al.*, 2020), volcanic eruptions (Kristensen *et al.*, 2020; Black, 1981), tectonic activities such as tectonic uplifts and earthquakes, and tsunamis (Losey, 2005; Reyes *et al.*, 2018; Kázmér *et al.*, 2016; Mourtzas, 2012; Hutchinson *et al.*, 2019).

Sustainability and ecological resilience

In contrast to the significantly altered fisheries mentioned above, some case studies show the presence of long-lasting and relatively stable fisheries. The evidence of sustainable and long-lasting fisheries is crucial to provide alternative models for modern fisheries and resource management to resolve fish stock depletions and trophic cascades caused by overfishing and climate change. A prominent example is the mass harvest of low-trophic forage fish by prehistoric fisher populations that are proven to be highly sustainable, such as the mass harvesting of smelt (Osmeridae) in Northern California (1309-109 BP) (Palmer *et al.*, 2018). There are mixed views to the main factors of sustainable fishing, including high ecological resilience of low trophic fishes, active resource management or traditional ecological knowledge (TEK), and technological constraints, where a combination of multiple factors should have involved in shaping a sustainable fishery. For example, in their review of global prehistoric fisheries (including marine mammals and invertebrates), Erlandson and Rick (2008, pp.302–303) have concluded that there is no evidence of a global trend in preindustrial fishing that shows a shift toward fishing down the food web due to overfishing. The authors suggest that a possible factor for the lack of evidence of large-scale prehistoric overfishing globally is due to technological and labor constraints in harvesting high trophic level pelagic fishes that are more vulnerable to overfishing. Technological constraints of prehistoric fishing such as durable fishing equipment, preservation techniques, and sailing and seafaring ability (Roselló-Izquierdo and Morales-Muñiz, 2008) that greatly affect fishing efficiency and stock landings are evident especially when compared to modern fishing techniques.

Nonetheless, some archaeological evidence points to at least some extent of sustainable practices and resource management. Such practices are often termed as traditional ecological knowledge (TEK) as they differ starkly from modern industrial fishing that target largest and spawning individuals (Sanchez, 2019). A good example is the evidence of size-selective fishing concentrated on smaller and nonspawning adults that have supported sustainable fisheries in northern Japan (5700-5600 BP) (Komiya *et al.*, 2019), central California (2550-200 BP) (Sanchez, 2019), and central Georgia Bight (4650-450 BP) (Reitz *et al.*, 2022). Other sustainable fishing techniques include the sex-selective harvesting of male salmon in the Salish coast, Canada (2800-300 BP) (Efford *et al.*, 2023); a generalist exploitation of diversified target species without the sole target of high-trophic and large bodied fish, termed as fishing 'across' the food web, in California's Channel Islands (1385-115 BP) (Elliott Smith *et al.*, 2023) and the Florida Keys (AD 800-1250) (LeFebvre *et al.*, 2022). The evidence of sustainable ancient fisheries and effective resource management provides critical models of sustainable fishing and alternatives for modern human-fish interactions. Archaeological evidence historicizes the roles of humans in harvesting, managing, and shaping marine resources, hence highlighting the role of marine resource stewardship for current and future conservation and management efforts (Sanchez, 2020; Carothers *et al.*, 2021; Sanchez *et al.*, 2023).

Alternatively, ecological resilience due to large abundance, shorter reproductive cycles, and higher reproductive rates, of low trophic forage fishes have supported several large-scale and long-term ancient fisheries. For example, the stable mass harvesting of Pacific herring (*Clupea pallasii*) on the Northwest coast of North America (10,000-100 BP) despite significant natural ecological variability (McKechnie *et al.*, 2014; Thornton and Moss, 2021). Ecological resilience of higher trophic level species that are highly adaptive to natural perturbations such as the resilient Pacific cod (*Gadus macrocephalus*) fishery at the Sanak Island, Gulf of Mexico (2550 BC to AD 1540) (Maschner *et al.*, 2008) is also observed. Other sustainable fisheries are supported by highly resilient marine ecosystems such as the long lasting fisheries fueled by the highly productive coastal upwelling of the Peru Current (13,000-2800 BP) (Reitz *et al.*, 2008) and the California Current (10,000-300 BP) (Jones *et al.*, 2016).

2.4.5 Marine resources sustainability and management

As mentioned above, though there is some evidence pointing to prehistoric overfishing, the implications of prehistoric human predation fade into insignificance when compared to modern fishing and industrial fishing except for the cases of locally extinct marine mammals mentioned earlier. The most significant difference that sets apart 'modern' fishing from 'prehistoric' fishing is its levels of technology, investment, and impacts. First perceived as an endless resource, global fisheries grew exponentially after the Industrial Revolution in the 1890s, and have led to multiple stages of fisheries collapses in different parts of the world since the 1920s (Bourque *et al.*, 2008). This rapid collapse of global fisheries within the last century is caused by large-scale commercial fishing, or industrial fishing that effectively remove a large part of a fish population that hugely reduce spawning populations and alter ecological structures (Pauly *et al.*, 2002; Steneck and Pauly, 2019). This mode of fishing that targets a small number of targeted species and their largest individuals has proven to be extremely unsustainable. For example, following the collapse of the Peruvian anchoveta stock in the early 1970s, the industry still struggles to recover despite extensive management and restoration efforts, creating significant socio-economic implications to the country (Field *et al.*, 2011). In this case, current efforts focus on rebuilding and restoring fish depleted marine fish stocks and their supporting ecosystems to their biomass prior to overfishing (Worm *et al.*, 2009). These efforts are challenged by our limited knowledge of pre-industrial ecological baselines that only exist in archaeological, paleontological, and historical records (Dillon *et al.*, 2022; Erlandson and Rick, 2008), hence expanding our notion of the issue of 'shifting baselines.' The concept of shifting baseline in fisheries science was proposed by Pauly (1995) to recognize that the baselines used to monitor changes in marine ecosystems were not static. Instead, ecological baselines have shifted according to fishing pressure of different times, even during historical periods when global fisheries data were unavailable. Archaeological data sheds light on of pre-industrial ecological baselines in the deeper pasts, as fishery baselines might have shifted even due to low level artisanal fishing in the prehistoric contexts (Pinnegar and Engelhard 2008; Jackson et al. 2001, see above).

By serving as proxies for changes in past environments, climates, and human-fish interactions, the study of ancient fisheries yields critical insights to support current marine resources management, conservation, and restoration efforts. This interest of linking past fishery records to present-day issues is the primary focus of the field of marine historical ecology (Erlandson and Rick, 2010; Reitz *et al.*, 2008; Braje *et al.*, 2005; Lotze and McClenachan, 2020) by documenting pre-industrial ecological baselines, long-term human-fish interactions, trends of ecological and environmental variability, with implications for conservation activism (Balée, 2018). Archaeological fish data provide baseline information on past fish abundance, biogeography, and biological behaviors, which informs contemporary conservation and fisheries management decisions. In other words, the baselines of marine ecosystems prior to industrial fishing are of particular importance to modern fisheries management and restoration. Additionally, marine historical ecology examines long-term records of ecological resilience, fish-human ecodynamics, and aquatic environmental variability from an anthropocentric perspective (Balée, 2006, p.81). From this viewpoint, marine historical ecology offers a comprehensive understanding of past fisheries that were constructed by multiple agents but with a focus on anthropogenic activities. This anthropocentric view of marine historical ecology contributes to the study of the ecology of current fisheries by putting the role of humans in shaping, exploiting, and adapting to past marine ecosystems in a historical context, which highlights the importance of marine ecosystem stewardship (Barrett, 2019; Sanchez, 2019, pp.2–4; Erlandson and Rick, 2010; Morales-Muñiz and Llorente-Rodriguez, 2020; Orton, 2016).

Archaeological evidence of long-lasting and sustainable fisheries that show effective management of fisheries resources (see above) provides long-term and site-specific data that is critical to modern ecological modelling, risk management, and restoration decisions (Sanchez *et al.*, 2023; Sanchez, 2019; Dalzell, 1998). In addition, Butler et al. (2012) argue that archaeology further contributes to modern fisheries management by shedding light on TEK and sustainable maritime practices in the past that will help to generate innovative and more effective fisheries management today that are better connected to local communities, by providing high resolution empirical data on long-term and cross-cultural socioecological models that enriches our understanding of sustainable resource exploitation and management (Molnár and Babai, 2021; Singleton *et al.*, 2023). Thornton and Moss (2021) further argue that site-specific archaeological data offers a finer-grained, place-based record of local and traditional knowledge (LTK) that speaks critically to local communities and avoid the issue of “historical amnesia” resulting from overgeneralization. In essence, archaeological data serves as a foundational resource, providing both baseline information and a richly diverse historical database for contemporary fisheries management and restoration efforts.

3. Background to the study of prehistoric fisheries in Taiwan

3.1 Ecological and environmental conditions of the Taiwanese waters

Taiwan lies at the edge of the Eurasian continental shelf and is located at the conjunction of the South China Sea (SCS), the East China Sea (ECS), and the Western Pacific. Surrounded by multiple tropical and subtropical water bodies and ocean currents, the hydrology in the area surrounding Taiwan fluctuates seasonally and shapes distinct marine ecologies that support highly productive fisheries. Notably, the Taiwanese waters are one of the most biodiverse hotspots globally, comprising about 10% of global marine fauna (Hwang *et al.*, 2006, p.944).Understanding the intricate oceanographic and hydrological processes in the Taiwanese waters is crucial to our understanding of modern and prehistoric fisheries.

The bathymetry and hydrography of Taiwan’s surrounding waters varies starkly due to its location on the edge of Eurasian continental shelf and the collision and subduction front of the Eurasian plate and the Philippine Sea Plate. The Eurasian continental shelf forms the underlying shallow (< 200 m) and generally flat seafloor to the north to west coast of Taiwan. Smaller regional submarine features include submarine canyons and regional depressions were formed by subaerial erosion during sea level lowstands during the Late Pleistocene, and low sand ridges formed by active geomorphology and sedimentation processes since the post-LGM sea level highstand along the Taiwan Strait (Chiang and Yu, 2022). On the northeast to the south of the offshore bathymetry of Taiwan deepens steeply after a wider (10 km) shelf on the northeast and a narrower (<2 km) shelf on the east, reaching a deep continental slope of 4000 to 6000 m. To the northeast and southeast lies the active collision margin between the Eurasian

Plate and the Philippine Sea Plate, the Ryukyu Arc in the north and the Luzon Arc in the south, forming various ridges and deep troughs along the surrounding waters (Yu and Song, 1993).

The Kuroshio Current is the western boundary current of the Noth Pacific Ocean and is the main driver of oceanographic and ecological conditions around the Taiwanese waters. The warm Kuroshio Current is considered to hold the highest marine biodiversity across the globe, as its high temperature enhances fish spawning and growth, while its constant northward flow helps the dispersion of marine species (Saito, 2019). The Kuroshio Current originates south from the east of the Philippines. Flowing northward from the equator, it branches off south of Taiwan, forming a main current that flows into the ECS along the east coast of Taiwan year-round, and two branch currents that seasonally intrude the Taiwan Strait and the SCS, forming highly productive spawning and fishing grounds and transporting marine species along the way (further discussed below). The obstruction and branching off the Kuroshio Current, along with the unique topography and hydrology along the coasts of Taiwan have resulted in very distinct marine environments and fish ecologies that support distinct fisheries in the coasts of the island.

On the west coast of Taiwan, the Taiwan Strait is a narrow waterway on the Eurasian continental shelf, separating Taiwan from continental Asia and connecting the South China Sea and the East China Sea. Seasonal wind patterns and summer storms resulted in a seasonal change of current regimes in the Taiwan Strait that consists of three currents: the Kuroshio Branch Current (KBC), China Coastal Current (CCC), and South China Sea Current (SCSC) (see **Figure 1**). The circulation of these currents is dominated by the monsoon system, mainly by the northeasterly (NE) monsoon in the winter and the southwestern (SW) monsoon in the summer. During the winter or from late autumn to early spring (November to March), the NE monsoon transports the cold CCC from the ECS into the Taiwan Strait. The CCC flows southward along the west side of the strait to enter SCS but is obstructed by the warm KBC on the east side of the strait at the Changyun Ridge. During the spring when the NE monsoon weakens, the KBC flows over the Changyun Ridge to enter the northeastern part of the Taiwan Strait.

During the summer, the SW monsoon transports the warm SCSC from the SCS into the Taiwan Strait that continues flowing northward to enter the ECS. This wind-driven circulation causes seasonal changes in sea surface temperatures and salinity, shaping the abundance and diversity of biotic communities (Hwang *et al.*, 2006; Jan *et al.*, 2002; Tseng *et al.*, 2020). Besides, the obstruction and abrupt change in bathymetry near the end of the Penghu Channel causes turbulent mixing and topographic upwelling that also enhance marine productivity (Lo *et al.*, 2010, p.1091). Similar processes are driven by tropical storms and typhoons in the summer (Tseng *et al.*, 2020, p.2). The flow of currents also facilitates the transportation of tropical and subtropical species, resulting in a highly biodiverse fishing ground in the Taiwan Strait (Chen *et al.*, 2014).

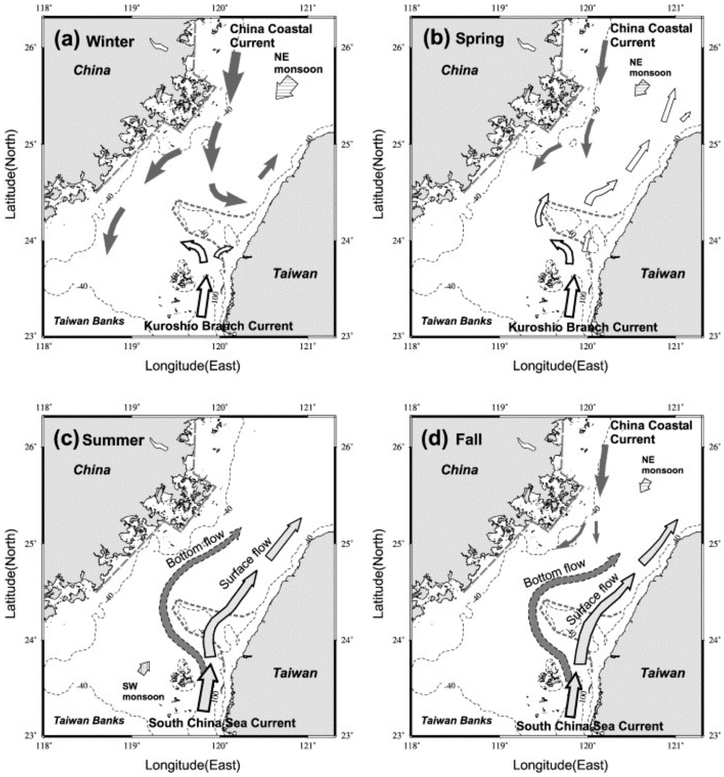

Figure 1: Sasonal circulation of major currents in the Taiwan Strait. (Jan et al. 2002, Fig. 14)

On the east coast of Taiwan, the year-round northward flow of the Kuroshio Current continuously transports heat, nutrients, and marine species northward. This process remains relatively stable throughout the year, contributing to the constant influx of diverse fish species into the region (Lo *et al.*, 2010). The southwestern and northeastern waters of Taiwan are shelf-break regions where the shallow continental shelf break into deep continental slopes, characterized by the deep continental slope and submarine canyons in the southwest (Chiang and Yu, 2021), and the continental slope, submarine canyons, and the deep Okinawa Trough in the northeast (Yu and Song, 1993). The northward intrusion of Kuroshio Current and the KBC into these two regions during the winter, driven by the NE monsoon form turbulent fronts that result in intense mixing that is a key to high marine productivity. Besides, the submarine topography of both regions supports constant topographic upwellings that maintain high marine productivity year-round. In addition, off the southwestern coast, the southward flow of SCSC and major terrestrial runoff from the Gaoping River during the summer further enhance local productivity and fisheries (Hsieh *et al.*, 2017).

