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Pacific Islands Ichthyoarchaeology: Implications for the Development of Prehistoric Fishing Studies and Global Sustainability

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Abstract: The Pacific Islands—consisting of culturally diverse Melanesia, Micronesia, and Polynesia—is the ideal region to investigate the development of prehistoric fishing studies, as nowhere else on Earth is there such environmental contrasts among island types and their marine environments. We review the ichthyoarchaeological literature for the Pacific and assess developments in recovery methods, reference collections, taxonomic identifications, quantification, taphonomy and site-formation processes, ethnoarchaeology, approaches to diet and subsistence reconstructions, sustainability, and the importance of applied zooarchaeology for fisheries management and conservation. Ichthyoarchaeologists are beginning to work more closely with resource managers, fisheries biologists, policy makers, and indigenous communities to produce holistic studies of conservation management, resource sustainability, and assessments of human impacts on marine ecosystems over centuries to millennial time scales.

Keywords: fisheries management, historical ecology, ichthyoarchaeology, Pacific Islands, zooarchaeology

Introduction

The antiquity of fishing and the exploitation of marine and freshwater resources have been significantly extended in recent years (Erlandson and Rick 2010). 1.95 million years ago, Early Pleistocene hominins were exploiting freshwater resources (catfish and turtles) in the Turkana Basin in Kenya (Archer et al. 2014). Marine fisheries were more routinely exploited along the western coast of South Africa by ca. 50,000 BP during the Late Stone Age, and possibly even earlier in the Middle Stone Age (e.g., Henshilwood et al. 2001; Klein et al. 2004). There is evidence of fishing at Jerimalai shelter in East Timor by 42,000 BP (O'Connor et al. 2011) and the exploitation of marine mollusks and fish in the western Pacific, at Buang Merabak, Papua New Guinea, by ca. 40,000 BP and at Matenkupkum, New Ireland, by ca. 33,000 BP (Allen 2003; Gosden and Robertson 1991; Leavesley et al. 2002; Szabó and Amesbury 2011).

Erlandson and Fitzpatrick (2006) have explicitly synthesised the broader anthropological, archaeological, and ecological significances of island and coastal archaeology, where research agendas range from the antiquity of coastal adaptations, to the development of maritime technologies, cultural responses to “isolation,” and human impacts on coastal resources (e.g., Montenegro et al. 2014; Weisler et al. 2012). Ichthyoarchaeology is a vital component of island and coastal archaeology research and is essential for addressing fundamental questions in Pacific Islands prehistory. In this article, we globally contextualise our review of the Pacific Islands ichthyoarchaeological literature, focusing on recovery, analysis, and the interpretation of archaeological fish remains.

The Pacific Islands

The Pacific Ocean is the largest and deepest of the world ocean basins. We use “Pacific” to refer to the geographic region that comprises Melanesia, Micronesia, and Polynesia. The 22 Pacific Island countries and territories are dispersed across the tropical and subtropical Pacific Ocean, an area that exceeds 27 million km² (Figure 1). The distinction between Near Oceania—New Guinea, the Bismarck Archipelago, and the Solomon Islands as far east as San Cristobal—and Remote Oceania—all other Pacific Islands—was first proposed by Pawley and Green (1973). Near Oceania has the greatest biogeographic diversity (marine and terrestrial) and the earliest evidence of human occupation, and both Austronesian and non-Austronesian languages are spoken; in contrast, only Austronesian languages are spoken in Remote Oceania (Green 1991). Beyond the Solomon Islands, eastward across Remote Oceania, the distance between islands increases, which reduces intervisibility (Montenegro et al. 2014); this posed a natural constraint on human colonisation and influenced the later settlement of Remote Oceania (ca. 3,000 BP) compared to Near Oceania (ca. 50,000 BP) (Irwin 1992; Kirch 2000; Summerhayes et al. 2010).

Dispersed across the Pacific Ocean are island-arc islands (New Zealand is the largest), high volcanic islands (of midplate hotspot origin such as Hawai‘i), low coral atolls, and *makatea* (raised limestone) islands; each support diverse biota (Figure 2; Springer 1982; Stoddart 1992). The western Pacific is a vast region of island-arc and high volcanic islands (e.g., Fiji, New Caledonia, Solomon Islands, and Papua New Guinea). The coastal waters surrounding these islands are highly productive due to terrestrial runoff, the upwelling created by the deflection of large-scale ocean currents around the islands, and vast coral cover (Bell et al. 2011). When high volcanic islands are relatively young, they lack developed coral reefs, but over time these reefs develop into fringing reefs, then barrier reefs separated from the island by a lagoon. In contrast, atolls (distributed 10,000+ km from Palau in the northwest to Ducie Atoll, Pitcairn Islands in the southeast; Figure 1) are rarely more than 2–3 m above sea level and have poor coralline soils, consistent exposure to salt-laden winds, and an absence of surface freshwater. Importantly for occupation, atolls have the highest area of reef to land size of all island types. Finally, makatea islands are raised reef islands and are most common in the Solomons, New Guinea, Palau, Marianas, Fiji, and Tonga; on average, biodiversity is higher on these islands as is endemism; however, due to phosphate mining (e.g., Banaba and Makatea Islands), it has been difficult to reconstruct native biota (Stoddart 1992).

In general, from west to east across the Pacific, terrestrial and marine diversity decreases. The Coral Triangle is situated in the Indo-West Pacific Ocean (Figure 1), where the high species diversity (e.g., 1660 fish species from Papua New Guinea; Froese and Pauly 2014) is particularly evident compared to the Caribbean Sea, the centre of diversity in the Atlantic Ocean, where only about 700 species of fish are reported (Rocha 2003: 1165).

Modern Fisheries, Conservation Biology, and Applied Zooarchaeology

Wolverton and Lyman’s (2012) edited volume explores avenues of applied research over the past decade that contribute to the conservation and management of modern terrestrial and aquatic populations. Applied zooarchaeology is a broad theme that globally links archaeology across geographic regions, and we use it to synthesise the key issues in Pacific ichthyoarchaeology research as well as broader issues in archaeology.

Goods and services from coral reefs provide more than \$375 billion to the global economy per annum (Pandolfi et al. 2005: 1725), yet reefs across the globe are in decline. With the loss of turtles, sharks, groupers, and long-lived corals, which support diverse fish and invertebrate populations, a return of trophic structure and clear conservation goals are a necessity. Just as the Pacific Islands are geologically, biologically, culturally, and socially diverse, so too is the archaeology of the region and its ability to inform globally relevant issues—food security, sustainable exploitation of fisheries

resources, and the impact of changing climates on the world's marine ecosystems. Within the marine sciences, global initiatives are devoted to these concerns, such as the Sea Around Us Project (www.seaaroundus.org), which assesses the impact of fisheries on marine ecosystems, and the History of Marine Animal Populations (HMAP) (www.coml.org/projects/history-marine-animal-populations-hmap), which considered both historical and environmental datasets to evaluate marine populations before and after significant human impact. More recently, social scientists, archaeologists, sociologists, anthropologists, and economists have developed research links with marine scientists to provide complementary data that evaluate human–environment interactions and contribute culturally informed conservation and management strategies (e.g., Aswani et al. 2012; Erlandson and Rick 2010; Johannes 2002; Jones 2009; Kittinger et al. 2014; McKechnie et al. 2014; Morrison and Hunt 2007; Wake et al. 2013). Even minor variations in climate or biodiversity on a time scale of years to decades can significantly alter marine ecosystems (e.g., Hughes et al. 2007). Archaeology provides data to highlight these long-term trends by tracking changes in species size and composition and fisheries productivity. Fish are critical to food security in subsistence fisheries and market-based economies across the Pacific Islands (Bell et al. 2009); the region is ideal for discussing changing themes and future research directions for archaeological studies of marine fishing globally (Aswani and Allen 2009; Butler 1994; Gifford 1951; Jones 2009; Leach 1986; Nagaoka 2005).

Schwerdtner Máñez et al. (2014: 1) highlight promising advancements in marine historical research, but these research agendas are yet to be integrated into a multidisciplinary global history of human–ocean interactions. The Oceans Past Initiative (OPI) was awarded a grant from the European Union to establish the Oceans Past Platform; the collaboration draws on expertise from history, archaeology, social science, and marine science to assess human–environment interactions primarily in European waters over the last two millennia (<http://hmap.sea.ee/index.php/eu-cost-action-network>). Schwerdtner Máñez and colleagues have proposed establishing a global research network for marine historical research, the OPI, which would act as a virtual network to connect researchers globally. We contribute to this discourse by highlighting contributions and future directions of archaeological faunal research to broader marine management studies in the Pacific Islands and globally.

Archaeology of Pacific Fishing

Twenty years ago Kirch and Weisler (1994: 285) wrote that the rapid expansion in the archaeology and prehistory of the Pacific Islands likely would lead to increased regional specialisation. Indeed, over the last two decades Pacific archaeologists have continued to produce high-resolution chronologies for regions, archipelagos, islands, and key sites. There also has been increased emphasis on multidisciplinary research—matching worldwide trends—and a movement toward subdisciplinary

specialisation. Following the early emphasis on material culture, the analysis of finfish and shellfish remains garnered the most attention as Pacific archaeologists recognised that marine subsistence is fundamental to island economies (e.g., Ambrose 1963; Smart 1962). Over the past 70 years the analysis of Pacific archaeological fish remains has developed into a discrete subdiscipline with changing field collection methods, identification procedures, quantification protocols, and progressively more comprehensive research agendas.

The major analytical themes and issues shared across Pacific archaeology are colonisation and settlement, human impacts on island environments, prehistoric economic systems, exchange and interisland contacts, and the development of complex societies (Kirch and Weisler 1994: 286). Human interaction with the marine environment (especially prehistoric fishing practices) is a critical component. Methods for inferring past subsistence systems are fundamental in archaeology, and the themes we discuss are relevant to broader zooarchaeological studies (e.g., Lupo 2007; Twiss 2012).

We review the zooarchaeological and ichthyoarchaeological literature that provides analytical and methodological contributions rather than descriptive site reports (i.e., list of taxa only or “laundry lists,” see Lyman 2015). References are primarily English, although some relevant non-English articles are included.

We review the highpoints and trends in more than 70 years of fishing studies in the Pacific with an eye to suggesting future research directions. We address key themes including an introduction to Pacific fishing studies (material culture and fish bone analysis), recovery methods, reference collections, taxonomic identifications, quantification, taphonomy and site formation processes, diet and subsistence reconstructions, ethnoarchaeology, sustainability, and fisheries management and conservation.

Early Approaches to Pacific Fishing Studies: Material Culture

Prior to World War II, the limited archaeological research that had been conducted in the Pacific focused on the classification of material culture informed by ethnographic observations. Pioneering works provided syntheses of fish capture techniques and material culture, primarily in Polynesia (e.g., Anell 1955; Best 1929; Buck 1927; Hamilton 1908).

The early focus in Pacific archaeology and anthropology on fishing resulted in culture-historical sequences based on fishhook form (i.e., style and function). In the eastern Pacific, typologies were based on hook form and associations with cultural groupings, such as, “Pacific types,” “Polynesian type,” and “western Polynesian culture” (e.g., Beasley 1928; Burrows 1938; Skinner 1942). Influenced by *Fishhooks*, the pioneering publication by Emory et al. (1959), more systematic and

formal methods of fishhook classification were developed. The volume detailed a formal typology for classifying Hawaiian fishhooks and investigation of temporal variation in fishhook form. A methodological shift occurred between the 1920s and 1970s, as analytical and quantitative methods were formalised. Archaeological research focused on a new interest in the economic significance of prehistoric fishing through fish bone analysis.

New Directions in Pacific Archaeology: Fish Bone Analysis

In *Fish Remains in Archaeology and Paleo-Environmental Studies*, Casteel (1976) demonstrated the significance of archaeological fish bone analysis, addressing seasonality, morphometric studies, subsistence reconstructions, and fish mortality profiles (i.e., age of fish when captured). Casteel influenced the development of archaeological fish bone analysis worldwide (e.g., Thieren and Van Neer 2014; Zohar et al. 2008), but these analyses occurred earlier in America and Europe than in the Pacific Islands. Gifford (1951) reported the first study of prehistoric diet using fish bone from Fiji archaeological sites, with taxonomic identifications by the ichthyologist Fowler (1955). Gifford and Shutler (1956) and Gifford and Gifford (1960) employed standardised excavation techniques, which documented preliminary taxonomic identifications of fish bone.

Archaeological fish bone often was acknowledged but not identified to taxon (e.g., Golson 1961; Suggs 1961; Trotter 1955). Gifford's pioneering Pacific work lapsed until the 1960s, when Shawcross (1967, 1972) carried out a diet-breadth study at Galatea Bay and assessed population dynamics based on reconstructed caloric values of archaeological fish remains. In Hawai'i, Kirch (1971, 1975, 1979) completed preliminary taxonomic identifications of fish dentaries from cultural resource (heritage) management and research projects.

Although fish bone was not routinely collected and analysed in the Pacific Islands until the early 1970s, these early pursuits demonstrate a methodological shift from predominately material culture to holistic research agendas. By the early 1970s, fish bone analysis was still underdeveloped in Pacific archaeology, and Davidson (1971) stressed the necessity for specialist work given the importance of fishing in the region, including the establishment of fish bone comparative collections and the development of systematic taxonomic identification protocols (Green and Kelly 1970: 184).

Recovery Methods

The first systematic use of screening in the Pacific, on Fiji, was by Gifford (1951), who used 3.2 mm (1/8'') sieves to address settlement history, diet, and subsistence. The use of screens for recovering archaeological material was inconsistently adopted in the Pacific before the 1970s (e.g., Allo 1970), with some later instances recorded outside the region (e.g., Seeman 1986). Archaeologists are still

evaluating the implications of screening protocols on reconstructions of prehistoric subsistence (e.g., Gordon 1993; James 1997; Nagaoka 2005; Vale and Gargett 2002; Wake 2004a; Zohar and Belmaker 2005). Gobalet and Jones (1995) suggested that an absence of fine-mesh sieving impacts the accuracy of fish bone analysis; consequently, there was a movement away from 6.4 mm (1/4'') screens in North America during the 1970s; 3.2 mm screens are most commonly used today, but

1.6 mm (1/16'') mesh is ideal. Cooke and Ranere (1999: 105) state that 6.4 mm screens are sufficient for recovering bones of large mammals, but the recovery of fish remains requires a minimum size of 3.2 mm mesh. Partlow (2006) queried the emphasis on the use of finer-mesh screens within the global fisheries literature, given that a more pressing concern is the inconsistent use of screen sizes across a region. In Pacific archaeology, there has been a preference toward 3.2 mm and/or 6.4 mm screens since 1960.

Ichthyoarchaeologists recognised that screen size influenced fish bone recovery and subsequent subsistence reconstructions, so efforts have been directed toward improving data quality (Casteel 1972: 382). Butler (1987, 1988, 1993, 1994), Nagaoka (1994, 2005), and others (Gordon 1993; Jones O'Day 2001; Weisler 1993) have highlighted the impact of screen size on the recovery of fish remains, research that led to the adoption of systematic recovery protocols in Pacific archaeology. Butler (1987), in a North American study, water screened all excavated material through nested 1.6, 3.2, and 6.4 mm screens and demonstrated that the number of identified specimens (NISP), richness, and relative abundance were affected by screen size. Butler (1988: 104) then reviewed fish bone data from Pacific Island Lapita sites and identified taxon body size as a major factor that affects the recovery of fish bone elements. The relationship between screen size and element representation also has been used to distinguish between natural and cultural salmonid deposits (Butler 1993). Using both archaeological fish remains and experimental analogues, Nagaoka investigated the impact of 3.2 and 6.4 mm screens on fish bone recovery (1994) and of element representation (2005) in a Pacific context. Ono and Clark (2012) argue that the elements used for taxonomic identification are more critical than screen size for representing species diversity and that regional syntheses are problematic when inconsistent screen sizes have been used across studies.

Currently 3.2 mm screens are considered the most useful for the recovery of fish remains (e.g., Fitzpatrick et al. 2011; Weisler et al. 2010). Fine mesh screening (<3.2 mm) has been more widely implemented outside the Pacific (e.g., Erlandson et al. 2005; Robson et al. 2013). Selective fine screening can provide representative data (e.g., Weisler 2001) that establish a benchmark to determine bone loss through the larger screens (e.g., 6.4 mm) and to assess the effects of screen size on species richness and abundance. It is up to the researcher, however, to decide whether to reduce the area excavated in order to conduct more systematic fine mesh screening.

Reference Collections

Before reference collections were established, ichthyology manuals were the primary source for aiding taxonomic identification of archaeological fish bone (e.g., Clothier 1950). Prior to the 1980s, Fowler's (1955) volume of illustrations of select elements was the most widely used resource in the Pacific (e.g. Davidson 1971; Kirch 1973), but more comprehensive manuals are available for New Zealand (Leach 1997) and Hawai'i (Dye and Longenecker 2004). Although faunal reference collections for taxonomic identification are preferable (Hamilton-Dyer 2013), Pacific fish bone studies during the 1970s and early 1980s were hindered by reference collections that did not adequately represent the species diversity of a region. Reference collections are no longer the primary issue restricting archaeological fish bone identifications in the Pacific and elsewhere. Archaeologists rarely report the taxa held within a reference collection, and data quality is rarely discussed in faunal analysis. There also are inconsistencies in the recording of biological (e.g., age and sex) and environmental variables (e.g., local ecology, water depth, and temperature), for fish used as reference specimens.

The use of incomplete reference collections for analysing archaeological fish bone assemblages can bias measures of diversity, limit interpretations, and impact data quality (Wolverton 2013: 385–389). A list of taxa in a reference collection should be published with each site analysis as supplementary material or on a dedicated university or museum website (e.g., Allen 1992a; Gobalet 2001; Wake 2004a: 175; Walter et al. 1996; Weisler 2001). It is not sufficient to list only the university or institute where the collection is held (e.g., Amundsen et al. 2005; Enghoff et al. 2007; Jones and Kirch 2007).

Gobalet (2001) conducted a blind study among experts in archaeology, zoology, and fisheries biology to assess differences in taxonomic identification of a fish bone assemblage from California; the differences in taxonomic identifications ranged from predominately family level to mainly species level. The quality of taxonomic identifications is rarely tested (Driver 1992: 41; Wolverton 2013). Wolverton (2013: 392) suggests a statement of data quality in scholarly publications may be useful, but first laboratory procedures must be assessed and existing standards accepted or improved (e.g., Gobalet et al. 2005). The identification of the number of specimens required in a reference collection to ensure confidence for each identification level is useful for mitigating overidentification of archaeological bones.

An ideal reference collection contains at least half a dozen examples of each species, representing a variety of ages, sex, and capture environments. However, it is the identification criteria and protocol standards established in zooarchaeology that provide quality assurance (Wolverton 2013: 393). It is useful for ichthyoarchaeologists to work closely with ichthyologists and fisheries departments when

establishing reference collections to ensure accurate species identification and determinations of age and sex of the reference fish. For example, when analysing an assemblage from Pakistan, Desse and Desse-Berset (1999: 345) noted a change in morphology of sciaenid otoliths from juvenile to adult that was consistent with taxonomic assignments of two different species. Even though comprehensive reference collections may facilitate higher-level taxonomic assignments, species richness is ultimately dependent on sample size (Lepofsky and Lertzman 2005; Lyman and Ames 2007).