In general, the highly productive waters around Taiwan are major spawning and nursing grounds to most commercially important fish species that appear in large schools seasonally and year-round riding on major ocean currents (Yeh, 1992; Hsieh *et al.*, 2011, p.160; Su *et al.*, 2011; Lo *et al.*, 2010; Hsieh *et al.*, 2017; Shimose *et al.*, 2009). Besides, the diverse marine environment encompasses shallow sand-dominated shelf region, mangroves, river estuaries, shelf slopes, coral reefs, and deep submarine canyons, which support highly diverse endemic species (Lo *et al.*, 2010; Shao, 1999). Recently, the rise in sea surface temperature (SST) has altered current regimes and fish species distribution. The altered current regimes have enhanced the KC and declined the CCC, which will shift fishing seasons and further influence the reduced fish catch in the area (Ho *et al.*, 2016). The effects of rising SST can also be seen where the already reduced fish stock of flathead grey mullet (*Mugil cephalus*), an important commercial species in Taiwanese fisheries, is further affected by the increase in mean sea surface temperature (SST) and other climatic events. Climatic variability has altered the abundance and migration behavior of grey mullet in the Taiwan Strait, which might cause the fishing ground to be shifted northward or even out of the Taiwan Strait (Lan *et al.*, 2014; Ho *et al.*, 2016). The effects of the rise of global sea temperature is well studied and observed in many parts of the globe, which cause the ‘tropicalization of catch’ where the catch of warm water species increase and the catch of cold water species decrease (Cheung *et al.*, 2013).

Not only in Taiwan, similar trends are observed in Korea (Park *et al.*, 2023), Japan (Sugisaki and Murakami, 2017), and China (Liang *et al.*, 2018), where changes in species distribution, biogeography, and seasonality caused by climate change have greatly altered fisheries.

3.2 Modern Taiwanese Fisheries

Fisheries are a crucial industry in modern Taiwan. In recent years, fishery production in Taiwan accounts for the highest yield within the country's domestic agricultural industry, and contributes to roughly 3% of the country's total GDP (Yang *et al.*, 2022, p.23). Modern fisheries in Taiwan mainly consist of four sectors: distant water fisheries (conducted in waters beyond the 200-nautical-mile (nm) Exclusive Economic Zone), coastal and offshore fisheries (conducted in waters within the 200-nm Exclusive Economic Zone), and aquaculture. Modernized fisheries were developed during the Japanese occupation (AD 1895-1945); industrialized and extensive fishing were practiced starting from the 1950s. This study focuses on the coastal and offshore fisheries and marine ecology in Taiwan. Main fishing methods include net fishing, lighted net fishing, trawling, commercial angling, fish larvae harvesting, whitebait fishing, and trawling (Ministry of Agriculture, Executive Yuan, 2011). Traditional fishing methods that have recently declined or lost include fire fishing, marlin spearfishing, stone weir fishing, beach seine net fishing, and trap fishing (Lin, 2015).

Coastal and nearshore fishing in Taiwan peaked in the 80s and resulted in substantial overfishing, causing a major collapse in coastal fish populations in the 90s, heavily impacting the fishing industry, fish ecology, and the livelihood of local fishermen. Currently, coastal fish populations still struggle to be revived despite various conservation and restocking efforts . Notably, economic species in the Taiwan Strait that yielded high production in the 80s are now critically endangered, greatly altering the abundance and species composition of target species and the structure of marine ecosystems. This already troubled fishery system is now further impacted by ocean pollution and climate change (Shih *et al.*, 2009; Ho *et al.*, 2016; Chen *et al.*, 2014).

There are 72 major targeted fish species in these waters, where all but two (swordfish (*Xiphias gladius)* and Japanese eel (*Anguilla japonica)*) species spawn in coastal and offshore waters around Taiwan (Shih *et al.*, 2009). The top 10 targeted species include *Scomber australasicus* (spotted mackerel), *Coryphaena hippurus* (dolphinfish), *Decapterus maruadsi* (round scad), *Trichiurus lepturus* (cutlassfish), *Thunnus albacares* (yellowfin tuna), *Carangoides malabaricus* (Malabar trevally), *Isurus glaucus* (mako sharks), *Trachurus japonicus* (Japanese jack mackerel), *Pennahia argentata* (Silver white croaker) and *Makaira mazara* (Blue Marlins). Most targeted species are highly migratory species that appear in nearshore and inshore waters to spawn. Fish migrations are highly dependent on sea surface temperatures and ocean currents, making fisheries in Taiwan and the Kuroshio Region highly sensitive to climate and environmental changes (Ho *et al.*, 2016). Due to global warming, regime shifts in target species have been observed in fish catch data in Taiwan and the wider Kuroshio Region most prominently since 2005. A stark decrease in winter and cold-water species, and an increase in summer and warm-water species has been noted. Existing fishing grounds have shifted north, causing a reduction in fish catch of some important species, for example the culturally valued species, the flathead grey mullet (*Mugil cephalus*) (Ho *et al.*, 2016, p.10).

Efforts to address this ecological crisis have prompted extensive studies examining the impacts of overfishing since the advent of industrial fishing in the 1950s (Ju *et al.*, 2020; Liao *et al.*, 2019; Liu *et al.*, 2009) and has resulted in a series of strict fishing restrictions to manage, conserve, and revive the hugely reduced fish stock and deeply affected fisheries (Liu *et al.*, 2011; Chiu *et al.*, 2022; Huang and Chuang, 2010; Tseng and Kao, 2022). However, the deeper time impact of shifting climate and human harvesting strategies has not yet been addressed. Fisheries data prior to the 1950s will shed light on pre-industrial baselines and provide alternatives for sustainable fisheries that facilitate current and future ecological or fisheries modeling. How past changes in climate impacted these resources may also help inform our expectations for the impact of the current climate crisis. In addition, this line of inter-disciplinary data helps to historicize the roles of human fishing in fisheries and ecological studies and relationship and highlights the importance of marine ecosystem stewardship (Barrett, 2019; Sanchez, 2019).

3.3 Environmental history of the coasts of Taiwan

Coastal environments are known for their importance to prehistoric human occupation due to their proximity to marine resources and marine travel routes. Mounting data of prehistoric coastal occupations have shed light on prehistoric settlement patterns, marine subsistence activities, and maritime human dispersals (Fitzpatrick *et al.*, 2015). Notably, coastal lowlands that were exposed during sea level lowstands throughout the Pleistocene are suggested to be productive refugia for human, faunal, and floral populations in the face of extreme climate and environmental changes (Bailey and Flemming, 2008). However, these sites are mostly submerged by the Holocene sea level rise, except a small fraction of sites that are uplifted or located on steep offshore drop-offs at plate boundaries (d'Alpoim Guedes *et al.*, 2016; Bailey and Flemming, 2008), making underwater exploration necessary to better understand these time periods of human prehistory during the late Pleistocene and early Holocene (Hershkovitz and Galili, 1990; Gusick and Faught, 2011; Gusick *et al.*, 2022). -

Similarly, a comprehensive understanding of the environmental history of the coasts of Taiwan is crucial to the study of ancient fisheries in Taiwan. Generally, coastal environmental histories and the archaeological pasts can be examined on multi-scalar temporal and spatial scales depends on the research question and specific time periods (Bailey, 2007; Lambeck and Chappell, 2001). On a larger scale, eustatic sea level (ESL) changes and isostatic movements affected by global ice volume changes during the Last Glacial Cycle (circa 120-11.5 ka) and the Holocene (11.5 ka-present) provides a global view on the impacts of environmental and sea level changes on human lives (Lambeck and Chappell, 2001; Lambeck *et al.*, 2014). On a smaller scale, regional sea level curves provide a more nuanced sea level records that consider regional glacio-isostatic and tectonic processes (Lambeck and Purcell, 2005; Sivan *et al.*, 2001). On a higher resolution, relative sea level (RSL) provides the actual sea level fluctuations experienced at local coasts by considering all global, regional, and local processes such as offshore and coastal geomorphologies (i.e. see Shtienberg et al. 2017). On an even finer scale, archaeologists have called for the consideration of local human experiences that better illustrates socio-ecological histories (Rivera-Collazo, 2022; Holland-Lulewicz and Thompson, 2024). To provide a multi-scalar environmental history of Taiwan, this section will first review what is known about the regional sea level history of Taiwan, and local environmental history of the coasts of Taiwan.

3.3.1 Regional Sea level history

A regional sea-level change curve for the East China Sea (ECS) since the LGM based on large scale sedimentary mapping by Li et al. (2014) is adopted for this study (**Figure 2**). This regional sea level curve provides an up-to-date and high-resolution sea level model backed by radiocarbon dating and sedimentological data. The sea level history of the ECS generally conforms to the global LGM sea level curve, with the earliest obtained date from study (23 ka cal BP). Sequencing stratigraphy shows three sea level tracts: lowstand system tract (23-15.4 ka cal BP.), transgressive system tract (15.4-7 ka cal BP.), and highstand system tract (7 ka cal BP to present). LGM in the ECS is dated between 23-19 ka cal BP; sea level reached the lowest stand, at -135m at 21 ka cal BP, and the highest stand (Maximum flooding surface, MSF) was reached at 7 ka cal BP, identified based on the erosional boundary lying under the transgressive boundary and the start of modern circulation systems. Post-LGM transgression has occurred since 19 ka cal BP, followed by three significant events of sea level rise that all comprise rapid rising phases (RRP) and slowly rising phases (SRR) that correlate with the warming and cooling events since the end of LGM, such as the Bølling–Allerød warming that corresponds to RRP II (15.4-12.9 ka cal BP) and the Younger Dryas cooling that corresponds to SRP II (12.9-11.0 ka cal BP) (Table 1).

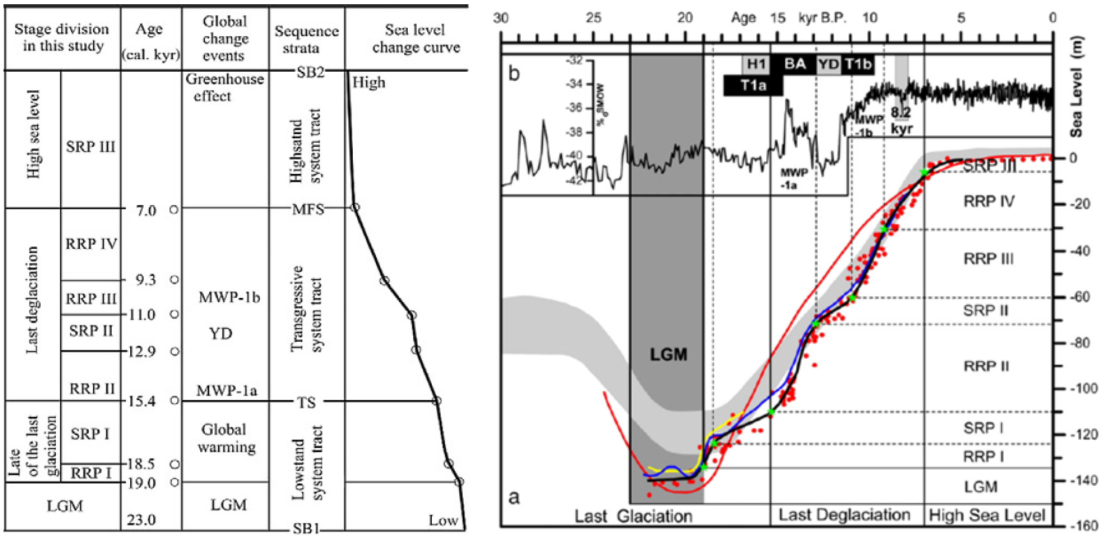

Figure 2: Sea level rise curve and phase partition since LGM. (Li et al. 2014: 394, Table 1 and Fig. 2).

Table 1: Phases of the sea level rise and shoreline movement in the ECS since the LGM. (Modified from Li et al. 2014, Table 2).

Phases	**Age (cal kyr BP)**		**Sea level change (m)**	**Sea level rise rate (mm/yr)**	**Shoreline movement of the ECS (m/yr)**	
	Range	**Period**			**Max**	**Mean**
LGM	23.0-19.0	4	>135	-	-	-
RRP I	19.0-18.5	0.5	135-125	20	100	33
SRP I	18.5-15.4	3.1	125-110	5	20	10
RRP II	15.4-12.9	2.5	110-72	15	105	50
SRP II	12.9-11.0	1.9	72-60	6	52	22
RRP III	11.0-9.3	1.7	60-31	17	165	38
RRP IV	9.3-7.0	2.3	31-6	11	56	18
SRP III	<7.0	7	6-0	<1	-	-

The relative sea level change in Taiwan is highly variable depending on the distinct coastal geologies of Taiwanese coasts. The following sub-section will discuss the environmental histories of the distinctive east, north, west, and south coasts of Taiwan to delineate the relative sea level history of Taiwan that is experienced by prehistoric populations.

3.3.2 Environmental history of the coasts of Taiwan

Taiwan has a coastline that is approximately 1,566 kilometers long, with four main types of coastal landscape: eastern fault coast, western emergent coast, northern mixed coast and southern coral-reef coast. (National Science and Technology Council, 2001). The coastal environment of Taiwan is characterized by its active tectonic activities, high sedimentation rate, fluctuating sea levels, and frequent severe climatic events (Chen *et al.*, 2004). This active and complex environmental history of Taiwan closely affected prehistoric and modern coastal populations, as well as the preservation and visibility of coastal archaeological sites. For example, in their studies focused on climate-induced demographic changes in Taiwan, Leipe et al. (2023, p.16) pointed out that rather than increased precipitation, alluvial expansion caused by riverine sedimentation was likely the main cause of the population decline on the east coast of Taiwan during 2700-2300 BP. Coastal sites of different times are unevenly dispersed and preserved along these geologically and hydrologically (see above) distinct coasts, providing instrumental information to aid our understanding of prehistoric fisheries in Taiwan. This section reviews the brief environmental history of different coastal environments in Taiwan.

Taiwan lies at the convergent boundary of the Philippine Sea Plate and the Eurasian Plate that undergoes active and complex tectonic and seismic activities (**Figure 3**). Currently, the Asian continental margin subducts beneath the Philippine Sea Plate south of Taiwan, forming the uplifted coral reef coast of the Hengchun Peninsula at the southern tip of Taiwan at an average rate of 3.5 ± 0.3 mm/yr. The Philippine Sea Plate collides with the Asian continental margin on the east coast of Taiwan, forming the uplifted fault coast east of the Eastern Coastal Range at 5.3 ± 0.8 mm/yr; the Philippine Sea Plate subducts beneath the Asian continental margin on the northeast of Taiwan, forming the Ryukyu arc and a back-arc basin off the shore of northeastern Taiwan (Wang and Burnett, 1990; Huang *et al.*, 2012) (see **Figure 3**). Located on the steep boundary plates and with its rapid tectonic uplift (4-10 mm/yr) (Hsieh *et al.*, 2004), the east coast of Taiwan remained exposed as land throughout the entire Late Pleistocene and Holocene. The earliest Upper Paleolithic sites dated prior to the end of the LGM (15,000 BP) in Taiwan are all located on this uplifted coast. The coast of the Hengchun Peninsula, located at the southern tip of Taiwan, was submerged marine terraces that are formed during the late Pleistocene sea level highstand prior to 6000 BP, and are gradually uplifted to around 10-30 m above sea level today (Liew and Huang, 1990; Li, 1989). The current sandy beaches on the southeast coast and the alluvial plain on the southwest coast of southern Taiwan were intruded by sea level rise after the LGM ca. 8000 BP, forming various marine bays and brackish lagoons, which was later switched to terrestrial environments due to the stabilization of eustatic sea level, tectonic uplift, and alluvial expansion of the alluvial plains (Chen *et al.*, 2021; Kung *et al.*, 2012).