Digitised reference material complements physical reference collections. Pacific-focused online resources similar to OsteoBase (www.mnhn.fr/osteo/osteobase/), hosted by the Natural History Museum in Paris, or Archaeological Fish Resource (<http://fishbone.nottingham.ac.uk/>), hosted by the University of Nottingham in the UK, can enhance identifications of Pacific archaeological fish bones given the high biodiversity in the region (see Hamilton-Dyer 2013: 81–82, for a comprehensive list of online reference collections and osteology reference works). Establishing open-access online fish bone reference collections will improve data quality and also the capacity of archaeologists to contribute to research outside our immediate focus, including conservation biology and food security.

Taxonomic Identifications

Lockerbie's (1940: 407) excavations at Kings Rock, Otago, New Zealand, provided one of the earliest reports of fish bone in the Pacific. Taxonomic identifications were not completed but the likely taxa present were suggested based on local knowledge and included barracuda, grouper, and cod.

Initially, zoologists and ichthyologists completed taxonomic identifications of Pacific archaeological fish bone; examples include Fowler for Gifford (1951) in Fiji and Woods for Spoehr (1957) in the Mariana Islands. No formal identification protocols were implemented, and primarily mouthparts (i.e., dentary and premaxilla) were identified. Parrotfish (Scaridae)—closely followed by wrasse (Labridae)—were commonly reported as the dominant taxa (e.g., Kirch 1975, 1979); because of the high bone density and unique morphology of their upper and lower pharyngeal grinding plates, they are easily identified to family. Not until the late 1970s did Leach and Davidson (1977) develop the first systematic protocol for the taxonomic identification of Pacific archaeological fish bone.

Element Selection

The first stage of analysis is determining the fish bone elements that have preserved in the assemblage (Driver 1992). The researcher should attempt to identify all elements. Because mouthparts of Pacific fish were considered the most useful for taxonomic identifications (Fowler 1955), taxonomic identification has been based on a limited range of fish bone elements (e.g., five paired cranial elements, Leach 1986). There has been a movement away from a focus on primarily mouthparts and

other paired cranial bones to including more postcranial elements, including vertebrae across a diverse range of taxa (e.g., Lambrides and Weisler 2013; Ono and Clark 2012). Perhaps due to lower taxonomic diversity—in some cases—or the influence of historical precedent, all fish elements were systematically identified in assemblages across Europe, the Mediterranean, Middle East, North America, and South America decades earlier than in the Pacific Islands (e.g., Desse-Berset and Desse 1994; Moss 2011; Rick et al. 2001; Robson et al. 2013; Wake 2004b). This comprehensive analysis of elements was linked to studies of butchery practices or processing techniques, element representation and preservation, variability between site use, and trade and movement of resources (Barrett 1997; Colley 1984; Enghoff 1997; Lauwerier and Laarman 2008; Tourunen 2008)—analyses that have not been as widely investigated in the Pacific.

Leach and Davidson (1977: 166–168) were the first to develop routine fish bone taxonomic identification protocols in New Zealand. This new protocol incorporated five paired cranial elements (dentary, premaxilla, maxilla, quadrate, and articular; see Figure 3) and “specials” (e.g., pharyngeal grinding plates, unique anal and dorsal spines, and some vertebrae; see Weisler 2001: 110, fig. 7.4). The method focused on elements considered diagnostic across all taxa and excluded most other elements (Leach 1986). Conversely, Butler (1988: 108–109) argued that reconstructions of prehistoric human behaviour would be influenced by differential impacts of taphonomy between taxa and post depositional processes when only a restricted number of elements are identified (also Nicholson 1992, 1996). Variations in fish processing between taxa may result in different elements being deposited at a site; therefore, it is critical to analyse elements from both the cranium and postcranium (Butler and Chatters 1994: 416–417; Masse 1989: 383; Walter 1998: 64).

Recent developments in Pacific fish bone identification protocols include more cranial elements used for taxonomic identifications and the routine consideration of all vertebrae. Initially, analyses documented the implications of an expanded range of identified cranial elements, with results confirming alterations to richness and abundance of identified fish taxa (e.g., Jones O’Day 2004; Ono and Clark 2012; Vogel 2005; Weisler 2001; Weisler et al. 2010). The most commonly identified of these expanded cranial elements in Pacific fishing studies include basipterygium, ceratohyal, cleithrum, coracoid, epihyal, hyomandibular, interopercle, opercular, palatine, parasphenoid, posttemporal, preopercular, scapula, subopercular, supracleithrum, supraoccipital, and urohyal (Figure 3; see also Leach 1997: 7, fig. 1). Not all of these elements are technically cranial elements; the posttemporal, supracleithrum, cleithrum, and scapula are elements of the pectoral girdle, but for consistency across the Pacific fishing literature they are referred to as expanded cranial elements. Fishing studies outside the Pacific Islands still identify a greater range of the so-called cranial

elements—e.g., elements of the neurocranium, hyopalatine arch, opercular series, infraorbital series (Amundsen et al. 2005; Desse-Berset and Desse 1994; Thieren and Van Neer 2014).

The identification of all vertebrae, which has lagged behind studies in other regions, has been the most recent advancement in Pacific fishing research (e.g., Morales 1984). Only unique or special vertebrae were identified in early Pacific archaeology (e.g. Davidson 1971; Wallace and Wallace 1969). X-ray identification—a method more commonly used outside the Pacific to identify all fish vertebrae (e.g., Desse and Desse 1983; Desse and Desse-Berset 1997)—was employed only for distinguishing between black-tipped and white-tipped sharks in the Pacific (e.g., Leach and Davidson 1977). The analysis of vertebrae was most commonly restricted to the identification of the distinctive shark, ray, and skate (Elasmobranchii) vertebrae (e.g., Clark and Szabó 2009; Weisler and Green 2013), and the ultimate vertebrae of tuna, mackerel, and bonito (Scombridae) (e.g., Fraser 1998). More specific identification of sharks, rays, and skates beyond subclass Elasmobranchii are uncommon in Pacific fishing literature. Ono and Intoh (2011: 256) relate this to the element types (vertebra, teeth, spines, and dermal denticles) that preserve in archaeological sites, which are morphologically similar and difficult to identify even to family. Significantly, Ono and Intoh (2011: 267–268) were able to classify some elasmobranch vertebrae based on morphology to family—Carcharinidae and Lamnidae—and those vertebrae identified as Carcharinidae were further divided into five distinct taxa; more specific identifications are critical for assessing the contribution of shark to prehistoric diet (Rick et al. 2002).

Ono (2003, 2004) demonstrated that the systematic identification of all vertebrae can alter the taxonomic abundance and richness of fish bone assemblages by identifying six additional taxa (Acanthuridae, Caesionidae, Carangidae, Belonidae, Ephippidae, and Scombridae) in an assemblage from the Bukit Tenkorak site, Borneo Island (Ono and Clark 2012). Lambrides and Weisler (2013, table 2) explicitly documented this trend by tracing the development of fish bone identification protocols in three datasets: the five paired cranial bones and “specials,” expanded cranial bones, and all vertebrae. Including vertebrae doubled the minimum number of individuals (MNI) for surgeonfish (Acanthuridae) and replaced groupers (Serranidae) as the top ranked taxon at a Henderson Island (Pitcairn Group) site (Lambrides and Weisler 2013, table 3). Clearly, regional syntheses can be problematic when fish bone assemblages have been analysed using an inconsistent range of elements.

The analysis of archaeological vertebrae has been extensive outside the Pacific, due to superior preservation of vertebrae in some regions (e.g., along the northwest coast of North America), their usefulness for seasonality studies, and analyses of butchery patterns. To facilitate accurate osteometric reconstructions, it is critical that archaeological vertebrae are identified to type (e.g., thoracic, precaudal, caudal; see Figure 4) and that their position along the vertebral column is

determined (Enghoff 1994; Gabriel et al. 2012). Morales (1984) and Butler (1993) recognised the importance of distinguishing between specific vertebrae types rather than grouping archaeological vertebrae into precaudal and caudal (e.g., de Jong 1994; Van Neer 1986) or considering vertebrae as a single type (e.g., Cerón-Carrasco 1994; Seeman 1986). Comprehensive vertebrae identification should be routinely incorporated in Pacific fish bone analyses to improve interpretations of assemblages and to keep abreast with global trends in methods (e.g., Barrett et al. 2011; Van Neer et al. 2007).

Otoliths—hard calcareous bodies found in the neurocranium (see Weisler 1993: 131, fig. 1)—and scales have not been consistently identified in Pacific archaeology compared to other regions (e.g., Carenti 2013; Joslin 2011). Weisler demonstrated the importance of identifying otoliths (see also Allen 1972; Frimigacci 1980) by providing the first identification of mullet (*Mugilidae*) for the Hawaiian Islands (Weisler 1993: 145), flying fish (*Exocoetidae*) for the Marshall Islands (Weisler 2001: 109), bonefish (*Albulidae*) and whiting (*Sillaginidae*) from New Caledonia (Weisler 2002: 208), 14 species of fish never found before in New Zealand middens (Weisler et al. 1999: 43), and new fish records for Australian waters (Crouch et al. 2007: 57; Weisler and McNiven 2015). Fish scales are not commonly identified in Pacific archaeology, with the exception of triggerfish and box fish (e.g., Allen 1992a; Weisler 2001); however, reference collections are yet to be developed.

Recent changes to Pacific fish bone taxonomic identification protocols are starting to reflect global trends, including the introduction of comprehensive vertebrae analysis (e.g., Gabriel et al. 2012; Huber et al. 2011). Given the increasing demand for high-quality archaeological faunal analyses for archaeology and to inform modern conservation and management strategies, it is paramount that Pacific ichthyoarchaeologists continue to use all elements for taxonomic identification.