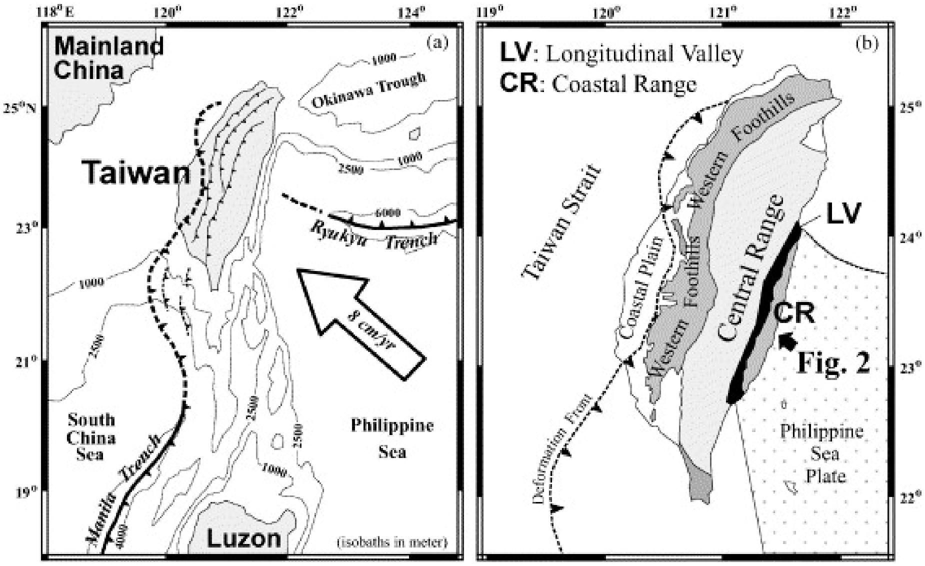

Figure 3: Tectonic setting of Taiwan (a) and morpho-tectonic framework of Taiwan. (Hsieh, Liew, and Hsu 2004: Fig. 1).

The west coast of Taiwan, the Western Coastal Plain or the Jianan Plain, is a vast coastal lowland plain (<100 m) of the shallow Eurasian continental shelf that borders the shallow Taiwan Strait. With an average depth of less than 100 m deep, the Taiwan Strait was exposed as a landbridge during the multiple sea level lowstand events of Glaciations, facilitating the migration of human and land mammals from mainland China to Taiwan (Lin, 1966; Chen and Xu, 2010). The Taiwan Strait was last exposed as a landbridge that is connected to mainland China during the LGM (23 ka cal BP) when the sea level was ~117 m below present sea level (Li *et al.*, 2014). The Taiwan Strait was fully inundated at least by 14 ka

BP when sand ridges started to form over its modern shallow-strait environment (Liao, 2006) caused by post-LGM sea level rise that peaked ~6000 BP when the shoreline was ~20 km inland on the west coast of Taiwan (Chen *et al.*, 2010). This drastic change in relative sea level has caused huge changes in coastal and inshore environments of the west coast of Taiwan, altering resource availability and fishing behaviors in the region.

Adjacent to the Taiwan Strait, the tectonically stable west coast of Taiwan has undergone drastic environmental changes caused by sea level changes and high fluvial sedimentation in conjunction with the Pleistocene Sea level changes. Taiwan has high and steep mountains and experience high frequency of earthquakes, typhoons, which alongside with its wet-monsoonal climate has caused exceptionally high erosion and depositional rate along the river basins and coasts of Taiwan, actively modifying the coastal environments and relative sea levels (Ruetenik *et al.*, 2020; Hsiung and Saito, 2017). For example, the high sediment yield of the western rivers, one of the highest in the world, has formed thick Holocene fluvial deposits offshore in the Taiwan Strait, with a deposition rate that exceeds 10 mm/yr (Ruetenik *et al.*, 2020, p.2), and on the western coastal plain, with some parts reaching 100 m-thick (Liu *et al.*, 2008). This has caused the westward shifting of the paleoshoreline on the western coastal plain since 6000 BP (Tsang and Li, 2018, pp.80–96). This process is recently reversed by increased anthropogenic activities in coastal regions, causing the erosion of coastal beaches and the landward shift of western shorelines (Tsai, 2022). High sedimentation rate also renders underwater archaeological studies challenging due to the accumulation of thick Holocene sediment (>20 m) above the LGM sea-land unconformity on the Taiwan Strait seabed (He *et al.*, 2021; Liao, 2020). On the contrary to the west coast, tectonic uplift and severe erosion offsets high riverine depositions on the east coast has caused the fall of relative sea level of more than 10 m over the past 10 ka (Ruetenik *et al.*, 2020, p.5). Similar phenomenon is observed in the Hengchun Peninsula (as mentioned above), as well as the eastern islands of Lanyu and Ludao, where coral reef terraces are continuously being uplifted and exposed with an average rate of 2.2± 0.2 mm/yr (Wang and Burnett, 1990).

Northern Taiwan underwent distinct geological processes compared to the rest of Taiwan due to its location that made it the earliest collision front of the Eurasian Plate and the Philippine Sea Plate around 6 Ma. It has undergone similar collision and orogenic activities as the current south-central Taiwan until 0.8 Ma, when the process ceased and propagated south to its current position. Northern Taiwan is since associated with the southeast-facing Ryukyu arc system stretching from the northeast and has undergone faulting, rifting, volcanism, subsidence, and uplift (Teng *et al.*, 2001). The Taipei Basin was formed early (0.4 Ma), being fed by alluvial sediments, and has undergone active environmental change due to eustatic sea level changes, basin-subsidence, and sediment supply changes since the LGM. Affected by these complex processes, sequence stratigraphy obtained from sediment cores show that the environmental fluctuations of the Taipei Basin as a subsiding deposition sink of three terrestrial streams with high sedimentation rate (modern rate: ~1.75 mm/yr). The Taipei Basin remained a fluvial plain but experienced a rise in RSL during the LGM lowstand (35-20 ka) as opposed to a general regression observed on the Western Coastal Plain and the Taiwan Strait due to its rapid subsidence rate (~2.67 mm/yr). The Taipei Basin was inundated as a marine estuary by the post-LGM transgression since ~10.2 ka and only turned into a fluvial terrestrial basin after 7. ka, with a slower subsidence rate (1.75 mm/yr) and stable eustatic sea level (Su *et al.*, 2018)

Studies show that rapid changes of sea level during the Holocene must had significant implications for the ancient peoples and biomes living along the paleo-shorelines (Li *et al.*, 2014, p.396) by greatly altering the area of easily accessible western coastal plain in Taiwan due to its unique topography that is mainly covered by high mountains (Chen and Xu, 2010; Chen *et al.*, 2004) (see **Figure 4**). Effects of the depletion of plains and grasslands as habitats could be seen by the extinction of megafauna in Taiwan during the early Holocene (Chen and Xu 2010), which might have a similar effect on human lives and subsistence activities. Besides, the exposure and submergence of the land bridge and continental margins would affect the accessibility and proximity to different resources on land and in the sea, as well as human migration (Ho, 2011; Chiu and Chen, 2016).

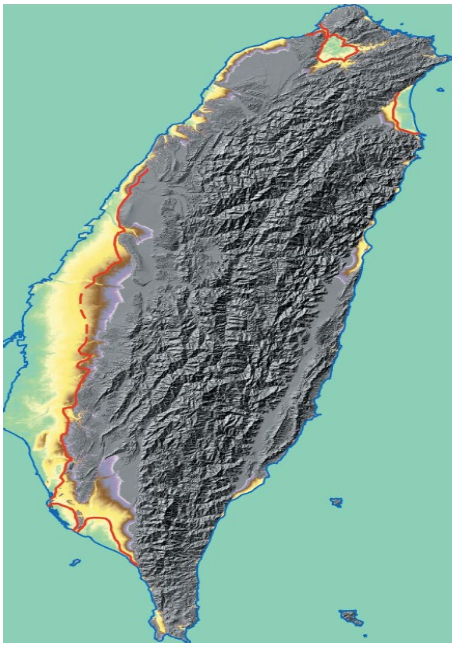

Figure 4: The map of the current coastline (blue) and paleo-coastline (red) at 6-5ka. (Chen and Xu 2010: 155, Fig. 14).

3.4 Taiwanese archaeology

Taiwanese archaeology started in the 19th century during the Japanese colonial era and has greatly developed into a professional academic field since 1960s. Initially, archaeological studies in Taiwan received most of its support and funding from state-funded research agencies. After the implementation of the Cultural Heritage Preservation Act (CHPA) in 1982 (updated 2016), the private sector, developers with the need to comply to the CHPA, has replaced the public sector to become the main source of funding for most archaeological excavations. Without a strong governmental agency overseeing these privately funded and privately conducted excavations, archaeology has been increasingly privatized with limited government scrutiny (Zorzin *et al.*, 2022). Recently, most archaeological excavations and studies are centered on salvage archaeology and cultural management resources (CRM) which helped to secure funding for large excavation projects like the Tainan Science Park Project but at the same time limited the development of scientific oriented research.

There are different views on the specific dates and names of cultural chronologies or "culture" (文化) in Taiwan. For the sake of simplicity, this thesis will employs the following archaeological chronology by referencing chronological frameworks employed by Pearson (2023d) and Chen's (2017) that facilitate regional comparisons:

- Paleolithic: 30,000 to 6500 BP
- Preceramic: 6500-5500 BP
- Early Neolithic: 5500 to 4500 BP
- Middle Neolithic: 4500 to 3500 BP
- Late Neolithic: 3500 to 2500 BP
- Metal Period: 2500 BP to AD 1624
- Historical Period: AD 1624 to 1945

Pearson employed the term Contact Period (AD 1500 to 1663) to highlight the period of initial European contact. However, following Chen (2017), my thesis will include this period with the general Historical Period (AD 1624-1945). This chronological framework is delineated based on changes in material cultures, however, a broad-spectrum subsistence strategy remained relatively constant since the Paleolithic period despite the emergence of rice and millet cultivation (after 4800 BP) (Tsang and Li, 2018; Deng *et al.*, 2022; Pearson, 2023d), as well as pig domestication (~1500 BP) (further discussed below).

Due to its geographical location at the edge of East Asia and South China Sea, and its geological environment as an island, the prehistory of Taiwan is largely shaped by geological activities such as sea level rise and tectonic uplifts, as well as long-distance interactions with Southeastern China, the Ryukyus, and Island Southeast Asia. Most notably, archaeological, linguistic, and genetic evidence show that Taiwan played a crucial role in the spread of Austronesian populations from East Asia 'into' Taiwan (~6000 BP) and 'out of' Taiwan (after 4000 BP) to Island Southeast Asia and the Pacific Islands

(Matsumura *et al.*, 2019; Ko *et al.*, 2014; Lipson *et al.*, 2014; Bellwood, 1991). Prehistoric populations in Taiwan remained in close contact with the adjacent regions across the South and East China Sea after until the Historical Period. During the Early Neolithic period (6400-4500 BP), there were maritime material exchange networks connecting Taiwan with Southeast China as evidenced by similar typologies of pottery and stone adze tools, and Southeast Asia through the vast exchange network of Taiwanese nephrite and the common use of ridged stone bark cloth (tapa) (Chi and Hung, 2010; Hung *et al.*, 2007; Pearson, 2023d). During the Metal Period (2500 BP-AD 1624), the exchange networks expanded to include Japanese and Chinese coins, glass beads, as well as local and regional deer hide trades (Pearson, 2023d; Yen, 2017). In what follows, I detail the archaeological cultures of coastal Taiwan across time.

Evidence for the Paleolithic Period (30,000-6500 BP) in coastal Taiwan comes from a few sites that were found in uplifted coastal caves on the east coast of Taiwan. Often identified as belonging to the Baxiandong or Changbinian Cultures, these sites have yielded no associated human remains, but stone tools represent a pebble tool industry with abundant flaked stone implements with C14 dates clustering between 27,000 and 15,000 BP (Chen, 2017). These cave sites on the east coast are the only archaeological evidence of pre-Holocene human occupation in Taiwan. Succeeding this early human occupation is a ~8,400-year-hiatus (15,000-6,600 BP) of archaeological evidence of human occupation (Hung *et al.*, 2022). The only exception to this hiatus is the five archaeological sites found on Liangdao Island, an island that is located on the east end of the Taiwan Strait (~118 km offshore of Taiwan). Located closer to or ~35 km offshore of the southeast coast of China, the Liangdao site (8320-7434 BP) is the only early evidence of human occupation during this hiatus and yielded the oldest human remains currently found in Taiwan (~8320-7560 BP) (Institute of Anthropology, National Tsing Hua University, 2015; Chun-Yu Chen, 2019). Its age during this hiatus and DNA analysis that show affiliation with both modern mainland Chinese and Pacific-Oceanic population are often used to support the ‘out of Taiwan’ hypothesis of Austronesian migration (Hung *et al.*, 2022). The absence of pre-6500BP archaeological sites on the west, south, and north coasts can be presumed to be caused by the inundation, burial and erosion caused by post-LGM transgressions (see section 3.3). However, it is unclear why there is a hiatus on the tectonically uplifted east coast and inland areas that are unaffected by sea level changes.

The subsequent human occupation dates to ~6500-5500 BP (Preceramic Period) and is found on the east coast and at the Eluanbi site in southern Taiwan. Often viewed as the Preceramic Culture or the persistent Paleolithic Culture, stone and bone tools found suggest hunter-fisher populations who did not use pottery and polished stone tools. The first human remains found in the Taiwanese archipelago is dated to this period, which is a female skeletal remain found in the Xiaoma Cave site of the east coast of Taiwan that dates to ~6189-5725 BP. Some scholars suggest that this individual is unaffiliated to the Neolithic Austronesians and a probable connection with the Southeast Asian Negritos based on bone morphometrics that indicates a smaller stature (Hung *et al.*, 2022). Ceramic and polished stone tools started to appear in archaeological assemblages after 5500 BP, marking the advent of the Early Neolithic Period (5500-4500 BP). Clear evidence of domesticated rice (*Oryza sativa*), foxtail millet (*Setaria italica*), and broomcorn millet (*Panicum miliaceum L.*) were found on all north, east, south, and west[2] coasts and date to 4600 BP (Deng *et al.*, 2022). The practice of a mixed farming of rice and millet is suggested to be spread to Taiwan from Southern China and persisted throughout all succeeding archaeological periods in Taiwan (Deng *et al.*, 2022; Leipe *et al.*, 2023; Kaikkonen, 2019). Despite the early evidence of agriculture since the Early Neolithic, these Neolithic populations in are suggested to have been maritime oriented fishers and forages who practiced agriculture as a complementary strategy who originated in Southeastern China and crossed the inundated Taiwan Strait to occupy the rich estuaries along the coasts of Taiwan (Li, 2013; Pearson, 2023a; Chang, 1989). Local sea level history supports the maritime nature of these early populations as land connection with the Eurasian continent was completely obstructed after 14 ka BP. They are commonly viewed as the ancestors of Austronesian

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[2] The mid-Holocene (~5000 BP) sites, the Nanguanli and Nanguanli-East sites, in Southwestern Taiwan that are currently located ~20 km inland were located on the paleoshoreline (Tsang and Li, 2018).

populations including those in Taiwans. Not all scholars agree, however, in seeing Taiwan as the initial steppingstone in the Austronesian migrations. Some suggest that the main route for the diffusion of Austronesian cultures was the south China Sea route instead of the Taiwan Strait (Solheim, 2000).

Early Neolithic (5500-4500 BP) sites are only found in coastal areas, and coastal populations gradually expanded their range and moved to inland mountains during the Middle Neolithic (4500 to 3500 BP). Steep mountainous topographies and limited arable land might have contributed to this late occupation of the inland areas, a phenomenon also observed in the adjacent of Fujian, Southeastern China (Kaikkonen, 2019, p.220). The material culture remains relatively uniform under the single Dabenkeng Culture during the Early Neolithic, but regional differences increased into the Middle and Late Neolithic periods (3500 to 2500 BP). Following the increased variability in localized cultural traditions, a significant increase in site numbers and population density is observed during the Middle Neolithic (4500-3500 BP), probably due to populations migrating from southern China (Leipe *et al.*, 2023). By the Late Neolithic, highly varied material cultures and occupational patterns are observed in the Penghu Islands, and north, central, southern and eastern Taiwan. Nonetheless, populations actively interacted with each other, including both intermarriage and trade. A distinctive east-west island-wide material exchange network is evident by the flow of goods made of olivine basalt from Penghu Island in the Taiwan Strait and nephrite from the east coast. An intermarriage hypothesis was proposed based on the adoption of similar material typology, especially gray black pottery from the west coast, in central Taiwan (Pearson, 2023b, p.73). In addition, intensification of stone tools and pottery making, fishing activities, as well as megalithic building are found across different sites. Long-distance contacts with mainland China in Northern Taiwan and Southeast Asia in the east coast of Taiwan are observed by the presence of stepped adzes in the north, and nephrite and megalithic monuments in the east. These novel developments of the Middle and Late Neolithic show increased social complexity and socio-economic connections over a vast area that encompasses the coastal, inland, and offshore island sites in Taiwan, as well as the wider ISEA, southern China, and southern Ryukyu region.

During the Metal Period (2500 BP to AD 1624), local bronze casting and new materials obtained through trade and exchange from China and Southeast Asia, such as Chinese and Japanese coins and glass beads, are seen as novel material cultures comparing to the Neolithic. Regional exchange among different regions within and outside the peninsula persisted and enhanced, especially the extensive maritime deer skin trade (Yen, 2017) and the vast exchange network of jade, iron, and glass beads across the SEA. Iron objects and glass beads of Southeast Asian origin (northern Thailand and Vietnam) were found in early Metal Period sites (~2400 BP). Iron objects are later manufactured locally ~2100 BP in different parts of Taiwan and glass beads are continuously obtained through long-distance trade from Southeast Asia (Liu, 2021). Similarly, the maritime trade of Taiwanese nephrite reached its peak during the Metal Period, where Taiwanese jade blanks or finished jade ornaments are found in contemporaneous sites across mainland and island Southeast Asia (Hung and Chao, 2016). Long-term interactions between Taiwan and China weakened since 1000 BP, when Fujian and Guangdong were integrated into the Chinese imperial system, isolating the Austronesian Taiwan from Sinitic Chinese influences (Pearson, 2023e, p.180). Informal interactions with Chinese populations persisted through Chinese fishermen, pirates, merchants, and navy (Shepherd, 1993, p.6).

The broad spectrum subsistence strategy that include fishing, hunting, and foraging remained relatively constant throughout the Metal Period to pre-Dutch contact despite the ongoing practice of cereal cultivation and the domestication of pigs in about 1500 BP (Pearson, 2023d). Currently, there are mixed views on the domestication of the two existing breeds of domesticated pig (*Sus scrofa domesticus*), the Asian pig breed and the smaller-sized Lanyu pig breed (蘭嶼豬), in Taiwan. The Asian pig breed shares a similar ancestral lineage with the Asian wild boar (endemic to mainland Asia) and the Formosan Wild Boar (endemic to Taiwan). There are split views on whether suid domestication in Taiwan (~1500 BP) occurred locally (Chuang, 2021) or through foreign influences from mainland China (Li *et al.*, 2015). (Li et al. 2015). On the other hand, the Lanyu pig, the other endemic domesticated pig breed to Taiwan, is currently absent in the Taiwanese archaeological record. Recent DNA analysis have shown that the Lanyu pig breed is phylogenetically distinct from the Asian and European domesticated pig breeds, hence suggesting a local domestication process in Taiwan (Chen *et al.*, 2011; Wu *et al.*, 2007). Due to its absence in archaeological records, the domestication of the Lanyu pig is termed as a “cryptic” domestication event (Larson *et al.*, 2010). The Lanyu pig’s relatedness with domesticated pigs in the Phillipines have sparked discussions on the potential human-mediated maritime dispersal domesticated pig in the region (Li *et al.*, 2017; Layos *et al.*, 2024), more research is needed to delineate the domestication of the Lanyu pig in prehistoric Taiwan.

The Historical Period in Taiwan last from the colonization by Dutch (AD 1624 to1661), Spanish in northern Taiwan (AD 1626 to 1646), Chinese (AD 1661 to 1895), and Japanese forces (AD 1895 to 1945) (Chen, 2017) to the establishment of the modern Republic of China in 1945. Subsistence patterns and resource exploitation drastically changed during the Dutch occupation due to the influx of Chinese immigrants. The introduction of the coinage system, luxury goods, large scale agriculture greatly shifted local ecology and social structures, and Taiwan became the major exporter of deer hides, venison, sugar, and rice. By the end of the eighteenth century, the western coastal plains were primarily colonized by Han Chinese, turning deer hunting fields into farmlands. Despite a certain degree of coexistence and the importance role of plain indigenous communities during the 18th century (Shepherd, 1993), coastal indigenous populations were forced to move inland, or risk being killed or Sinicized (Chen, 2017, p.278; Shih, 2012). This has resulted in the almost complete loss of language, traditional economies, and cultures of the coastal plain tribes (平埔族). More research of archaeological and historical records is needed to retrace and reconstruct the traditional hunting-fishing economies of the west coast of Taiwan during the Historical Period.

4. Ancient fisheries in Taiwan

4.1 General overview of prehistoric fisheries in Taiwan

The earliest archaeological sites in Taiwan in during the Upper Paleolithic Period (30,000-15,000 BP), which all belong to the Baxiandong complex on the east coast, often lack the 'maritime components' where fishing tools and marine faunal remains are almost absent (Chen *et al.*, 2018, p.40). The lack of evidence of marine exploitation coincides with and is explained by the lack of Upper Paleolithic sites in Taiwan, where most coasts of Taiwan, other than the uplifted east coast, were submerged during the Holocene sea level highstand (ca. 6-8ka, see above).

With the absence of underwater archaeology in submerged prehistoric sites, the earliest evidence of fishing in Taiwan is found in the Baxiandong sites, the Eluanbi II site, and the Longkeng site that are dated to the Preceramic Period (6500-5500 BP). Fish resources were important to the human diet throughout the Neolithic to the Metal Period. For example, human behavioral ecological models and archaeological data suggest a moderate to high reliance on fishing (never less than 20 %) even after the adoption of crop cultivation during the Neolithic Period (Yu, 2021, p.166). Zooarchaeological and isotopic data have shown that this general high reliance on marine resources among coastal populations only transitioned to be regionally varied after the Metal Age (1500 BP-AD 1624) (Figure 5, C.-Y. Lee, Chen, and Wu 2018; W.-C. Chen 2006). This transition in diet pattern, whether with a significant increase or decline in marine resource reliance, is widely observed globally, a phenomenon caused by the pivotal economic change when new long-distance trading networks of the Bronze (Metal) age economy took hold (Hudson and Fernández, 2023). The reduction of reliance on marine resources moving into the Metal Period is evidenced by stable isotope analysis of human bone collagen, where a significant shift from marine resources towards land-based plants and animals was observed (Lee et al., 2018).The causes behind this transition is less clear for both sites in both studies mentioned, but possible factors include shifts in cultural perceptions of fishing (Hudson and Fernández, 2023), resources depletion, and local or regional climates that favor agriculture (Chi and Hung, 2012, p.26). Regional variabilities in subsistence patterns can be observed during this period. Marine subsistence activities declined in the Hengchun Peninsula (Li, 2002), with a switch in focus towards terrestrial resources, a trend also observed in

Southeastern China's complex forager culture (Chi and Hung, 2012); while sites on the southwestern coastal plain show a persistence of fisheries throughout the Metal Period (Pan, 2021; Tsang and Li, 2013).

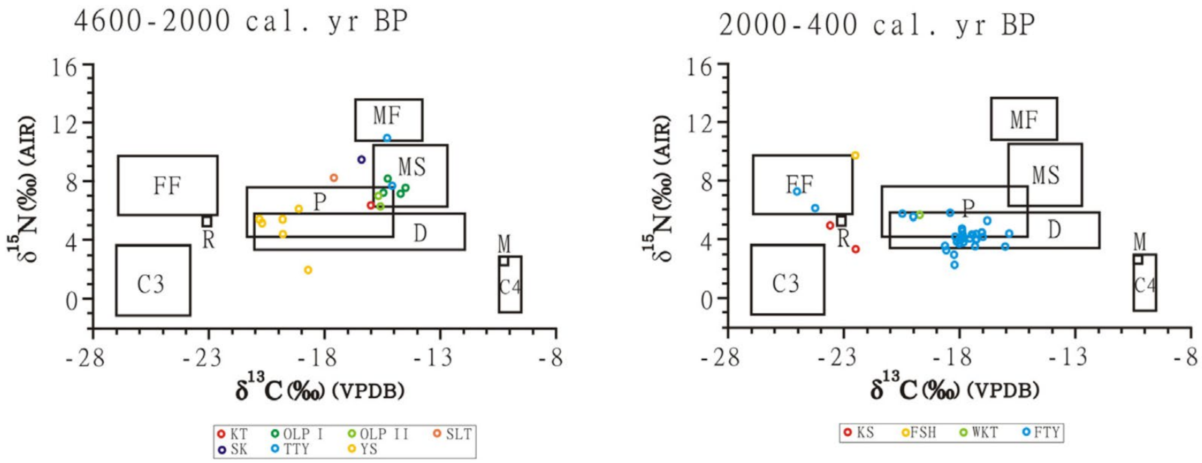

Figure 5: Stable isotopic values of human bones that showed a significant decrease in marine food consumption from various sites in Taiwan (Lee, Chen, and Wu 2018:358, Fig. 3). C3: modern C3 plants; C4: modern C4 plants; M: modern millet grain; R: modern rice grain; D: deer flesh; P: pig flesh; FF: freshwater fish flesh; MF: marine fish flesh; MS: modern marine shellfish flesh.

Despite the overall transition from maritime to terrestrial resources, fishing intensified at certain sites since the Neolithic-Metal age transition (~2500 BP), mostly on the western coastal plains where frequent contact with Chinese fishers took place during the Contact period. Chinese historical records indicate frequent interactions with Chinese fishermen since the Metal Age and suggest a larger-scale fishery primarily practiced by Han Chinese immigrants during the Dutch occupation (Lin, 1997), who also started aquaculture along the west coast of Taiwan since the end of Ming Dynasty (AD 1368 to 1644) (Tseng, 2012, p.7).

Studies focused on prehistoric fisheries in Taiwan are scarce. Though fishing tools such as net sinkers and fish remains are commonly found in most coastal sites, it is challenging to quantify and accurately reconstruct prehistoric fisheries data due to the nature of rescue archaeology which uses recovery methods that are biased towards larger sized specimens. For example, as mentioned above, a 1.6 mm screen size is the ideal size to retrieve fish remains from archaeological excavations. At the very least, sieve sizes smaller than 3 mm should be employed to retrieve ancient fish remains. However, in

Taiwan, fine screening (<1.6 mm) is hardly practiced in most archaeological excavations due to time and cost constraints and in general only using a 2 cm screen to wet sieve is a common practice in salvage archaeology (Yu-Pei Chen, 2022, p.405)

After the introduction of the Cultural Heritage Preservation Act (CHPA) in 1982 (updated 2016), the private sector has replaced the public sector to become the main source of funding for most excavations. Development-led archaeology is carried out under the name of salvage-, rescue- or contract-archaeology, resulting in the production of a massive amount of archaeological excavations and reports that remain in the grey literature and do not comply to the standards for academic research (Maa-Ling Chen, 2022; Zorzin *et al.*, 2022). For example, the Huagangshan Site that is located on the east coast of Taiwan has undergone 11 surveys and rescue excavations from 1929 to 2017 by 5 different excavators from different institutions through different contracts by multiple developers. This site is the type of site of the Huagangshan Culture, a cultural period of the Late Neolithic Period (3500-2500 BP) of the east coast of Taiwan and has yielded rich archaeological data spanning over 5000 years but the data is scattered in multiple excavation and archaeological records (Chen and Yao 2017:14)[3]. Efforts to incorporate and analyze fisheries data across grey literature have been critical but these reports are limited in numbers (Hsieh, 2014; Pan, 2021; Yu-Pei Chen, 2007b). Below I review existing studies focusing on fisheries and grey literature available online that are not included in the previous literature.

4.2 Literature on Prehistoric Fisheries in Taiwan

Published academic articles and theses focused on fishing tools and fisheries are limited but have provided crucial information of prehistoric fisheries in Taiwan. Studies on prehistoric (30,000 BP-AD1624) fisheries available in Taiwan include analyses of fishing tools (Yu-Pei Chen, 2007b; Hsieh,

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[3] Research, excavation history, and some excavation reports are available for registered archaeological sites on the National Cultural Heritage site (https://nchdb.boch.gov.tw/).

2014; Lee, 2022), shellfish remains (Wei-chun Chen, 2019; Li, 2005a; Chen Wei-Chun, 2007; Li *et al.*, 2005), fish remains (Pan, 2021; Lin *et al.*, 2022; Li, 2002), subsistence activities (Chen, 2006; Li, 1989; Liu, 2012; Li, 2002; Li, 1993; Li, 2013), and human remains (Lee *et al.*, 2017; Lee *et al.*, 2018; Lee *et al.*, 2016; Institute of Anthropology, National Tsing Hua University, 2015).

4.2.1 Fishing tools

Fishing tools are crucial archaeological evidence to understand prehistoric fishing due to their high durability and larger size that overcome retrieval biases and taphonomic processes. However, the interpretation of the fishing gears and fishing techniques is extremely challenging due to the highly diverse toolkits, human behaviors, fish anatomy and fish behaviors. Interpretations of prehistoric fishing methods based on modern analogies should be done with extreme caution due to the highly modified marine ecosystem, fish behaviors and biology, as well as the fishing environments (Morales-Muñiz, 2010, pp.48–52). A combination of rich archaeological and ethnographic data along with the thorough understanding of the historic biology of targeted fishes is crucial to better reconstruct prehistoric fisheries based on fishing tools and ichthyoarchaeological remains (Morales-Muñiz, 2010; Alfaro-Giner, 2010).