Identification Level

The taxonomic level—family, genus, or species—of archaeological fish bone identifications impacts reconstructions of prehistoric fishing practices. Positive under identification is better than tentative overidentification. Family-level identifications have dominated the tropical Pacific fishing literature; this partly relates to high marine biodiversity, incomplete reference collections, experience of the analyst, and greater analytical expediency. With the expansion of comparative collections, more specific identifications have been achieved in the tropical Pacific (e.g., Butler 2001; Jones and Quinn 2009; Weisler et al. 2010) in contrast to temperate New Zealand where greatly reduced biodiversity facilitates routine species-level identifications (e.g., Anderson 1986; Davidson et al. 2000; Leach et al. 1995). Outside the Pacific, there has been an emphasis on genus- and/or species- level identifications (e.g., Archer et al. 2014; Carder et al. 2007; Cooke and Ranere 1999; Joslin 2011;

Makowiecki and Van Neer 1996; Rick and Erlandson 2011; Villagran et al. 2011; Zangrando 2007). For example, given the importance of salmon (*Oncorhynchus* spp.) in Pacific Northwest prehistory, morphometric measures have been used to facilitate species-level identifications of vertebrae (Huber et al. 2011; but see Moss et al. 2014).

Taxonomic assignments to family, genus, or species impact the resolution of data used to infer prehistoric capture methods. A recent example is the debate surrounding the evidence for offshore fishing at Jerimalai shelter (East Timor) given that only family-level taxonomic identifications of Scombridae (tuna, mackerel, and bonito) were completed. Half of the identified fish bone assemblage from the earliest deposits of Jerimalai shelter was argued by the authors to be from pelagic fish (specifically tuna) (O'Connor et al. 2011). Anderson (2013: 880) disagrees with this assertion given that Scombridae is a large and diverse family that comprises many species—in addition to tuna—so it is not possible to know specific ecological information and common capture techniques with only family-level identifications. This debate highlights the importance of having adequate reference collections, or incorporating additional techniques such as aDNA analysis and peptide mass fingerprinting (PMF), which facilitate species-level identifications when morphological attributes are indistinguishable for a family or genus, or when taphonomic factors impede finer taxonomic identification.

DNA Analysis, Peptide Mass Fingerprinting, and Morphological Analysis: Complementary Techniques?

Globally, concerns have been raised over the certainty of taxonomic identifications (skeletal element and taxon) and the need for objective frameworks to allow comparisons between assemblages (e.g., Gobalet 2001; Lernau 1996). With the development of PMF and modern/ancient DNA extraction protocols, species-level taxonomic identifications are enhanced (e.g., Butler and Bowers 1998; Hlinka et al. 2002; Moss et al. 2014; Richter et al. 2011; Speller et al. 2005; Yang et al. 2004). The application of aDNA analysis for the taxonomic identification of Pacific archaeological fish bone was investigated by Nicholls et al. (2003) using an assemblage from Aitutaki, in the southern Cook Islands. Previous molecular studies of ichthyoarchaeology remains completed by Butler and Bowers (1998) in North America and Hlinka et al. (2002) in Australia reported variable outcomes. Nicholls et al. (2003) provided more promising results by DNA sequencing modern grouper (*Serranidae*) samples and then extracting useful aDNA from 21 of the 29 tested archaeological cases, which resulted in 19 species-level identifications. These methods complemented traditional morphological identification techniques by facilitating genus- and species-level identifications. Despite a reduction in aDNA costs, the survivability of aDNA is variable, and universal primer sites for fish can be challenging to locate (Richter et al. 2011: 1503).

The ubiquity of salmon remains at some Pacific Northwest sites led to the development and application of aDNA analysis to facilitate species-level identifications. Because of high analytical costs, only small samples can be analysed (e.g., Ewonus et al. 2011; Moss et al. 2014; Speller et al. 2005; Yang et al. 2004), which can produce conflicting interpretations of the same site (Ewonus et al. 2011; Grier et al. 2013). In these cases, it is necessary to use a method that is cost effective and enables large samples to be analysed, such as peptide fingerprinting.

Zooarchaeology by mass spectrometry (ZooMS) uses PMF for the rapid and cost-effective taxonomic identification of archaeological bone; species are identified to taxon by differences in the mass of the peptides, hence, the identification of bone is achieved using a “molecular barcode” (Buckley et al. 2009; Doorn et al. 2011; Richter et al. 2011). This method aids traditional zooarchaeological analyses and is particularly useful when bone is too fragmented for morphological identification (Richter et al. 2011: 1508). ZooMS has not been extensively implemented for fish bone identifications, and despite the work involved to establish regional databases to facilitate taxonomic identifications, it has the potential to contribute to all marine and freshwater fishing studies.

Quantification

Appropriate formal methods for quantification of zooarchaeological material have received significant global attention (e.g., Binford 1981; Casteel and Grayson 1977; Grayson 1984; Harris et al. 2015; Marshall and Pilgram 1993), but these methods were not routinely incorporated in Pacific fishing studies until the late 1970s (e.g., Leach and Davidson 1977). In some early studies, qualitative measures such as presence/absence or classifications of “some,” “few,” or “many” were recorded (e.g., Davidson 1971; Gifford and Shutler 1956). Weights of unidentified archaeological fish bone have been reported (e.g., Davidson 1969; Kirch 1971; Skjølsvold 1972), but this did not continue beyond the 1970s, as weight is a problematic measure for quantifying temporal changes in abundance and richness of fish taxa and for estimating dietary contribution.

Exhaustive critiques of the benefits and limitations of MNI, NISP, and weight calculations have been discussed elsewhere (Grayson 1979, 1984; Lyman 2008: 21–140). Within the Pacific ichthyoarchaeology literature, it is rare for MNI, NISP, and weight to be reported in the same study (e.g., Weisler and Green 2013— examples outside the Pacific include Erlandson et al. 2005; Joslin 2011; LeFebvre 2007; Rick et al. 2001; Villagran et al. 2011; Wake 2004b). In general, the quantification of archaeological fish remains is regionally specific (e.g., North America, Pacific Islands, and Africa).

MNI allows taxonomic abundance and species richness to be determined, but MNI values increase with the number of aggregation units (Adams 1949: 23–24; Grayson 1979: 203–205). There was an

early preference in the Pacific fishing literature to report only MNI values (e.g., Allo 1970; Anderson 1981; Goto 1984; Leach and Intoh 1984; Masse 1986); this trend was less common outside the Pacific (e.g., Desse and Desse-Berset 1994; Morales 1984).

Allen and Guy (1984) discounted MNI values as they only provide minimum numbers—of a subset of the original deposit that has survived—rather than the complete assemblage. To address this limitation, a formula was developed to determine the possible number of individuals within a confidence interval. Allen and Guy (1984: 44) used left and right parrotfish (Scaridae) dentaries from a Papua New Guinea site to predict within 98% confidence that the original number of individuals was between 1.6 and 4.9 times greater than the MNI of 123. Masse (1989: 411) incorporated the number of weighted individual elements (NIE_{wt}), a measure that does not quantify fragments but rather elements; the “weighting factor” adjusts element counts based on the type and number of elements used to identify each species. This predicted the number of individuals that produced the archaeological fish bone assemblage, but given the limited number of elements used for taxonomic identification and the weighting protocol, no additional information was provided over traditional MNI. Formulae or models that derive theoretical values of the original number of individuals, which produce an archaeological faunal assemblage, do not improve the quality of subsistence reconstructions. In contrast, Orchard (2005) and Gabriel et al. (2012) *maximised* MNI values by using key measurements of fish bone and derived fish length reconstructions. The identification of element size mismatches has been applied in the Pacific to maximise MNI values (Anderson 1981; Ono and Intoh 2011), but Allen (1986: 67) argued that it can be difficult to determine size differences between elements. Lyman (2008: 80–81) has convincingly reasoned that MNI is redundant with NISP, as “interdependence of identified specimens is randomly distributed across taxa,” and since MNI is a derived value and heavily affected by aggregation, NISP is a more suitable method of measuring taxonomic abundance (Grayson 1984). These conclusions assume that all bone fragments or elements are considered equally for identification, which in Pacific fishing studies is not exclusively the case, given inconsistencies in the identification of “special” elements between taxa (e.g., scales of only triggerfish and boxfish are consistently identified in Pacific fishing studies). Because the number of identifiable elements varies between fish taxa, this increases the chances of identifying those taxa that have a larger number of identifiable elements (Grayson 1979: 201). As such, when NISP is considered independently, it can be a problematic measure of both abundance and the economic significance of each taxon to the overall assemblage (e.g., Rick et al. 2002: 111, discusses the economic significance of elasmobranchs in prehistory). The potential inflation of NISP from the identification of a variable number of elements between taxa including the “specials” could be reduced by dividing the number

of elements used to make the identifications for a particular taxon by the total NISP of identified archaeological specimens for the same taxon.

Grayson (1979) argues that despite the problems associated with NISP (also with MNI), it is possible to introduce other lines of complementary evidence, such as taphonomic studies. There are limited examples in Pacific fishing studies where only NISP was reported (e.g., Allen 1992a; Kirch 1988; Pearson et al. 1971; Weisler 1999, 2004), unlike fishing studies outside the Pacific, where NISP values are more commonly used as the only measure of taxonomic abundance (e.g., Amundsen et al. 2005; McKechnie 2007; Moss 2011; Rick and Erlandson 2011; Robson et al. 2013; Zangrando 2007).

Grayson (1979) and Lyman (2008) concur that NISP is the most useful measure of taxonomic abundance, and there has been strong historic precedent for this in North American zooarchaeological analysis. The consensus in the Pacific fishing literature has been to report both MNI and NISP, which allows for comparison between all Pacific fish assemblages, and these measures are complementary (e.g., Allen et al. 2001; Clark and Szabo' 2009; Davidson et al. 2000; Goto 1986; Kataoka 1996; Leach et al. 1999b; McAlister 2002; Ono and Intoh 2011; Weisler and Green 2013). Looking to the future, it is critical that all fish bone elements are equally considered for identification. Using MNI, NISP, and weight (including bone-to- meat weight measures) to analyse faunal assemblages provides more complete reconstructions of the economic importance of different taxa, which allows for comparisons between all fish and faunal classes, for assessment of fragmentation and postdepositional alterations, and the comparison of regional comparisons of datasets (Rick et al. 2002: 112). Studies outside the Pacific have utilised a wide range of quantification measures (MNI, NISP, weight, etc.) to analyse archaeological fish bone (e.g., Archer et al. 2014; Carder and Crock 2012; Carenti 2013; de Jong 1994; Wake and Steadman 2010; Wigen and Stucki 1988).

Standardising quantification protocols for application to all faunal analyses or specifically fish bone analysis is problematic, with researcher preference, geography, depositional context, and research framework each influencing these decisions. For this reason, transparency is paramount, as it allows assessment of quantification protocols implemented by analysts working in the same region and its impact on subsistence reconstructions. We are not advocating for a single universal approach or even for progress toward a specific outcome; rather, we encourage the use of a variety of quantification measures. Ideally, all raw data should be available as either supplementary data or by direct contact with the authors.

Taphonomy and Site Formation Processes

Due to its chemical composition, fish bone is more susceptible to degradation in archaeological sites than mammalian bone and therefore is less likely to be recovered from archaeological deposits (Szapak

2011: 3358). The preservation of faunal remains is influenced by a complex number of factors, including soil chemistry, bone density, burial time, and pre- and postdeposition mechanical breakage (Masse 1989: 428; Nicholson 1996).

In the pre-1980s Pacific ichthyoarchaeology, the problems associated with taphonomy and site formation processes were acknowledged but rarely addressed; these include the impact of soil pH on fish bone preservation (e.g., Allo 1970), the general friability of fish bone in archaeological deposits (e.g., Kirch and Rosendahl 1973; Pearson et al. 1971; Shawcross 1975), the effects that high oil content of tuna bone has on preservation (e.g., Davidson et al. 1998; Severance 1986), and the effects of scavengers such as dogs and pigs (Davidson 1971). There has been more intensive research on taphonomy and site formation processes outside the Pacific as it relates to storage and preservation (e.g., Carenti 2013; Jones 1984; Smith et al. 2011), butchery and processing techniques (e.g., skeletal element representation; Cerón-Carrasco 1994; Colley 1984; Van Neer et al. 2007; Zohar et al. 2001), trade and resource movement (e.g., Barrett 1997; Broughton et al. 2006; Carvajal-Contreras et al. 2008; Perdikaris et al. 2007), and cultural versus natural site accumulation (e.g., Van Neer and Morales 1992; Zohar et al. 2014).

The first formal taphonomic study of a Pacific fish bone assemblage was by Gordon (1993: 454), in Hawai'i, where the completeness of each bone, presence/ absence of burning, and other modifications were reported. Taphonomic studies of Pacific fish bone commonly focus on preservation and representation of elements. Bilton (2001) noted similarities between breakage patterns of the five paired cranial elements and different taxa to demonstrate the influence of differential preservation on the representation of taxa from archaeological sites (Rick and Erlandson 2011; Wichman 2006). By considering all elements for taxonomic identification, we can assess the influence of differential preservation between elements and taxa on species richness and evenness. For example, the analysis of vertebrae—in some instances more readily preserved than cranial elements of the same taxon—can provide a more accurate representation of taxonomic abundance (Lambrides and Weisler 2013; Ono and Clark 2012; Wigen and Stucki 1988).

It is necessary to assess the representation of different fish bone elements archaeologically and the influence of processing techniques and animal ingestions (Butler and Schroeder 1998), bone density mediated attrition of Pacific fish remains—are the most dense bones surviving, or is the relationship more complicated (see Lyman et al. 1992; Smith et al. 2011), and cut mark studies (Archer and Braun 2013; Willis and Boehm 2014; Willis et al. 2008). Controlled experiments should be undertaken to investigate the impact of trampling, burning, different substrates, and pH on the preservation of fish bones commonly found in Pacific assemblages. Pacific ichthyoarchaeologists should implement a

research agenda weighted more toward taphonomy and site formation processes to realign with global approaches.

Diet and Subsistence Reconstructions

Prehistoric human subsistence is a holistic interpretation of the wider sociocultural, technological, ecological, and taphonomic factors that influence human food procurement. This is linked to a thorough understanding of human diet, that is, what is eaten, how much, and the net energy returns and nutritional value of food items (Dennell 1979: 122). As zooarchaeologists, the theoretical and philosophical assumptions that underlie our research process and the methods we use to infer diet and subsistence practices are critical in shaping reconstructions of past human behaviour.

We focus on the disciplinary shift toward ecological approaches for inferring fishing practices in Pacific archaeology and specifically three key methodological approaches that have been adopted in the Pacific fishing literature and globally for understanding prehistoric diet and subsistence practices—behavioural ecology, cultural ecology, and historical ecology. While these approaches are not distinct paradigms or the only approaches for investigating prehistoric diet and subsistence practices, we discuss the literature according to these theoretical approaches.

Early Approaches

Few Pacific Islands fishing studies prior to the early 1970s discussed the implications of fish bone to aid reconstructions of prehistoric diet (e.g., Lockerbie 1940; Shawcross 1967). Even fewer studies completed taxonomic identifications of archaeological fish bone for diet and subsistence reconstructions (e.g., Gifford 1951; Wallace and Wallace 1969). Increases or decreases in fish bone assemblages, or more commonly, the relationship between marine and terrestrial diets over time was discussed, but since the quantities of fish bone identified to taxon were often low, temporal change was difficult to assess (e.g., Kirch 1971; Kirch and Rosendahl 1973; Pearson et al. 1971; Skjølsvold 1972).

More intensive fish bone analysis was completed by Shawcross (1967, 1972, 1975) at the Galatea Bay site in New Zealand to determine prehistoric population dynamics based on reconstructions of meat weight and calculated caloric values, research that has not been widely replicated. Approaches for reconstructing Pacific prehistoric fishing practices followed a different trajectory from that in other regions due to broad distinctions in research outcomes. In Europe and the United Kingdom, there has been an intensive focus on trade, the development of commercial fisheries, the growth of urbanisation, and the eventual globalisation of these fisheries (e.g., Barrett et al. 2004a, b, 2011; Orton et al. 2014; Perdikaris et al. 2007; Perdikaris and McGovern 2009). While these research outcomes

are not directly comparable to Pacific fishing studies, the broader thematic and methodological implications are pertinent to this review.

Ecological Approaches and Capture Techniques

In contrast to the early culture history focus in the Pacific literature, ecology-framed research dominated the 1970s. The exploitation of prehistoric marine habitats was investigated in conjunction with modern fisheries data, including fish feeding behaviour and ecology (Butler 1994). Fish capture techniques were assessed as part of wider enquiries of resource availability and prey choice using cultural and environmental datasets (e.g., Allen 1986; Allo 1970; Masse 1986).

Using fish bone assemblages from southern New Zealand sites, Anderson (1986: 151–160) investigated factors affecting the distribution of inshore taxa on the south and east coast; variation in local ecology and selective use of capture technologies were attributed to distinctions in species abundance and richness. Smith (2002) argued that early studies in New Zealand failed to emphasise the relative importance of fishing to other subsistence practices. These early New Zealand studies were the first in the Pacific to consider ecology and human agency to infer fish capture techniques and broader subsistence reconstructions.

The link between fish behaviour, marine ecology, and capture method was first determined in the Pacific in the 1980s; archaeological fish bone was analysed in conjunction with fishing-related artefacts and ethnography to infer fish capture methods (e.g., Goto 1984; Leach et al. 1995). The relationship between cod/grouper to parrotfish was assessed to determine dominant capture technique, with cod and grouper associated with deep water and baited hooks while parrotfish were likely netted inshore (e.g., Leach and Intoh 1984; Leach et al. 1984). It can be problematic to use family-level identifications to assess fish capture techniques. Multiple methods of capture may be utilised for an individual taxon, and extensive numbers of genera and species comprise most families, with each inhabiting different ecological zones. This is further complicated by fish growth stage; for example, fish larvae initially settle in a nursery habitat (e.g., mangroves) that is relatively protected, then juvenile fish migrate to the coral reef, often occupying benthic habitats as adults. This influences habitat choice and consequently resource availability and capture method by prehistoric fishers (e.g., Masse 1986: 112; Rolett 1989: 226–237); for these reasons Bertrando and McKenzie (2011) used measurements of archaeological precaudal vertebrae (from California sites) to distinguish between capture techniques (see Ono 2010; Pletka 2011). It also has been demonstrated that screen size has implications for the detection of different capture techniques (Bertrando and McKenzie 2011: 174, table 12.3). Butler (1994) considered the implications of assessing fish dietary preferences and behaviour to infer capture techniques, as this suggested the use of techniques that were capable of

catching, for example, carnivorous or herbivorous taxa (see also Allen et al. 2001). Given the difficulty in determining capture techniques, ethnoarchaeology and ethnobiology provide useful comparative datasets for conceptualising this complicated issue (e.g., Dye 1983; Johannes 1981; Jones 2011; Kirch and Dye 1979). Ethnoarchaeological research on Borneo Island by Ono (2010) suggests that season, wind direction, and tidal cycle are important factors for determining prehistoric capture techniques.

Multiple lines of evidence are used to infer fish capture techniques, including modern ecological data (e.g., fish feeding behaviour), age and size profiles as determined by archaeological fish remains, material culture, modern observations of indigenous fishers, and ethnography. Reconstructing fish capture techniques is one of the most difficult aspects of investigating prehistoric fishing practices as a single capture technique is rarely associated with an individual taxon. With a continued focus on experimental archaeology, our understanding of fishing strategies, method, and techniques can improve (e.g., McKenzie 2007).

Cultural Ecology

Cultural ecology is the study of human adaptation to an environment as mediated by culture (Sutton and Anderson 2010: 3–4). This approach, which suggests that a colonising population or culture will develop along the same trajectory across an archipelago of environmentally similar islands (Rolett 1989: 21), garnered popularity in Pacific archaeology during the 1980s, as analysts shifted from traditional artefact-centric approaches to address questions of prehistoric adaptation to marine environments (e.g., Goto 1984; Kirch 1980).