Fishing tools common in Taiwanese archaeological assemblages include net sinkers, fishhooks, fish gorges, harpoons, and others. Stone net sinkers are by far the most found fishing tools in Taiwan. In his intensive review of double-grooved stone net sinkers in Taiwan, Chen (2007b) recorded 93 coastal and inland sites with reported findings of double-grooved stone net sinkers from the massive amount of existing reports and published studies. Up until 2024, this remains the only study that attempted to summarize and compose collective data on prehistoric fishing across Taiwan. Other studies focused on stone net sinkers from specific sites and regions are conducted, contributing to our understanding of the social and functional differences between different types of stone net sinkers in Taiwan (Li, 1996a; Li, 2002; Hsieh, 2014). As fishing nets are rarely preserved in archaeological sites in Taiwan, our understanding of the making of fishing net remains limited. A rare case of net imprints on pottery sherds in Tainan (1600-500 BP) estimated that the diameter of fishing net threads as 0.5-1 cm, in comparison to the thin nylon thread (~0.25 cm) used in modern fisheries (Yu-Pei Chen, 2007b, p.126). In addition, ethnohistorical data suggests the use of plant fiber such as ramie (苧麻, *Boehmeria nivea*) and coast cottonwood (黃槿, *Hibiscus tiliaceus*) in traditional fishing net making (Pu, 2017; Zheng, 1996). Existing studies show that stone net sinkers in Taiwan can be grouped into three general groups based on tool morphologies: the notched-pebble (*Chinese: balance weight* 砝碼) type "砝碼型網墜", the grooved type "兩縊型/三縊型網墜", and the grooved-pebble type "帶槽卵型石網墜". Some scholars further developed detailed morphological groups under these major groupings (Hsieh, 2014, pp.144–145).

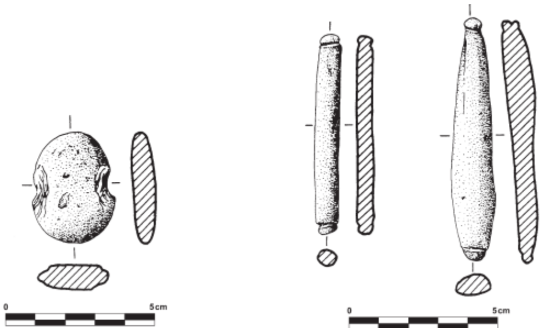

Figure 6: Net sinkers from the Forty-Eight Heights site of Eastern Taiwan. Left: notched-pebble type; right: grooved type (Li, 2002, p.58)

By combining archaeological and ethnographic data, stone net sinkers are inferred to be used in both net and rod fishing. Stone net sinkers with different sizes and shapes are suggested to be used for different types of net or rod fishing. The notched-pebble net sinker, which are the most common stone net sinkers found on the east coast (Yeh, 2001, p.41), are suggested to be used in deeper water fishing (Hsieh, 2014, p.6); while double-grooved stone net sinkers (Yu-Pei Chen, 2007b), smooth gorges (Lee, 2022), and stone net sinkers lying at the smaller and lighter end of the assemblage (Hsieh, 2014) might be used as a part of composite fishhooks or independent sinkers for rod fishing. In addition, larger and heavier stone net sinkers might be used in set net fishing (Hsieh, 2014, p.142),

Fishhooks are generally considered to be scarce in Taiwan, which differs starkly from the abundant evidence of hook and line fishing among Pacific Austronesians (Chen, 2018). Li (2002, p.61) notes that there were only 7 sites yielding fishhooks in Taiwan, including Fengbitou, Eluanbi I, Eluanbi II, Guishan, Baxiandong, Suogang (Penghu)[4]. Li suggests that the scarcity of fishhooks in Taiwan might be due to the limitations of retrieval methods that did not favor the use of screening in most large-scale excavations (Li, 2002, p.62). Fortunately, fishhooks and gorges[5] are reported in more sites across Taiwan recently, including several sites in the Wujiancuo site (五間厝, , Youxianfang site (右先方, 3300-2800 BP), Sanbaozhu site (三抱竹, 3800-3300 BP and 1400-1000 BP), and the Daoye site (道爺, 1400-1000 BP) in the Tainan Science Park (Tsang *et al.*, 2006; Tsang and Li, 2018), the Liangdao site (亮島島尾, 8320-7310 BP) (Taiwan Cultural Memory Bank, 2021),the Jiuxianglan site (舊香蘭, 1980-2300 BP) (Li and Yeh, 2005; Li and Yeh, 2006), the Qingshuishekouwei site (清水社口尾, 1350-1700 BP) (Lee, 2022; Lee, 2023), and etc. All sites mentioned previously are large-scale salvage excavations except the Liangdao site. Hence, recent data suggest the previous claim of the lack of fishhooks in Taiwan is no longer applicable. Among the fishhooks excavated, one-piece fishhooks "魚鉤" that include a shank and a hook are scarce, where fish gorges "魚卡子" or double pointed gorges "兩頭尖骨" (Li, 2002; Chen, 2006) are more commonly found (**Figure 7**).

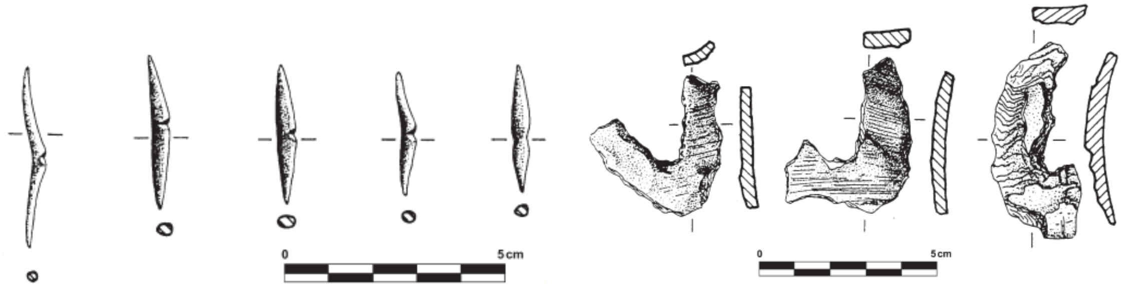

Figure 7: Common types of fish gorge (left) and fishhooks (right) found in Taiwan (Li, 2002, p.63).

In other cases, fish gorges are used as a part of a composite fishing tool (**Figure 8**). For example, Lee (2022) suggests that the double-pointed gorges excavated from the Qingshuishekouwei site (清水社

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[4] The last site of the 7 sites is not specified in the article (Li, 2002, p.61).

[5] Fish gorges are smaller points that work similarly as a fishhook. Without a hook, a gorge is easier to be manufactured but need to be swallowed and stuck within the fish throat to land the fish. Fish gorges are either discarded after landing the fish or requires extra efforts to retrieve after the harvesting of the fish (Salls, 1989).

口尾, 1350-1700 BP), where a groove is located on one end rather in the middle, are used as a part of composite fishhooks. Besides, one double-pointed gorge found at the site with smooth surface is suggested to be used in similar ways as a toggle-head harpoon “離頭銛” from Japan, a fishing tool that is reportedly found in the Liangdao site, an offshore island site that dates back to ~8000 BP (Lee, 2022).

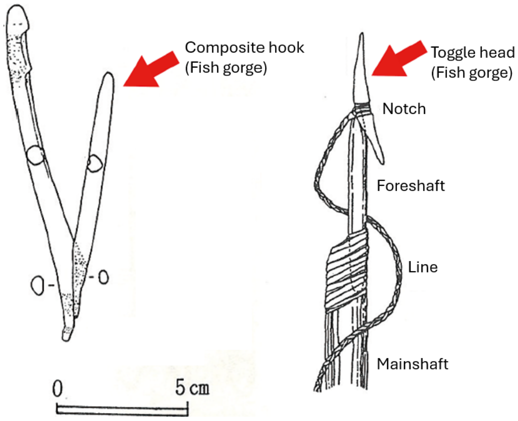

Figure 8: Examples of fish gorge used as a part of a composite hook (left) and a toggle-head harpoon (Modified from T.-T. Lee 2022, 6).

4.2.2 Shellfish remains

Shellfish are frequently found in coastal sites in Taiwan, especially found in large numbers in shell middens and refuse pits. With a larger size and higher resilience to site formation processes, shells were often found in larger numbers than fish remains in coastal sites, especially in excavations without the practice of screening. Shell middens were discovered in sites along all of the coasts of Taiwan since the Paleolithic Period (~8000 BP) (Chun-Yu Chen, 2019). Most notably, shell middens dominate zooarchaeological remains in coastal sites dating prior to the Middle Neolithic (4500-3500 BP). For example, shell middens of this period are found on the Matsuu Island (~6000 BP) (Bureau of Cultural Heritage, n.d.), on the south coast (~5200-2500 BP) (Li, 2009; The Academia Sinica Center for Digital Cultures, n.d.; Central News Agency, 2022), on the southwest coast (~4800-4200 BP) (Tsang and Li, 2018; Tsang *et al.*, 2006; Li, 2013).

Several studies focused on archaeological shellfish assemblages with complete species lists and stable isotope analysis provided important information on prehistoric shellfish harvesting. Li et al. (2005) analyzed shellfish assemblage from various sites on the Penghu islands (4700-4300 BP). The results showed that the prehistoric islandic populations exploited highly diverse shellfish taxa year-round at different island sites that have extremely limited land resources. Shellfish taxa abundance and composition have fluctuated due to coastal environmental change rather than overfishing. In addition, shellfish abundance and size of the archaeological assemblage were significantly larger than modern populations (2005, p.96), showing a significant shift in ecological baseline from the prehistoric populations. Oxygen stable isotope analyses on shellfish remains were carried out to reconstruct fishing seasons and paleo-environments (Pearson, 2023b, p.71). Despite their importance and frequent co-occurrence with fish remains, their relationship with fishing activities remains less clear in most sites, as shellfish and fish remain are often analyzed and interpreted independently.

Marine and freshwater shells are seen as the main source of protein to paleo-human diets due to their accessibility, abundance, and predictability, such as the case in the Guishan site and Kenting site on the Hengchun Peninsula of southern Taiwan (4500-4500 BP) (Li, 2005b; Li, 2005a). However, the determination of the role of shellfish in human diets based on abundance should be done cautiously due to the difference in meat yield and meat processing methods (Erlandson *et al.*, 2009; Erlandson, 1988). For example, Pan (2021) suggests that shellfish, despite their abundance and domination (95 % of the zooarchaeological assemblage), is seen as less cost-efficient due to their low calorific value and larger shell volumes that are inedible when compared to terrestrial mammals, especially cervids and suids at the Xiliao site (3500-500 BP). Similarly, human bone stable-isotope analysis have shown that marine fish was the main contributor to human diet rather than marine shells at the Liangdao site (8320-7310 BP) despite the domination of shellfish in the zooarchaeological assemblage (Chun-Yu Chen, 2019, p.11).

4.2.3 Fish remains

Marine zooarchaeological studies are scarce in Taiwan but are provide crucial information to understand the past fish ecology, target species, fishing techniques, and their changes through time. This section reviews three case studies of icthyoarchaeological studies with fish remains that are identified to at least the family level.

Case study 1. Eluanbi II

Site History

The Eluanbi II site is located at the Eluanbi National Park in the southern tip of Taiwan and was continuously occupied during 5000 BP to 2500 BP, which is the one of the two sites in the south coast that dates to the Preceramic Period (6500-5500 BP). Two major archaeological excavations were carried out at the site in 1982 by Kuang-chou Li and in 1993 by Kuang-ti Li. Rich marine faunal remains, fishing tools, and shell ornaments were found at the site, suggesting that fish was the main source of food in the region. The marine zooarchaeological assemblage from this site is well studied to analyze fishing subsistence strategies, mainly studied by Kuangzhou Li (1996b; 1996c) and Kuang-ti Li (1989; 1993; 2013; 2002), which remains as the best studied marine zooarchaeological assemblage in Taiwan. An analysis of fishing tools was conducted on both datasets but detailed ichthyoarchaeological analysis with fish species list is only available for the 1993 dataset.

Site Chronology

In the 1982 excavation, fifteen 2x2 m, one 2x3 m and one 1x1 m pits were divided into 5 regions. Four well defined cultural layers were identified within the site, which are recognized as the general prehistoric cultural stratigraphy across the Hengchun Peninsula. Named after the Eluanbi II site, this cultural sequence is called “Eluanbi Cultural Phases 鵝鑾鼻史前文化相”, and is now widely accepted and used in local archaeological literature. The four Eluanbi Cultural Phases are: Phase 1 (5000-4000 BP): Preceramic sequence dominated by stone tools and shell remains; Phase 2 (4000-3000 BP):

Neolithic sequence characterized by fine cord marked red ceramic, diversified stone and shell tools, and the emergence of fishhooks; Phase 3 (3000-2500 BP): Neolithic sequence characterized by painted ceramic, and a proliferation of agricultural stone tools, bone needles, and fishhooks; Phase 4 (2500-1500 BP): Neolithic to Metal Period sequence is characterized by plain ware ceramics and a decrease in marine faunal remains. Similar cultural sequences were found in the 1993 excavation. These phases correspond to the following cultural chronology in this study respectively: Preceramic, Middle Neolithic, Late Neolithic, and Metal Periods. The Eluanbi II site and the Longkeng site are the only two Preceramic sites found in Taiwan other than the east coast.

Archaeological Evidence

Fish and marine faunal remains

Faunal remains of the Preceramic sequence from the 1982 assemblage were analyzed with a focus on shellfish remains, the most abundant zooarchaeological remains (95.5%). Fish bone is the least abundant faunal remains and are all identified as diodontids (Li, 1996c, p.130). Mammal bones mainly consist of cervids (true deer) and suidae (wild boar). Dominating the faunal assemblages of both excavations is marine shellfish (**Table 2**). Turban shells, which are large marine gastropods with hard shells and a strong calcareous operculum, dominate the shellfish assemblage. The green turban (*Turbo marmoratus*), the largest turban shell species in Taiwan, consists of the major mollusk species at the site, accounting for 89.58% (45.9 kg) and 73.3% of mollusks from the 1982 and 1993 assemblages, respectively. The thick and robust operculum of *Turbo marmoratus* can be manufactured as useful tools such as shell scrappers and net sinkers or floaters. Notably, the findings of 109 shell scrapers made of the operculum of *Turbo marmoratus* within the Preceramic sequence support the importance of shellfish to human diets and tool manufacturing (Li, 1996c, p.126). Other shellfish species include a smaller turban species, *Turbo sandwicensis*[6], and clams such as *Cyclina sinensis*, *Asaphis violascens*, and Tridacna.

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[6] Known as *Turbo argyrostomus* in local literature.

Scholars have mixed views on the relative importance of marine shells and fishes to human diets, which are further discussed below.

Table 2: Faunal remain distribution of the Preceramic sequence in Eluanbi II from the 1982 assemblage (Li 1996c:128).

	Net weight (g)	**% of total**
Shellfish	51,350	95.50%
Turtle shell	1,738	3.23%
Mammal bone	668	1.24%
Fish bone	12	0.02%
Total	53768	100%

Fish remains are better analyzed for the 1993 dataset, where they are identified to 15 families (**Table 3**) and some are quantified by weight (**Table 4**). The fish assemblage in Eluanbi II is dominated by offshore pelagic taxa, which are species that are only found in the open ocean, especially dolphinfish (Coryphaenidae) and sail-fish (Istiophoridae), which is the only site dominated with by offshore taxa in Taiwan (Pearson, 2023c, p.64). Inshore species were also constantly found throughout the occupation of the site, including reef species such as reef-associated parrotfish (Scaridae) and nearshore schooling mullets (Mugilidae). Requiem shark (Carcharhinidae) remains significant throughout the occupation, but its wide range that can be found both inshore and offshore requires further higher identification to determine fishing techniques and fishing grounds.

Table 3: Taxa list of the 1993 fish assemblage of Eluanbi II (Modified from K.-T. Li 2002, Table 1). Weight data of certain taxa are available in **Table 4**.

Taxa (Family)	**Common name**
Nearshore	
Muraenidae	Moray eels
Mugilidae	Mullets
Lethrinidae	Emperors, emperor breams
Labridae	Wrasses
Scaridae	Parrotfish
Acanthuridae	Surgeonfish
Balistidae	Triggerfish
Diodontidae	Porcupinefish
Lutjanidae	Snappers

Table 3 continued

Serranidae	Sea basses and groupers
Carcharhinidae	Requiem sharks
Pelagic	
Istiophoridae	Marlins
Sphyraenidae	Barracudas
Carangidae	Jacks, pompanos, and runners
Coryphaenidae	Dolphinfish

Table 4: Quantity data of the Eluanbi II fish assemblage that are available in Weights (g).

Taxa	**Common name**	**Preceramic**	**Mid Neolithic**	**Late Neolithic**	**Metal**	**Total**
Nearshore		113	302	1193	378	1984
Carcharhinidae	Requiem sharks	81	191	449	140	861
Mugilidae	Mullets	27	87	610	204	928
Scaridae	Parrotfish	4	16	86	34	139
Diodontidae	Porcupinefish	1	8	48	-	56
Pelagic		38	56	1167	997	2258
Coryphaenidae	Dolphinfish	0	7	285	109	401
Istiophoridae	Marlins	38	49	882	888	1857
Total		**151**	**358**	**2360**	**1375**	**4242**

Fish bone weight indicated an increase from stratum 1 (4%) and stratum 2 (8%), peaked at stratum 3 (56 %), and declined in stratum 4 (32%). High fish weight in stratum 3 is accompanied by the highest yield of offshore taxa of dolphinfish, sail-fish and mullet, and the highest number of fishing tools, suggesting an intensification of fishing subsistence strategies (Li, 2002). The constant findings and low abundance (<3%) of porcupinefish (Diodontidae) that inhabits the intertidal zones and are thought as poisonous and not consumed by modern populations, is interesting and was suggested to be of symbolic uses in the past (Li, 1989). The decline of fish abundance observed in the latest occupation phase (2500-1500 BP) coincides with similar phenomena observed in other sites across Taiwan (discussed below). Mullets are schooling fish that migrate to the coastal waters (30 m in depth) of western and southern Taiwan every November to February. Mullets, especially the flathead gray mullet (*Mugil cephalus*), are an important target species to historical and modern commercial fishing. They are harvested and processed for mullet roe or “Karasumi,” a delicacy in Taiwan, China, and Japan.

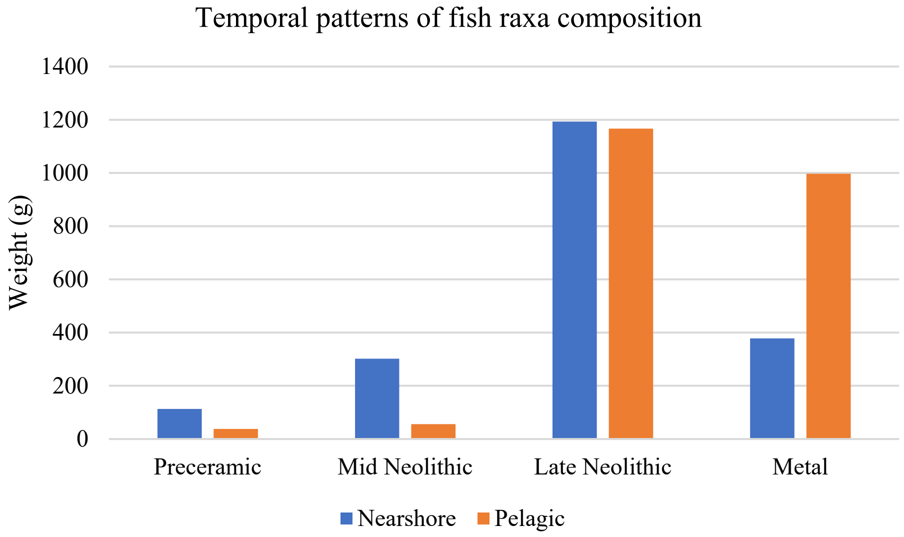

Figure 9: Fluctuations of fish taxa based on fish bone weights in Eluanbi II. (Modified from K.-T. Li 2002).

Fishing tools

Fishing tool analysis is conducted on the 1993 assemblage. Net sinkers (fishing weights used in net fishing and angling) and fishhooks made of stone, bone, and shells were found in high numbers in the Eluanbi II and studied in detailed with reference on ethnographic fishing records by Kuang-ti Li in two separate studies (1989; 2002). Net sinkers were found in large numbers (n=242) and are concentrated in the last two strata (3000-1500 BP), with varied morphologies that are thought to represent functional differences. Most (n=221) net sinkers are made of lithic, except some (n=21) that are made of the operculum (shell structure) of *Turbo marmoratus* and one was made of coral fragments (Li, 2002, p.59). Fishhooks are rarely found in archaeological sites in Taiwan but are found in large numbers on the site. The Eluanbi II was one of the seven known sites with the findings of fishhooks (Li, 2002, p.62), and more fishhooks have been discovered from archaeological sites in Taiwan (see below). There were 4 and 58 fishhooks found in the 1982 (Li, 1989, p.28) and 1993 datasets respectively, primarily consisting of one-piece and composite gorges. Fishhooks are made of lithics, deer bones, and shells. The abundance of fishing tools was low in the first two strata, significantly increased and peaked in Stratum 3 and declined in Stratum 4, correlating with the observation from fish bone assemblage. The morphologies of fishing tools remained relatively constant in the last two strata, suggesting the persistence of similar fishing techniques. However, fish bone assemblage showed slight changes in species composition during this time (3000-1500 BP), especially the constantly high numbers of marlins in the last two strata, which is thought to be caught by spear fishing (Li, 2002, p.60). Hence, the functional relationship between trends observed in net sinker types and target species is less clear (Li, 2002, p.56).

Analysis and interpretation on ancient fisheries

Based on zooarchaeological data, prehistoric subsistence at the Eluanbi II site was focused on shellfish harvesting and shifted to marine fishing through time. There is a significant increase in offshore taxa, especially dolphinfish and marlins, observed during stratum 3 (3000-2500 BP) that corresponds to Middle and Late Neolithic. Currently, these taxa are highly migratory pelagic species that migrate to the offshore waters off the northeast, east and south coasts of Taiwan during specific seasons of the year (Shao, n.d.). Hence, the presence of these taxa in Eluanbi II indicates adequate naval technologies to access offshore fishing grounds at least by the Late Neolithic (3500-2500 BP). This includes the ability to manufacture seaworthy watercrafts and navigational techniques to harvest and transport fish back to the site (Bednarik, 2003; Arnold, 1995). Hence, the finding of pelagic taxa in archaeological fish assemblage sheds light on the prehistoric naval technologies (Amesbury, 2013; Vostretsov, 2022), which are currently underexplored in Taiwan. A comparable ichthyoarchaeological assemblage dominated by marlins and dolphinfish (*Mahimahi*) (Amesbury and Hunter-Anderson, 2008), is observed in the Batanes Islands, the northernmost part of the Philippine archipelago, which is proposed to be a link between Taiwan and Southeast Asia for Austronesian migration (Bellwood and Dizon, 2008). Better quantification and lower levels taxonomic identifications are crucial to further understand fishing behaviors, seasonality, and the connection between fisheries of southern Taiwan and northern Philippines. For example, marlins and dolphinfish are economically important species with distinct behaviors and seasonal distribution off the east coast of modern-day Taiwan, which are well documented (Johnson 2023). This information can be used to expand our understanding of prehistoric offshore fisheries when comparable taxonomic and quantification units are established.

Additionally, the abundance of shallow water taxa, such as sharks, parrotfish and porcupine fish, increased through time, showing a similar increase in nearshore fishing techniques and fishing efforts (**Figure 9.**). A combination of ethnographic data and archaeological data shows seasonal exploitations of different marine species using different fishing techniques that highlight the extensive knowledge on marine ecology and resource exploitation. Ethnographic records of the Ami tribe, known to still practices marine foraging and fishing on the east coast of Taiwan, suggests the use of at least five types of fishing methods at the site: bottom line fishing, trolling, spearing, scoop net fishing, cast net fishing, dip net fishing, beach seine fishing, and poisoning (Li, 2002; Li, 1989). However, a better understanding of fish species composition and size is needed to understand the behaviors and anatomy of targeted species. This information is essentially for accurately linking ethnographic records of fishing technologies with archaeological fish assemblages (Morales-Muñiz 2010, see section 2.2). In addition, it remains unclear whether fishing was for self-sustenance or trade. It is interesting to note that remains of porcupinefish, now believed to be poisonous and not eaten, can be found continually at Eluanbi II since the beginning of the settlement (Li, 2002, p.55). As discussed above, the consumption behaviors of toxic fishes such as diodontids and tetraodontids are highly cultural-specific and sheds light on spatio-temporal changes of sociocultural values. A focus on the consumption patterns of diodontids and tetraodontids in other sites in Taiwan will contribute to our understanding of cultural preferences and interactions.

Case study 2. Xiliao

Site History

Located in Tainan, the Xiliao site lies on the alluvial plain of the Tsengwen River on the central part of the vast Jianan Plain, the largest plain on the island of Taiwan. The site was first discovered during the environmental impact assessment for a highway construction by Yi-Chang Liu in 1992 and has undergone multiple large-scale rescue excavations from 2006 by contract excavations conducted by the Institute of History and Philology, Academia Sinica. Pan's (2021) Master's thesis identified and analyzed fish remains from the rescue excavation to study the fishing subsistence of past populations at the site. This study is the only study focused on the identification of all fish remains (bones, otoliths, teeth) from a site in Taiwan.

Site Chronology

The Xiliao site contains four distinct cultural layers based on ceramic typology: the Middle Neolithic Period (4500-3500 BP), Late Neolithic Period (3500-2500 BP), the Metal Period (2500 BP-AD 1624). The site has undergone ongoing environmental changes in parallel to the Holocene sea level rise since the earliest occupation. Currently located around 17 km inland, the site was located on the shoreline of the paleo-marine bay ca. 4000 BP formed during sea level highstand prior to 6000 BP. The paleoshoreline continued to retreat towards the west throughout the occupation of the site due to stabilized eustatic sea level and alluvial deposition of the Tsengwen River. The site turned into a fully terrestrial-alluvial plain, surrounded by multiple river deltas during the second phase of occupation ca. 3300 BP. During the Metal Period (1800-350 BP), an inland sea, the Taijiang inland sea and was only drained during the end of the 1800s (Pan, 2021, p.27).

Archaeological Evidence

Fish and marine faunal remains

Marine faunal remains consist of the main part of the ecological remain assemblage, where shellfish (95% of total NISP) was the most abundant. Fish (NISP=20,067, weight=1381.501g) accounts for 2.17% of the ecological remains (**Table 5**). 6,256 specimens were selected for identification due to their diagnostic features as skull bones, otoliths, teeth, pharyngeal teeth, lateral ethmoids, and pelvic fin spines (Pan, 2021, p.39). NISP=1625 (25.98% of the selected assemblage, and 8% of the total fish assemblage) were identified to 33 taxa, including 1 Class, 4 Orders, 25 Families, 1 genus, and 2 species (**Table 6**). The two species identified in the assemblage are *Larimichthys crocea* based on otoliths, and

Arius maculatus based on otoliths and lateral ethmoids. The increase of number through time does not reflect significant changes in subsistence activities due to the difference in sample sizes where site area increases significantly from the Middle Neolithic to the Metal Period.

Table 5: NISP and weight distribution of ecological remains of the Xiliao site (Modified from Pan 2021: 30, Table 3).

	NISP	**Weight (g)**	**% of total**
Shell	879,854	3,842,126.93	95%
Mammal, Bird, Amphibian	16,550	175,993.19	2%
Fish	20,067	1,381.501	2%
Plant	6,699	140.279	1%
Crustacean	1,585	1,433.031	0.17%
Reptile	11	177.755	0.001%
Total	924,766	4,021,253.69	100%

Table 6: Species list of identified fish remains throughout the three occupational periods at the Xiliao site (Modified from Pan 2021: 55-56. Table 12).

Taxa	**Common name**	**Middle Neolithic**	**Late Neolithic**	**Metal Period**	**Total**
Freshwater		1	94	392	487
Cobitidae	True loaches	-	51	200	251
Synbranchidae	Swamp eel	-	32	143	175
Cyprinidae	Minnows and carps	1	11	49	61
Brackish		0	11	33	44
Ariidae (including *Arius maculatus*)	Ariid catfish	-	6	23	29
Siluriformes	Catfish	-	5	10	15
Brackish, nearshore		10	69	336	415
Haemulidae	Grunts	-	2	4	6
Sciaenidae (including *Larimichthys crocea*)	Drums and croakers	1	17	188	206
Sparidae (including *Acanthopagrus*)	Seabreams and porgies	9	50	144	203
Nearshore		29	111	539	679
Paralichthyidae	Large-tooth flounders	-	1	15	16
Cynoglossidae	Tonguefish	-	-	5	5
Platycephalidae	Flatheads	-	-	9	9
Uranoscopidae	Stargazers	-	-	1	1

Table 6 continued

Anguilliformes	Eels	2	18	123	143
Lutjanidae	Snappers	1	15	66	82
Leiognathidae	Ponyfishes	-	6	61	67
Gobiidae	Gobies	-	11	28	39
Latidae	Lates perches	10	18	5	33
Serranidae	Sea basses and groupers	-	9	16	25
Mugilidae	Mullets	1	5	18	24
Sillaginidae	Smelt-whitings	-	1	13	14
Pristigasteridae	Longfin herrings	-	-	4	4
Carangidae	Jacks, pompanos, and runners	-	-	1	1
Menidae	Moonfish	-	-	1	1
Engraulidae	Anchovy		9	64	73
Trichiuridae	Cutlassfish	-	3	54	57
Belonidae	Needlefish	-	-	17	17
Clupeidae	Herrings and sprats	-	-	3	3
Selachimorpha	Sharks	14	14	32	60
Batoidea	Skates	-	-	1	1
Elasmobranchii	Shark and skates	1	1	2	4
Identified NISP	-	**40**	**285**	**1,300**	**1,625**
% of row	-	**63.49**	**24.61**	**25.82**	**25.9**
Undetermined	-	19	748	3,251	4,018
Unidentified	-	4	125	484	613
Total	-	**63**	**1,158**	**5,035**	**6,256**

Fishing tools

Fishing tools are extremely scarce at the site (n=27), including fish gorges and pottery net sinkers. Stone net sinkers that are found in large numbers in the Tainan Science Park sites that are located ~8 km from the site, are completely absent. Pan suggests that the ‘short triangular point’ at the site but are not considered as fishing tools might be potential fishing tools (Pan, 2021, p.95). Fish gorges that are found excavated at the site are mostly 3-5 cm, which might have contributed to the higher yield of Scaienidae and Sparidae, which have the sizes most suitable for bait fishing with the gorges (Pan, 2021, p.64).

Analysis and interpretation on ancient fisheries

This study focused on understanding human fishing behaviors based on the optimal foraging theory based on the spatial relationship of resource availability and human settlements. Identified taxa are evaluated based on temporal and contextual distribution, size measurements and a biodiversity index (Simpson's diversity index). Excluding the Middle Neolithic fish assemblage due to its small sample size, results show that there is no significant change in species composition through time (**Figure 10**).The abundance difference between Late Neolithic and Metal Period is suggested to be caused by difference in site and excavated areas. Hence, the author suggests that marine resource availability and fishing techniques remained relatively stable throughout the ~4000 years of human occupation.