Kirch's (1979, 1980, 1982) work in Hawai'i demonstrated the importance of ecological approaches for interpreting marine exploitation. Fish remains and their capture methods reflect behaviours dictated by local environmental constraints, "to which the population must respond in order to maintain its adaptedness—that is, a viable existence" (Kirch 1980: 39). While these approaches allow cultural adaptations to the environment to be better understood by moving beyond interpretations of culture as static, cultural ecology tends toward environmental determinism, suggesting that human action is dictated in large part by the local environment (Balée 1998). Given the limitations of a cultural ecological approach for understanding the past, Rolett (1989: 25) analysed Marquesas Islands faunal assemblages to determine whether similar patterns of change could be tracked between island groups or whether ecological distinctions were an important factor that mediated change. Ecological, ethnographic, material culture, and modern catch data were used to understand both capture method and targeted fish, but similar environments did not produce similar subsistence adaptations, as variation in prehistoric fish assemblages was identified at both the local level and between the islands

of the Marquesas. Dye (1990: 70) argues that these early ecological approaches are limiting and it is important to consider the social and historic processes that influence change.

Human Behavioural Ecology

The interpretation of zooarchaeological remains through the application of foraging models derived from behavioural ecology has become increasingly popular globally (e.g., Bird et al. 2002; Broughton 1997; Butler 2001; Nagaoka 2002a; Stiner et al. 2000). Behavioural ecology models are often viewed as constrained by the premise of optimality, which suggests that humans interact with their environment in ways that will maximise short-term reproductive fitness (Binford 1978). Human behavioural ecology (HBE) assesses how ecological factors can mediate variability in human behaviour (Lupo 2007: 145). Consequently, these models can be environmentally deterministic, and the application of prey choice models (what to select and what to pass over) and patch choice models (where to forage and for how long) must be completed using comprehensive datasets that acknowledge a wide set of inclusive variables (Kennett 1998; Stephens and Krebs 1986). Only then can archaeologists begin to disentangle the processes of culture change, with human decision making viewed “as a source of variation, rather than a force of change” (Allen 1992b: 184).

In her analysis of Cook Islands fishing strategies, Allen (1992a, b) evaluated the evolution of subsistence systems and associated adaptive strategies, demonstrating the complex relationship between fitness-maximising behaviours and the overall subsistence regime. Butler’s (2001) investigation of resource depression was one of the first to apply the prey choice model in the Pacific (see Butler 2000, for application in North America). Body size was used as a proxy for determining prey rank, and while the implications of mass harvesting were not incorporated in the model, technological changes and environment were considered (Butler 2001: 88). HBE models were applied in the Pacific by Butler (2001), Nagaoka (Nagaoka 2001, Nagaoka 2002a, b), and McAlister (2002). These analysts did not consider only species richness but the complex processes and strategies that mediate culture change and persistence. Fish size can be problematic for determining prey rank, but this is not to challenge its usefulness for informing prey selection strategies and particular capture techniques (e.g., Pletka 2011).

West (2009: 224) has argued that two major problems limit studies grounded in behavioural ecology: regional rather than local environmental data have been used to argue that climate change was not responsible for resource depression, and there are limited datasets that document prehistoric faunal abundance independent of the archaeological record. Investigating Alaska’s Kodiak Archipelago, West (2009: 232) developed fine-grained local climatic data using stable isotopes from archaeological fish otoliths and suggested that changes in fish population structure over time could not be attributed

to the abundance of salmon in the Karluk River or by local marine conditions; consequently, prehistoric subsistence practices are not always environmentally determined. A more diverse series of cultural and environmental factors must be investigated to develop these models, including dietary preferences and changes in the role of fish within the subsistence regime over time, changes in fishing technology, fish bone recovery methods and analytical techniques used, and local environmental data (e.g., Butler and Campbell 2004).

Jones (2011) and Leach and Davidson (2000) argue that models of optimal foraging derived from behavioural ecology are not suitable for understanding prehistoric fishing practices in the Pacific, as there is an overemphasis on maximising return for effort (for the North American Pacific Northwest, see Campbell and Butler 2010b). Jones (2011: 73) argues that these models are based on western constructions of optimality rather than on local definitions of success and value (Cannon 1998). Yet to what extent modern constructions of success and value can be applied to prehistoric populations is questionable, as it implies culture is temporally static. Still, Jones' (2011) discussion of optimality cannot be overemphasised. The major limitations of optimal foraging theory described by Jones (2011) and Leach and Davidson (2000) as it relates to Pacific prehistoric fishing practices are that fish are very abundant throughout the Pacific and easily captured in mass using nets and since humans cannot live on protein alone, plant carbohydrates must be considered. People do not seek out only larger-bodied prey and select larger over small fish. In addition, most of the assumptions are based on collecting and processing shellfish and terrestrial resources that generally require greater handling time than reef vertebrates.

Food procurement decisions are not necessarily determined by concepts of optimisation; resource availability, ease of procurement, the community or population size to be fed, types of technology available, and marine environments for exploitation are all important considerations (Erlandson et al. 2009: 721), as are the relationships between all faunal classes (e.g., fish, shellfish, domesticates, and birds). In regards to conservation behaviour, Campbell and Butler (2010b: 176) suggest the HBE approach fails to recognise the diversity of factors that are central to inferences of human subsistence strategies and how these systems may remain stable or change over time. When used appropriately and the limitations are clearly acknowledged, models derived from behavioural ecology are an excellent means of hypothesis testing, especially for assessing whether people were maximising short-term reproductive fitness. Although these models do not reflect the complexity of human behaviour, these simple frameworks highlight anomalies in the data, which may warrant further analysis.

Historical Ecology

Historical ecology is a conceptual framework that considers human interactions with landscapes as an integrative phenomenon where interactions are a means of understanding the formation of past cultures and human modified environments (Balée 2006: 76; Jones 2009: 618; Rick and Lockwood 2012: 46–47). Unlike optimality or systems theory models, historical ecology considers human agency, as variable socioeconomic, political, and cultural phenomena influence landscapes differently. Humans are not genetically presupposed to operate according to expected trajectories that manifest in predictable environmental outcomes. Historical ecology is a multidisciplinary approach that does not consider one dataset to be more valid than another—it is a “holistic engagement of knowledge” (e.g., Balée 1998, 2006; Erlandson et al. 2009; Fitzpatrick and Donaldson 2007; Jones 2009; Kirch and Hunt 1997; Ono and Clark 2012; Rick et al. 2014; Walter 1991). Archaeologists have noted the potential of historical ecology to provide unique and inclusive interpretations of human–environment interactions across broad temporal and spatial scales (Fitzpatrick and Intoh 2009: 463). Historical ecology focuses on the creation of the “landscape,” which is both a product of culture and environment and is inherently meaningful. Perhaps one of the most influential historical ecology studies of marine subsistence is the ongoing research on California’s Channel Islands (e.g., Erlandson et al. 1999, 2005, 2011; Rick et al. 2001, 2005). Similar work has been completed by Jones (2009, 2011) for Fiji’s Lau Group where modern and long-term marine biodiversity and human interactions with the local environment have been investigated using ethnography and biological surveys.

The earliest consideration of a historical ecological framework for analysing Pacific fishing practices was by Walter (1991), at Ma’uke, Cook Islands. Instead of drawing conclusions between the archaeology and modern ethnographic data, he emphasised the historical trends that shaped Ma’uke culture. Within Pacific archaeology and more specifically Pacific fishing studies in the last decade, historical ecology has provided a framework to engage the archaeology and to consider the interrelationships with local climate, ethnography, modern marine surveys, and historical records (e.g., Fitzpatrick and Donaldson 2007; Jones and Quinn 2009; Ono and Addison 2013).

A historical ecology approach provides archaeologists with a “best practice guide” for completing Pacific fishing studies, with multiple lines of evidence to provide a holistic interpretation of the past (Weisler and Walter 2002). As historical ecology successfully frames analyses of prehistoric fishing practices globally, a network of literature can inform our understanding of human interactions with marine environments over thousands of years and contribute to the conservation and fisheries management discourse (e.g., Barrett et al. 2004b; Cooke and Ranere 1999; Johannes 1978; McKechnie et al. 2014; Thornton et al. 2010).

Seasonality Studies

Determining seasonal exploitation of resources or seasonal occupation of a site is a fundamental component of prehistoric subsistence reconstructions (Monks 1981), but it is a research pursuit that has been more intensively studied outside the Pacific. In the Pacific fishing literature, stable isotope analysis and sclerochronology—shell growth pattern analysis (e.g., Burchell et al. 2013) and fish vertebral and otolith growth ring analysis (e.g., Desse and Desse-Berset 1997; Enghoff 1994; Perdikaris and McGovern 2009; Van Neer et al. 1999)—have not been as thoroughly used. We discuss approaches for inferring seasonality in the Pacific and suggest future research avenues grounded in the global literature.

Primarily in Pacific archaeology, seasonality of fish capture was inferred from fish behaviour data. Shawcross (1967) used the condition of archaeological snapper teeth as it relates to seasonal feeding behaviours. Kirch (1979) reconstructed caloric value based on midden constituents to determine the number of “man-years” represented by the archaeological assemblage and to infer seasonal versus permanent site occupation. Leach (1979) used modern catches and ecological data to determine if a specific fish species could be caught in a particular month at the Washpool Midden site in New Zealand. Oxygen isotope analysis was applied only in the late 1980s in the Pacific as a method for assessing seasonality. The reanalysis of Otago archaeological sites in New Zealand using marine shell carbonate demonstrated that fishing may have been a winter activity, which suggests closer reassessment of prehistoric seasonality (Till and Blattner 1986: 175). Red cod otoliths were sectioned to examine annual and seasonal growth rings for comparison with modern samples at the Shag River Mouth site in New Zealand (Higham and Horn 2000); however, Carlson (1988) and Van Neer et al. (2004) have demonstrated that seasonality studies based solely on incremental data of fish otoliths can be problematic.

In the Pacific, stable isotope analysis has commonly been used to analyse human, pig, and dog bone (e.g., Allen and Craig 2009; Jones and Quinn 2009; Leach et al. 1998, 2003; McGovern-Wilson and Quinn 1996; Valentin et al. 2006). These data have contributed to prehistoric subsistence studies, but there has been little in-depth application of these methods to seasonality studies. Similarly, sclerochronological analysis (e.g., Andrus 2011) has been applied outside the Pacific using both shellfish (e.g., Mannino et al. 2007) and fish otoliths (e.g., Geffen et al. 2011; Hufthammer et al. 2010; Van Neer et al. 2004) to ascertain season of capture, but it has not been consistently incorporated in Pacific fishing studies. These procedures require regionally specific environmental data (e.g., water temperatures, salinity, and tidal movement across all seasonal cycles) to determine how seasonal/annual cycles affect the environment, and a detailed understanding of fish biology, such as thermal tolerances and migration patterns, in order to comprehensively determine how a species reacts to its environment. As technologies and methods are rapidly improving, these techniques need

to be incorporated into Pacific subsistence studies (and specifically fishing studies); in most cases the only discussion of seasonality relates to ethnographic fishing lore (e.g., Ono and Addison 2009, 2013) or modern catch data and the occurrence of seasonal runs (e.g., Olmo 2013). These methods of seasonality studies seem warranted in the Pacific based on global applications.

Resource Sustainability and Fisheries Management

The investigation of resource sustainability within the social sciences is a diverse and multidisciplinary endeavour. Sustainability relates to broader processes of globalisation, sustainable development, and policy making, and how these may be negotiated by communities on local and global levels (e.g., Almas and Lawrence 2003; Kishigami and Savelle 2005; Lawrence et al. 2010; Redclift 2005). In archaeology, “sustainable” does not necessarily refer to the conservation of resources, rather it is an assessment of the interrelationship between the resources exploited and the environment in which they are exploited, and whether the carrying capacity of the environment sustained human populations over time. Resource sustainability and depression often are determined by changes in fish species abundance, richness, and size over time, as well as trophic-level analysis (e.g., Fitzpatrick et al. 2011; Jones 2011; Kennett et al. 2008; Morrison and Addison 2009; Weisler 2004; Weisler and Green 2013). Humans do not have unidirectional impacts on local resources, and the dialogue between climate, environment, and people must be considered.

Assessments of the sustainability of fish exploitation throughout prehistory has been utilised by archaeologists to inform sustainable fisheries management plans (e.g., Butler and Delacorte 2004), in an attempt to address growing awareness of global declines in fish stocks and coral reefs. This relates to the impact of the “shifting baseline syndrome,” a term defined by Pauly (1995) whereby a generation of fisheries experts accept as a baseline the abundance and species composition recorded at the beginning of their careers, with often little acknowledgement that, historically, the fish stocks were managed at a depleted state. It has been demonstrated that zooarchaeology offers pertinent insights into the long-term dynamics of fish populations and exploitation in the past, which is not temporally constrained to historical records (e.g., Aswani and Allen 2009; Dalzell 1998; McClanahan and Omukoto 2011; Pinnegar and Engelhard 2008; Rick and Fitzpatrick 2012). These studies also have considered traditional ecological knowledge, as it can meaningfully inform modern fisheries management (e.g., Campbell and Butler 2010a; Hamilton 2003; Jones 2007; McKechnie 2007; Thornton et al. 2010). The application of diversity indices, measures of trophic alteration, aDNA analysis, and stable isotope analysis not only track changes in fish community structure and range as represented in the archaeological record but contribute unique perspectives to modern fisheries research (e.g., Butler and Delacorte 2004; Erlandson et al. 2009; Morrison and Addison 2009; Pauly et al. 1998; Reitz 2004; Van Neer and Ervynck 2009). A balance between marine research and social

science datasets is required, but the emphasis on establishing multidisciplinary research projects (e.g., Sea Around Us Project and Oceans Past Platform; see also Barrett et al. 2004a; Jackson et al. 2001; Kittinger et al. 2011; Miller et al. 2011; Speller et al. 2012) will continue to redirect this discourse and ideally provide holistic conservation and management outcomes (Christie 2011).

Fisheries Management

Just as modern fisheries studies inform prehistoric reconstructions of Pacific fishing (e.g., Edwards et al. 2014), so too can the archaeology of fishing contribute to globally relevant questions of resource sustainability and the effects of climate change through the establishment of ecological baseline data (e.g., Carder and Crock 2012; Carder et al. 2007; Gobalet 2012; Gobalet and Jones 1995; Kittinger et al. 2014; McKechnie et al. 2014; Rick et al. 2014; Schmölcke and Ritchie 2010; Wolverton and Lyman 2012). Given the diverse environments that comprise the Pacific Islands, archaeologists conducting zooarchaeological research have a unique opportunity to provide an unmatched record of the relationship between humans and marine/terrestrial fauna distributions over variable temporal and spatial scales (Butler 2010: 150) and thus provide a unique perspective on current debates about biological conservation.

A pioneer for the implementation of traditional marine conservation methods in the Pacific Islands, Johannes (1978, 1981, 1994, 2002, 2003) demonstrated the value of indigenous knowledge and community-based management systems. In an archaeological context, Dalzell (1998) suggested that in regions such as the Pacific Islands, where expensive resources for conducting fisheries management schemes are not readily available, archaeological data can provide useful outcomes. Given the importance of culturally informed management strategies in coral reef conservation efforts (Johannes 2002), it is surprising that more Pacific fishing studies do not implement integrative approaches in collaboration with marine biologists (e.g., Aswani and Allen 2009; Jones 2009).

Globally, historical ecological approaches have been used to assess long-term anthropogenic and climatic alterations to ecosystems, generating population baseline data and restoration frameworks (e.g., Braje et al. 2012; Kittinger et al. 2011; Lotze and McClenachan 2014; McClanahan and Omukoto 2011; McClenachan et al. 2012; Newsome et al. 2010; Rick and Lockwood 2012; Rick et al. 2014). Stable isotope, aDNA, and DNA analysis have become critical components of interdisciplinary historical ecology research and provide insight into changes in population structure, interaction, adaptation, population size estimates, trophic ecology, and alterations to prey, habitat, and foraging preferences of taxa over time—also including humans.

Speller et al. (2012) used aDNA to study genetic diversity and population structure of prehistoric herring populations, research key to understanding temporal and spatial genetic variations in fish

populations (see Pääbo et al. 2004; Willerslev and Cooper 2005). aDNA can be utilised to identify species introductions and translocations, particularly relevant to island archaeology (Rick et al. 2014: 688), and effectively estimate population sizes across temporal scales, which is useful for addressing the shifting baseline syndrome (e.g., analyses of prehistoric European sturgeon remains by Ludwig et al. 2008).

Carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$) stable isotope ratios have been used to compare human bone collagen with food consumption remains to determine wider dietary patterns, particularly diet composition (e.g., Jones and Quinn 2009; Leach et al. 1998, 2003). Nehlich (2015) reviews $\delta^{34}\text{S}$ analysis and its usefulness for reconstructing dietary, ecological, temporal, and spatial trends. The advantages of completing isotopic analysis of archaeological fish remains have been demonstrated, which include refined assessments of diet composition (Vika and Theodoropoulou 2012), identification of trophic niches, feeding habits, and habitats of exploited fish species (Fuller et al. 2012; Häberle et al. 2015; Miller et al. 2010), as well as determining provenance and catch regions to identify trade and resource movement (Barrett et al. 2011; Orton et al. 2011). Stable isotope analysis is a powerful tool for restoration and conservation efforts, as it can provide high resolution and locally representative trophic ecology data useful for assessing long-term human–environment interactions.

The importance of this integrative research agenda has been clearly demonstrated, but it should be developed as part of global approaches to ichthyoarchaeological analyses. It is important to characterise the history of an ecosystem prior to the development of management programs (Jackson et al. 2001: 636). Significant archaeological contributions include aDNA and stable isotope analyses of ichthyoarchaeological remains, assessments of fish population structure, historic biogeography, and understanding human impacts over millennial time spans. Finally, the implementation of more collaborative projects between archaeologists, indigenous communities, marine/conservation biologists, economists, and social scientists (e.g., Glazier 2011) should provide new interdisciplinary perspectives on the globally relevant issue of fisheries management.

Metric Reconstructions, Sustainability, and Resource Depression

Overharvesting, alterations to subsistence strategies, environmental change, and resource sustainability each produce diverse archaeological signatures and these complex processes are often difficult to disentangle. Temporal alterations in subsistence fishing have been documented as a decrease in fish diversity (e.g., Fitzpatrick and Kataoka 2005), an increase in fish diversity (e.g., Ono and Clark 2012), alterations to fish species archaeologically present in response to climate change (e.g., sea surface temperatures; Enghoff et al. 2007; West et al. 2011), trophic level stability and/or

decline (Blick 2007; Kennett et al. 2008; Morrison and Addison 2009; Pestle 2013; Quitmyer and Reitz 2006; Wing 2001), and an increase and/or decrease in average fish size over time (e.g., Amundsen et al. 2005; Bartosiewicz and Takács 1997; Carenti 2013; Desse and Desse-Berset 1993; Owen and Merrick 1994; McKechnie 2007; Weisler 2004).

Casteel (1976) completed pioneering work on the applicability of metric reconstructions of live fish weight and length as determined by key measurements of fish bone, and Shawcross (1967, 1972, 1975) was one of the first to consider fish bone morphometric measures in Pacific archaeology (also Allo 1970). There has been an intensive focus in Pacific archaeology—particularly between 1970 and 2000—on the use of metric reconstructions of fish size to determine changes in prehistoric fishing practices and human impacts over time (e.g., Butler 2001; Davidson et al. 2000; Leach and Boocock 1995). Yet, a variety of datasets are integral for disentangling the multitude of processes (i.e., cultural, social, environmental) that mediate temporal shifts in prehistoric fishing practices; these include measures of diversity and evenness, fish density, rank-order abundance, metric reconstructions (applicability is a function of sample size), aDNA analysis, isotope analysis, and trophic-level analysis (e.g., Carder and Crock 2012; McClanahan and Omukoto 2011; Wing 2001). The focus here is the development and use of morphometric measures in Pacific fish bone analysis given their popular usage, but we also assess other methods that are routinely used globally to evaluate sustainability and resource depression in the past.