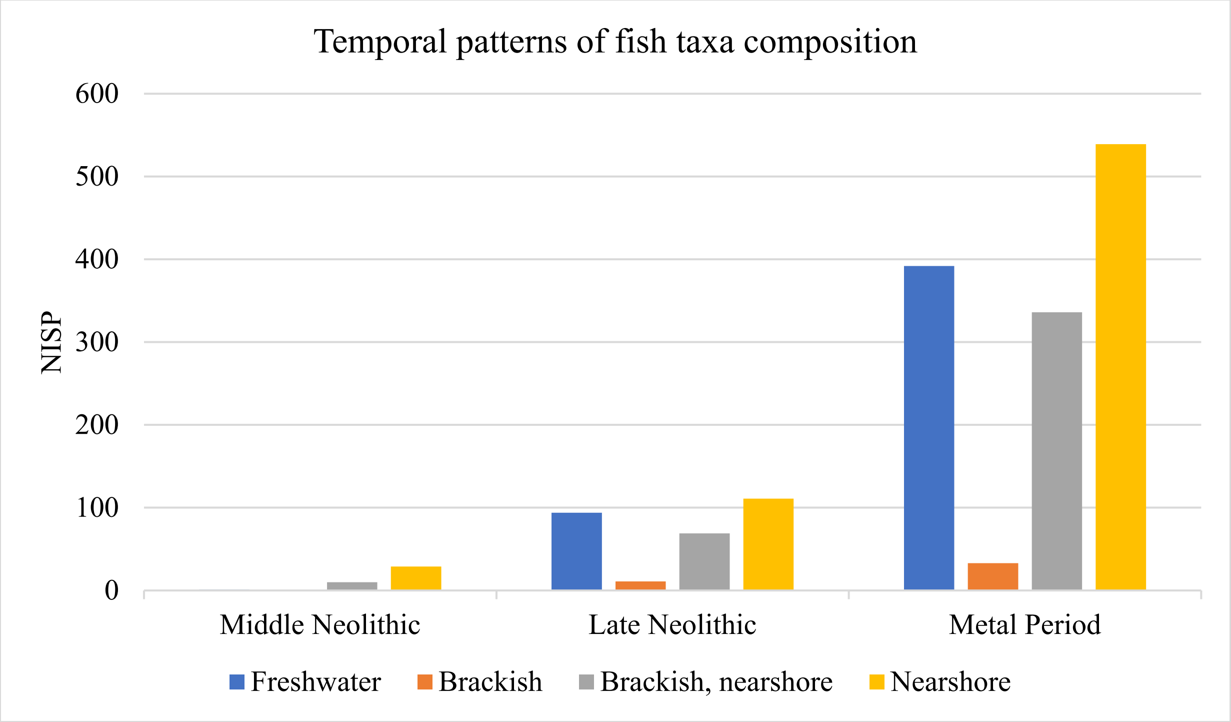

Figure 10: Fluctuations of fish taxa based on identified NISP through time at the Xiliao site (modified from Pan 2021).

The main target species are small to middle-size nearshore and freshwater fishes, especially Sciaenidae and Sparidae, which are thought to be fished by using baited gorges. The ubiquity of fish remains is calculated based on the number of test pits, rather than excavated volumes (Pan, 2021, p.65). In addition, the Simpson's diversity index shows highly similar values between the Late Neolithic and Metal

Period assemblage, with values of 0.915369 and 0.915584 respectively [7]. Notably, fish remains were mostly found in pottery firing pits and hearths, which might suggest that fish were used intentionally for firing practices or unintentionally discarded in these contexts (Pan, 2021, p.73).

The main target species, especially Sciaenidae and Sparidae, are typically found in a sandy bottom shallow marine environment that is surrounded by bays, lagoons, and deltas. This result conforms well with paleoenvironmental reconstruction where the palaeo-shoreline was shifting seawards, forming the Daofeng inland sea (古倒風内海) on the northwest side of the site, and a paleochannel of the Tsengwen River that is located nearer to the site compared to its current location (Pan, 2021, p.79). In terms of the role of fish resources in human diets, the ratio of fish to mammal remains rose in importance from 10.04% to 43.39% from the Late Neolithic to the Metal Period (**Table 7** and **Figure 11**), along with the increase of the abundance of marine shellfish, especially oysters. Though making up to ~95% of the total faunal assemblage (**Table 5**), marine shellfish is inferred to play a less important role as a source of protein due to its lower meat content and low cost-effectiveness (Pan, 2021, p.88). During the Late Neolithic, occupants at the site were practicing agriculture, suid husbandry, and deer hunting, with the increasing importance of agriculture, the importance of suids increased, where evidence of hunting (deer) significantly decreased, suggesting a more sedentary lifestyle (Pan, 2021, p.88) (see Table 3). To make up for this loss of protein source, prehistoric population at the site switched to a higher reliance of the easily accessible fish resources.

Table 7: The relative abundance of mammal and fish within the faunal assemblage of the Late Neolithic and Metal Period at the Xiliao site (Pan, 2021, p.85).

	Late Neolithic		**Metal Period**	
	Identified NISP	**Relative abundance (%)**	**Identified NISP**	**Relative abundance (%)**
Mammal	3451	89.96	1696	56.61
Fish	385	10.04	1300	43.39
Total	3836	100	2996	100

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[7] The diversity index values (D) are calculated as 1-D (Pan, 2021, p.45).

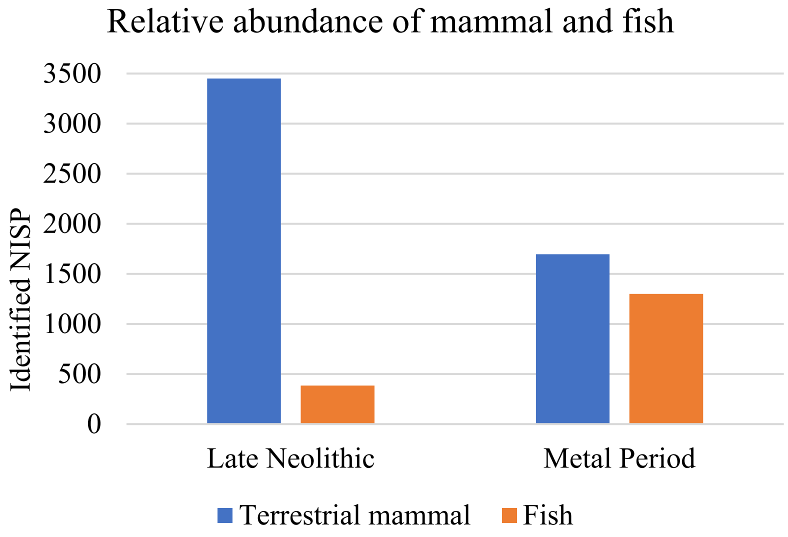

Figure 11: The relative abundance of mammal and fish within the faunal assemblage of the Late Neolithic and Metal Period at the Xiliao site.

Case study 3. Tainan Science Park sites (otoliths)

Site History

The Tainan Science Park sites are a cluster of 68 archaeological sites of different periods (4700 BP to present) that are located close to each other within the current Tainan Science Park, located in southwestern Taiwan. A large scale 15-year salvage excavation was commissioned by the National Science Council (NSC) and carried out by the Institute of History and Philology of Academia Sinica led by Cheng-Hwa Tsang, resulting in the excavation of 34 sites with extremely well preservations due to the protection of the thick alluvial sedimentation of the Tsengwen River. There are two studies focused on the otoliths, which are found in large numbers, from several sites in the Taiwan Science Park (Lin *et al.*, 2013; Lin *et al.*, 2022).

Site Chronology

The Tainan Science Park sites discussed in this study consist of five cultural chronologies with radiocarbon dates that correspond to the five chronologies adopted by this study: Early Neolithic (5500-4500 BP), Middle Neolithic (4500-3500 BP), Late Neolithic (3500-2500 BP), Metal Period (2500 BP-AD 1624), and Historical Period (AD 1624-1945). Currently located more than 20 km inland, the Tainan

Science Park was located on the palaeoshoreline during its initial opccupaiton during mid-Holocene (~5000 BP) (Tsang and Li, 2018). Earliest sites include the Nanguanli and Nanguanli-East sites (~5000-4200 BP) that contain the earliest evidence of cereal (rice and wheat) cultivation in Taiwan (see above). These sites experienced continuous environmental changes as the palaeoshoreline shifted westward to reach its current position ~1000 BP, switching from a coastal environment to a lagoonal and an inland environment. These sites were found buried under more than 2 m of alluvial sediments during the construction of the Tainan Science Park since 1995. A total of 68 sites were then excavated through the large scale 15-year salvage excavation from 1995 to 2010.

Archaeological Evidence

Fish and marine faunal remains

Large amounts of marine shells and fish remains (bones, teeth, otoliths) were found in several sites (Tsang and Li, 2018), but detailed fish remain analyses are only available in the two studies cited here that are focused on otoliths. A total of 1300 otoliths from 16 sites are analyzed, resulting in the identification of 1254 otoliths to a total of 30 taxa. A Multivariate principal coordinate analysis (PCoA), permutational multivariate analysis of variance (PERMANOVA) and similarity analysis (SIMPER) were carried out to test the significance of differences and similarities of fish taxa across and within the occupation periods. Statistical results show that species diversity and abundance declined and changed over time. *Larimichthys crocea* dominates the Early and Late Neolithic assemblages, and Ariidae dominates the Metal Period assemblage (see

Table 8). The size distribution of the dominant species, *Larimichthys crocea* was analyzed and fish size or total length (TL) was estimated based on the correlation curve of TL with otolith length (OL) and otolith height (OH) of modern reference collection. The size of *Larimichthys crocea* shows statistically significant differences through time, with a general increase in TL and OL. The size of *Larimichthys crocea* increased significantly across three occupational periods, with a gradual increase of inferred TL from 19.90 cm (Early Neolithic), 22.14 cm (Late Neolithic), and 25.71 cm (Metal Period).

The implications of these changes are further discussed below.

Table 8: Otolith species distribution through time at the Tainan Science Park. (Modified from Lin et al. 2022: 3, Table 2)

Family	Common name	Taxa	Early Neolithic	Middle-Late Neolithic	Metal	Historical	Total row
Brackish			41	21	212	0	274
Ariidae	Smooth-headed catfish	*Plicofollis nella*	–	4	14	–	18
Ariidae	Sea catfishes	Ariidae indet.	36	17	197	–	250
Channidae	Asian snakeheads	*Channa* sp.	5	–	1	–	6
Brackish, nearshore			700	83	126	1	910
Lateolabracidae	Asian seabasses	*Lateolabrax* sp.	–	2	–	–	2
Sillaginidae	Sillagos	*Sillago* spp.	106	6	22	–	134
Haemulidae	Silver grunt	*Pomadasys argenteus*	44	2	14	–	60
Haemulidae	Silver grunt	*Pomadasys kaakan*	2	3	6	–	11
Haemulidae	Grunts	*Pomadasys* spp.	15	4	49	–	68
Sciaenidae	Silver croaker	*Pennahia* spp.	2	6	8	1	17
Sciaenidae	Bearded croaker	*Dendrophysa russelii*	–	1	–	–	1
Sciaenidae	Drums and croakers	*Johnius* spp.	75	11	6	–	92
Sciaenidae	Large yellow croaker	*Larimichthys crocea*	452	47	19	–	518
Sciaenidae	Drums and croakers	Sciaenidae indet.	2	1	2	–	5
Sciaenidae	Spotted croaker	*Protonibea diacanthus*	1	–	–	–	1
Sparidae	Seabreams	*Acanthopagrus* sp.	1	–	–	–	1
Nearshore			47	9	6	7	69
Haemulidae	Saddle fish	*Pomadasys maculatus*	1	1	4	–	6
Haemulidae	Yellow-lined grunter	*Pomadasys quadrilineatus*	6	–	–	–	6
Sciaenidae	Reeve's croaker	*Chrysochir aurea*	2	4	–	–	6
Sciaenidae	Black croaker	*Atrobucca nibe*	–	–	–	6	6
Sciaenidae	White flower croaker	*Nibea albiflora*	–	2	–	–	2
Sciaenidae	Snapper kob	*Otolithes ruber*	9	–	–	1	10
Albulidae	Bonefishes	*Albula* sp.	–	2	–	–	2
Ophidiidae	Cuskeel	*Sirembo imberbis*	1	–	–	–	1
Mugilidae	Bluespot mullet	*Crenimugil seheli*	1	–	–	–	1
Mugilidae	Mullets	Mugilidae indet.	14	–	2	–	16
Gobiidae	Gobies	Gobiidae indet.	1	–	–	–	1
Engraulidae	Anchovies	*Thryssa* spp.	9	–	–	–	9
Serranidae	Seabasses and groupers	*Cephalopholis* sp.	1	–	–	–	1

Table 8 continued

Lutjanidae	Snappers	*Lutjanus* sp.	2	–	–	–	2
Pelagic			1	0	0	0	1
Exocoetidae	Flyingfish	*Cheilopogon* sp.	1	–	–	–	1
unidentified otoliths	–	–	14	10	22	–	46
Total	–	–	803	123	366	8	1300

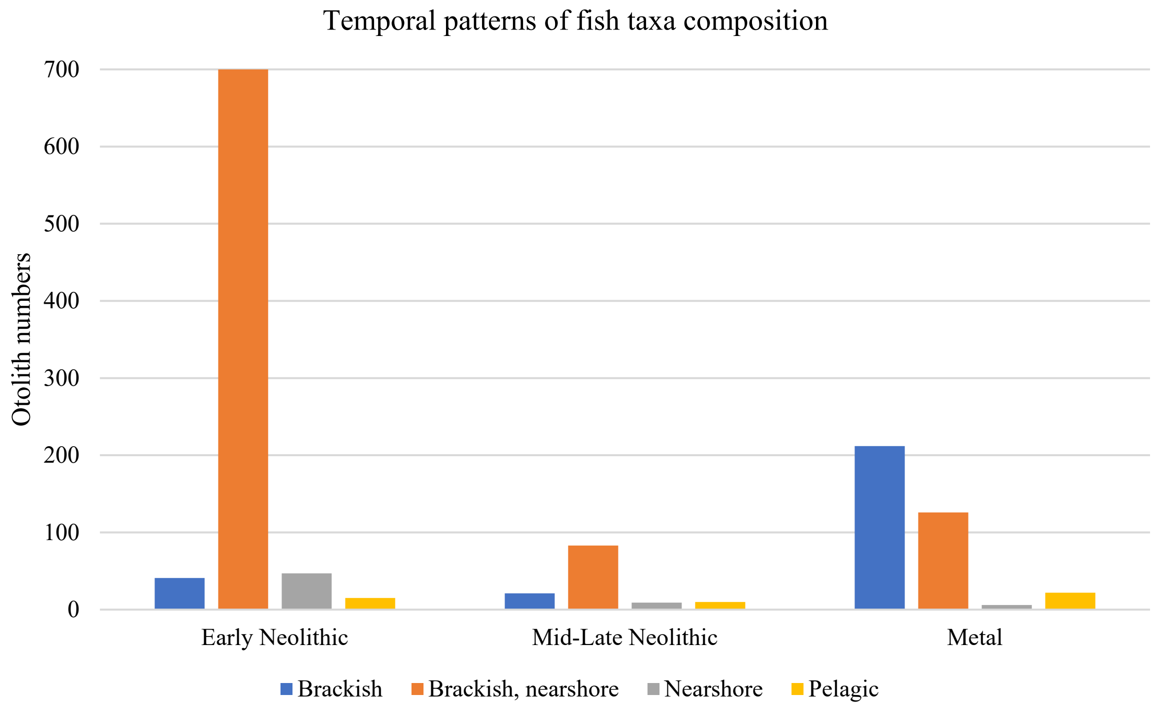

Figure 12: Fluctuations of fish taxa based on identified otoliths through time at the Tainan Science Park sites.

Analysis and interpretation on ancient fisheries

At Tainan science park significant changes of fish abundance and species composition over time is suggested to be caused by changes in coastal environment rather than the previous assumption of overfishing. Ariidae, the dominant taxa of the Metal Period, is adapted to lagoonal and brackish water, which coincides well with the known paleoenvironmental change at the site based on geological evidence. The site was transformed from a marine coast in the Neolithic to an inland site close to the Taijiang Lagoon during the Metal Period. This significant change greatly altered resource availability, causing a major shift in human fishing and diet. In addition, the increase observed in fish size over time is attributed to improved fishing techniques to harvest larger fish at deeper depths (Lin *et al.*, 2022, p.7). Changes in fishing techniques are left unexplored and there are no studies on the fishing tools found in the Tainan Science Park sites. Notably, the average length of the archaeological otolith assemblage of *Larimichthys crocea* at >200 mm is significant longer than the now-severely overfished and depleted modern population with an average length of 97 mm. This drastic difference highlights the importance of archaeology in understanding prehistoric baselines for the now-overfished populations. The cultural preference of the species *Larimichthys crocea* (large yellow croaker), a highly valued species in modern Chinese cuisine, might have originated from China, but further evidence is needed to explain the origin and spread of fish consumption behaviors. (Lin *et al.*, 2022, p.7)

4.3 Discussion

The fish assemblages from the three studies shed light on the prehistoric fisheries in Taiwan from 5500 BP-present in the southwestern and southern Taiwan (**Figure 13**). There are challenges to integrate and compare these datasets due to differences in cultural chronologies, taxonomic identification levels, and biogeographic associations. This section combines and discusses three datasets under the same cultural chronology and biogeography[8] association to facilitate comparative analysis.

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[8] Information on fish biogeography is based on modern fisheries distribution and are referenced from the Fish Database of Taiwan (Shao, n.d.) and the Ministry of Agriculture website (https://kmweb.moa.gov.tw/index.php).

Figure 13: Locations of the three sites discussed in section 4.2.

This comparative study of three ichthyoarchaeological studies in Taiwan also highlights the importance of cross-assemblage comparison to understanding regional fisheries trends. For example, ichthyoarchaeological data from the two sites on the coastal plain on Southwestern Taiwan, Xiliao and Tainan Science Park, reflects similar temporal changes. Environmental changes, specifically the retreating palaeoshoreline, has caused the significant increase of the relative abundance of brackish- and freshwater taxa in both sites (**Figure 14**). However, the increase of freshwater taxa in Xiliao is absent in Taiwnan Science Park, which might imply different adaptation strategies to the changing environments and proximity to rivers. Future ichthyoarchaeological analysis that considers the changes of sea level and paleo-river channels of the southwestern coast is crucial to further understanding human-environmental interactions through fisheries in this region. In contrast, there is no brackish and freshwater taxa found in Eluanbi II throughout the prehistoric occupation, and the archaeological fish assemblage was dominated by two pelagic taxa: marlins and dolphinfish. As the sole area in Taiwan and one of the few in Southeast Asia with evidence of prehistoric offshore fishing, future efforts should be directed towards achieving lower taxonomic identifications and understanding prehistoric naval technologies on the southern coast of

Taiwan. This information can further contribute to understanding socio-economic relationships with other offshore fisheries or maritime populations in the region (see Case study 1).

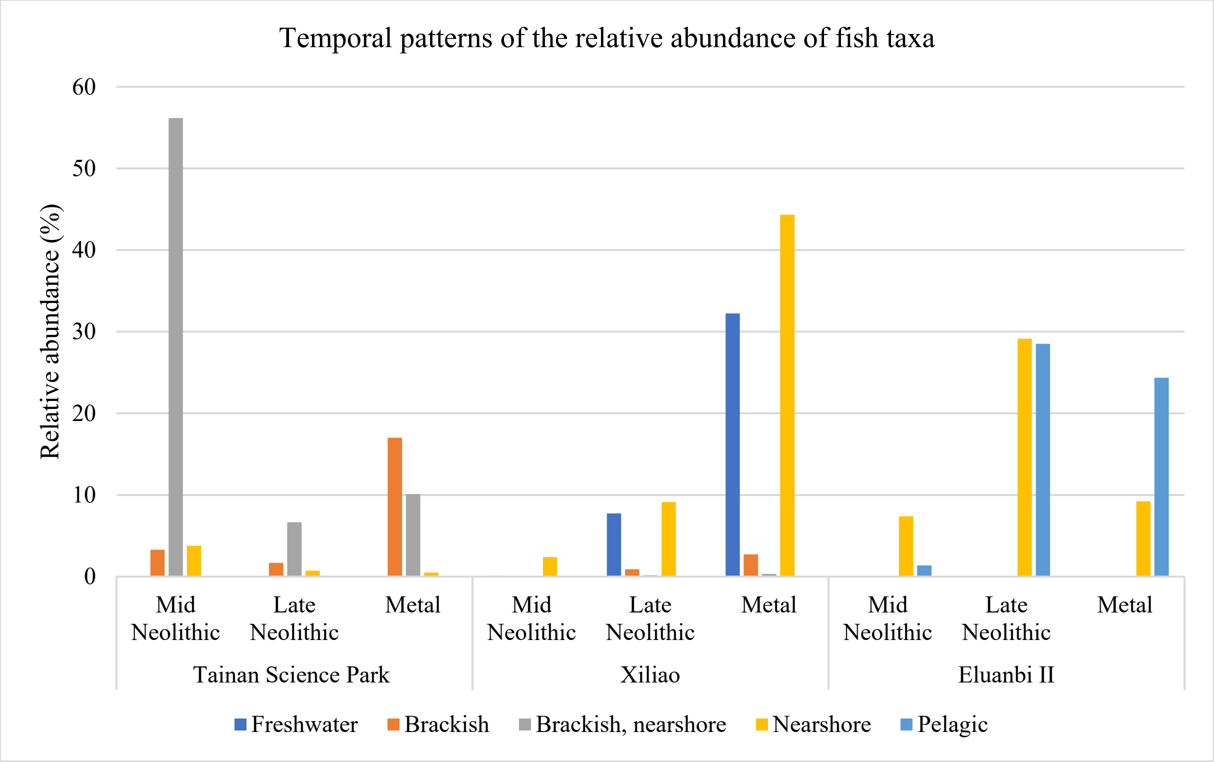

Figure 14: Temporal patterns of the relative abundance of fish taxa, in % of total assemblage from each site, from three sites discussed in this study.

Additionally, this comparative analysis highlights general trends in marine subsistence strategies in Taiwan and raises several questions. Marine subsistence, particularly fishing, on the southwestern and southern coasts of Taiwan heavily depends on environmental conditions, especially the proximity of archaeological sites to shorelines and rivers, as seen in Eluanbi II and Xiliao. The impacts of technological and social changes on archaeological fish catches are less understood and require more data. Moreover, it is interesting to note that the remains of a toxic nearshore taxa, porcupinefish, are only observed in Eluanbi II. The selective consumption of toxic fish is a distinct cultural behavior and can serve as a robust proxy for sociocultural changes in fishing societies. A better understanding of toxic fish consumption and the presence of these and other toxic fish taxa in different regions of Taiwan could be a valuable tool for exploring the cultural aspects of prehistoric fisheries in Taiwan (see section 2.4.3).

Besides, size estimation based on otolith length of the large yellow croaker from Tainan Science Park provides preindustrial baseline of fish size, shedding light on the shifted ecological baseline due to overfishing in the Taiwan Strait, a severely overfished area that have experienced a fisheries collapse in the 1980s and still struggles to recover (Chen *et al.*, 2014; Liu and De Mitcheson, 2008). This evidence suggests that morphometric analysis and size-age estimation of archaeological fish remains in Taiwan is crucial to reconstructing preindustrial ecological baselines that is crucial to modern fisheries management and restoration efforts (see section 2.4.5).

Moreover, changes in the relative abundance of mammal and fish remains at Eluanbi II and Xiliao show that marine fish rose in importance from the Early to Late Neolithic, compared to shellfish and terrestrial mammal remains, indicating the increased economic importance of fishing to human subsistence. In contrast to the general pattern of decreased fish consumption during the Metal Period based on paleodiet reconstruction (see section 4.1), the relative abundance of fish remains, especially brackish and freshwater taxa, increased significantly during the Metal Period in Xiliao and Tainan Science Park. This trend might be caused by the proximity of the sites to paleochannels and newly formed estuaries due to sea level decline. The integration of ichthyoarchaeological and paleodiet data from various sites with distinct environmental histories is crucial to understand the regional patterns of Metal-age fisheries in Taiwan, a crucial time period when prehistoric fisheries have undergone and shaped significant socioeconomic changes (Hudson and Fernández, 2023; Mylona, 2020). Additional data on the relative importance of marine and terrestrial faunal and plant food sources to the human diet is needed to better understand the role of fish to paleo-human diets. This is particularly important to provide quantified evidence to better understand the "fisher-farmer" subsistence pattern of prehistoric coastal populations in Taiwan (Bellwood, 2006; Hung and Carson, 2014).

In terms of taxonomic identification, archaeological fish remains were only identified to species through otoliths except a special case for the identification of *Arius maculatus* based on ethmoid bones. This observation highlights the limitations of taxonomic identification based on fish bone morphology in

Taiwan, an area where ichthyoarchaeological assemblages contain tropical and temperate fishes that are high in species diversity but with low individual counts (see section 2.3). Additionally, since all bony fishes have three pairs of otoliths that can be easily sided, otolith numbers offer more accurate quantification of fish assemblages compared to bone weight and NISP used in Case Study 1 and 2. Other than fish remains, fishing tools such as net sinkers, fishhooks, and gorges shed light on potential fishing methods. Net sinkers were found in in all three sites, with abundance data available for two sites, which are Eluanbi II (n=242) and Xiliao (n=27). Net sinkers suggest the use of net fishing and smaller net sinkers can be used for line fishing (Yu-Pei Chen, 2007a). In addition, the findings of fishhooks and fish gorges suggest that hook and line fishing were common in these sites. However, associating fishing methods with target species necessitates additional data, including lower taxonomic identifications and information from more ethnographic and experimental research. Future research including tool use-wear analysis and fish age-size analysis can expand our current understanding of fishing behaviors such as net mesh size and net or line manufacturing techniques (see section 2.2).

This study is limited by the small sample size of three case studies focused on the southern and southwestern coasts of Taiwan. Nonetheless, a comparative analysis across multiple ichthyoarchaeological datasets in Taiwan has highlighted the current state of ichthyoarchaeology in the region. More importantly, this literature review underscores the significant potential of fisheries studies in Taiwan, where ichthyoarchaeological and maritime archaeological research is extremely limited. In relation to the current advancements in ichthyoarchaeology (section 2), the next section proposes suggestions for future research in Taiwan to expand the current research focus.

5. Future Research

The following are some useful suggestions for future studies based on this review. First, higher resolution analysis and the utilization of legacy data. To achieve this, finer screening (<1.6 mm) during excavations is highly encouraged for optimal retrieval of fish remains. After the retrieval of fish remains, species identification to a lower taxonomic level, especially at least to the genus level, is crucial for further analysis and interpretation. Future analysis including age-growth analysis, isotopic analysis, and aDNA analysis can be utilized to expand the current scope of ancient fisheries studies. In fact, this thesis also highlights the rich data that exist in grey literature and museum collections. The immense potential of using legacy collections for higher resolution ichthyoarchaeological studies can be seen through Case study 3. Future collaborations with excavators and curators, and the incorporation of grey literature—often overlooked but rich in valuable information—will play a pivotal role in overcoming the current fragmentation in our knowledge. By working together across disciplines and leveraging existing resources, we can piece together a more comprehensive picture of Taiwan's ancient marine ecosystems and the human interactions that shaped them.

Next, ichthyoarchaeological records should be identified to lower taxonomic levels, especially to genus and species, for better interpretations. For example, this study adopts a parsimonious association of fish habitats by eliminating the "pelagic" group that was associated for taxonomic groups such as Elasmobranchii (sharks and skates), Sclachimorpha (sharks), Batoidea (skates), Clupeidae (herrings and sprats), and Belonidae (needlefishes) for the Xiliao assemblage (Pan, 2021). These taxonomic groups contain diverse genera and species that occupy a wide range of habitats that include riverine, brackish, **nearshore, and offshore environments. As the grouping of "pelagic" taxa implies seafaring and advanced** fishing techniques, this study modified the original biogeographic groupings due to the absence of well-defined pelagic taxa such as marlins and dolphinfish that are found in Case study 1. This observation highlights the importance of lower-level taxonomic identification to accurately reconstruct fish catch biogeography and fishing techniques as discussed above. As evidence in the case studies, fish otoliths are extremely useful to help identify ichthyoarchaeological remains to the species level in Taiwan. On top of that, Case study 3 demonstrates the role of interpreting legacy otolith collection in improving previous taxonomic identification that can completely change zooarchaeological interpretations (Ainis et al. 2021 and see above). Lower resolution taxonomic identifications can hugely improve our understanding of prehistoric fisheries and paleo-fish ecology in Taiwan. More importantly, fish stocks in the Taiwanese waters have distinct seasonal and spatial taxa composition due to changes in bathymetry and ocean currents (Lo et al. 2010; Hsieh et al. 2007, see section 3.1). Taxonomic identification lower than the family levels, and a clearer understanding of species seasonal distribution in the Taiwanese waters and the seasonality of prehistoric fisheries will improve our understanding of fishing behaviors, consumption patterns, fish catch biogeography, and seafaring techniques.

Moreover, the study of marine historical ecology that remains largely understudied holds great potential and importance in Taiwan in the face of increased ecological threats of overfishing and global warming. This focus on marine ecology further promotes interdisciplinary collaborations with marine scientists, ethnographers, and policymakers in fisheries management and conservation efforts. For example, ichthyoarchaeological data correlates to the current efforts of examining and incorporating TEK of indigenous fisheries to promote sustainable fisheries (Chang and Chung, 2022). Moreover, future studies of fishing tools other than fishing weights, such as fishhooks, nets, and watercraft, are needed to complement our understanding of fishing behaviors. More importantly, the study of fishing vessels and naval technologies is almost absent in the current literature due the lack of preservation of organic materials. Ethnoarchaeological and experimental archaeological data can serve as complementary data to understand previous naval technology in Taiwan, hence shedding light on past fishing practices and contributing to our holistic understanding of the expansive maritime migration and trade networks of Taiwan and adjacent regions.

Lastly, data of the earlier periods, especially the Paleolithic (30-15 ka BP) and Preceramic Period (6500-5500 BP), are extremely limited due to the submerged palaeocoastlines on the northern, western, and southwestern coasts of Taiwan. This gap in knowledge and archaeological data has hindered our current understanding of human maritime adaptations and fish ecological adaptations to climate and environmental changes during the glacial-interglacial transition, a scenario like what we face today. Fisheries data from this missing period directly addresses current efforts to tackle pressing issues, particularly climate change and sea level rise. Underwater archaeology and oceanographic studies are essential to understand this period of coastal adaptation in Taiwan. Specifically, efforts should focus on reconstructing clear environmental records of the western and northern coastal plains, where sites pre-Neolithic sites are completely absent, and locating submerged prehistoric sites that might be centered around palaeo river channels and estuaries (Gusick and Faught, 2011; Gusick *et al.*, 2022), as evidenced by case studies that are discussed above. Prehistoric fisheries in Taiwan cannot be fully understood until this gap in submerged prehistory is uncovered from the deep burial of Holocene sediments.

6. References

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