In Pacific archaeology, by the 1990s, it was acknowledged that fish size reconstructions could provide a statistically rigorous method to assess temporal changes in fish size; yet formal and replicable protocols had not been developed utilising Pacific taxa (Leach and Davidson 1981: 115; Nichol 1986: 185). Measurements of archaeological fish bone were recorded and changes in size were noted, yet the factors driving this change were not determined (e.g., Goto 1984: 60; Kirch 1982: 468–469; Masse 1989: 498–515). Though not widely acknowledged in the early Pacific literature, the contribution of the Desse's to the development of fish osteometry in archaeology cannot be overemphasised (e.g., Desse and Desse 1983; Desse and Desse-Berset 1994, 1996c). They determined that key bone measurements and fish length/weight were highly correlated (Desse and Desse-Berset 1996b: 172). These allometric relationships are a powerful tool for archaeologists assessing resource sustainability and prehistoric changes to fish population dynamics.

Leach and colleagues published an extensive literature on the protocols, implications, and benefits of fish osteometry with assemblages from New Zealand and used predominantly the five paired cranial elements and “special” bones (e.g., Davidson et al. 2000; Leach and Boocock 1994, 1995; Leach et al. 1999a, b). The caudal peduncle or ultimate vertebra of tuna, mackerel, and bonito (Scombridae) were measured to analyse temporal distinctions in the raw measurement values, but reconstructions

of fish length or weight were not regularly completed (e.g., Leach et al. 1997: 60–61; but see Fraser 1998: 128–142). Outside the Pacific Islands a wider range of cranial and postcranial elements have been used for decades to complete fish length and weight reconstructions (e.g., Desse and Desse-Berset 1996c; Enghoff 1994; Gabriel et al. 2012; Makowiecki and Van Neer 1996; Orchard 2003; Van Neer et al. 1999).

Vertebral morphometrics has had limited applications in Pacific archaeology (e.g., Desse and Desse-Berset 1996a; Ono and Intoh 2011). Ono and Intoh (2011: 267–271) assessed the applicability of determining fish weight and size from the diameter of tuna and shark vertebrae but suggested further work was needed to understand the variables that affect fish size, such as sexual dimorphism, individual variation, allometric scaling, and ecological factors (e.g., temperature). General comparisons were made between the vertebrae diameters of archaeological and modern specimens to determine live fish weights and length (Ono and Intoh 2011). Due to variability in vertebra diameter across the vertebral column of an individual specimen, it is problematic to consider vertebrae as a single and uniform element category, an issue often compounded by the difficulties of distinguishing between shark vertebrae types. Further analysis completed by Lambrides and Weisler (2015) demonstrated that archaeological fish vertebrae should be identified to taxon and type (e.g., atlas, precaudal) and, prior to fish size reconstructions, the position of each vertebra along the vertebral column should be determined (Desse and Desse-Berset 1996c; Gabriel et al. 2012; Makowiecki and Van Neer 1996).

The usefulness of morphometric measures for identifying temporal changes in fish size cannot be overestimated, but given the variability in faunal body size, prey availability, human predation, local climate, and environment, additional lines of evidence should be considered (e.g., Carder and Crock 2012; Jones and Quinn 2009; LeFebvre 2007; Ono and Clark 2012). To evaluate temporal changes in fishing practices in the Pacific, morphometric measures and simple comparisons of MNI values should not be the only analytical methods implemented. The assessment of taxonomic composition using indices of structure and similarity allows simple but informative questions to be addressed (e.g., Carder and Crock 2012; Fitzpatrick et al. 2011; Jones 2009; Joslin 2011; LeFebvre 2007; Lyman 2008). There has been a recent emphasis on the identification of trophic level alterations, which ranks marine organisms based on feeding behaviour (Pauly et al. 1998). Described as “fishing down the food web,” similar archaeological signatures also have been identified (Erlandson et al. 2009; Pestle 2013; Reitz 2004; Wake et al. 2013). Investigating fish exploitation in American Samoa, Morrison and Addison (2009) observed no change in the mean trophic level of the prehistoric fishery over time. Isotope and aDNA analysis are important datasets to be considered in Pacific ichthyoarchaeological analyses of resource sustainability as they facilitate high-resolution inferences of trophic ecology.

In the Pacific ichthyoarchaeological literature, there has been a focus on using osteometry and simple comparisons of MNI to evaluate changes in fishing over time. It is encouraging that a more diverse range of analytical protocols are being implemented, including changes in diversity and richness (e.g., Fitzpatrick et al. 2011), trophic analysis (e.g., Morrison and Addison 2009), and stable isotope analysis (e.g., Jones and Quinn 2009). These analyses can be integrated with material culture studies, locally specific environmental data, modern biological surveys, fish ecology and behaviour data, and ethnography to provide a fuller understanding of alterations to marine environments over time, which informs modern conservation agendas.

Ethnoarchaeology

“With special attention focused on material culture, objects, technology and all material associated with daily life, ethnoarchaeological studies document what ethnographic research often leaves undescribed” (Jones O’Day 2004: 54). From the early anthropological work in New Guinea by Malinowski (1922) and Powdermaker (1933) of the functionalist school of anthropology, to the more recent integrative approaches by Kirch and Dye (1979) and Dye (1983) in Tonga, and Jones (2007) in Fiji, ethnography has remained an important component of Pacific fishing studies. Ethnoarchaeology should produce an “interpretive history” (Jones O’Day 2004: 60) that draws on indigenous knowledge and traditions, archaeology, and western histories. Although these may provide competing constructions of the past, these interrelationships offer more holistic reconstructions of ancient lifeways. The incorporation of ethnohistorical records must still be used cautiously, for example, the disparity between archaeological and ethnographic records regarding the importance of salmon fishing along the California coast (Gobalet et al. 2004; Whitaker 2011). Ethnography can usefully inform HBE approaches as archaeologists can consider decision-making processes and determine possible costs, risks, and benefits associated with different fishing strategies (Colley 1986; Hoffman et al. 2000; Keegan 1986). Ethnoarchaeology is one possible approach to investigating the past, and the consideration of ethnographic data is a valuable component of a historical ecology approach; Jones O’Day (2004: 54–57) reviews the development of ethnoarchaeology as a subfield and its contribution to both archaeology and anthropology.

Titcomb’s (1972; also Kahā‘ulelio 2006) key ethnographic study demonstrated the economic and cultural importance of fishing to native Hawaiians and the contribution of ethnography to archaeological inference. Ethnography provides interesting insights into missing archaeological evidence as in the case of eel fishing in prehistoric New Zealand, where Marshall (1987: 75) investigated contemporary and historic ethnographies to infer the social and political dimensions of prehistoric eel fishing. Local language dictionaries also provide useful information on fishing techniques and strategies. The Marshall Islands dictionary (Abo et al. 1976) lists 66 words for fishing

techniques, describing, in many instances, the tools and bait used, time of day practiced, location on reef, inside or outside the lagoon, depth of water, and whether the technique is an individual or group pursuit (Weisler 2001: 106). Weisler's (1999: 31–33, 2001) study of Ebon, Maloelap, and Utrök Atolls in the Marshall Islands emphasised the importance of participant observation in archaeological analysis of prehistoric fishing practices as, for example, parrotfish bones are far more numerous in the Marshallese archaeological record than in the modern diet. Modern Marshallese fishers also related the location of important fishing grounds, tackle and bait used, and the number of people that would typically engage in a particular fishing strategy. However, there is not always a clear link between the ethnography and the archaeology of a region; despite the ethnographically documented sociocultural significance of pelagic fish in Kapingamarangi and Nukuoro, they were archaeologically absent (Davidson and Leach 1996).

Ethnobiologists, such as Johannes (1981, 2002), have emphasised the importance of traditional knowledge for understanding human–environment interactions and long-term resource conservation. Ono and Addison (2009: 18) considered Tokelauan fishing lore from an ethnoecological perspective to determine how people in the past and present conceptualise and exploit the marine ecosystem (see also Huntsman and Hooper 1996; Ono 2010). Ethnography provides archaeologists a means of looking beyond the economics of subsistence (faunal analysis) to investigate the intrinsic relationship between the economic and social paradigms surrounding food and subsistence in the past (e.g., Weisler and McNiven 2015). With regards to Pacific Island zooarchaeology, Jones has produced some of the most comprehensive and focused ethnoarchaeological studies, which evaluate social issues related to foodways, hierarchy, and identity in Pacific prehistory, primarily in Hawai'i and Fiji (e.g., Jones O'Day 2001, 2004; Jones 2007, 2009; Jones and Kirch 2007; Jones and Quinn 2010). This research has specifically targeted changes in marine diversity, population declines, and size changes in exploited species, and has directly linked this research to global themes of climate change and overfishing to provide long-term data for conservation and management regimes.

The Pacific is a culturally and environmentally diverse region, and when ethnography is articulated with archaeology it can be a powerful tool for understanding prehistory. Ethnography should continue to be incorporated in research approaches, such as historical ecology, to provide multifaceted reconstructions of prehistoric fishing practices, as it also foregrounds indigenous knowledge to produce sustainable fishing outcomes in a modern context.

Future Directions for the Archaeology of Marine Fishing

Refining Ichthyoarchaeology Methods and Methodologies

Field recovery techniques have progressed from the 1950s when fish bone was not routinely collected (if at all) to today where there is a near-universal preference for finer mesh (≤ 3.2 mm) screening. We hope to see Pacific archaeologists continue to implement screening and identification protocols that align with worldwide disciplinary ichthyoarchaeological trends for enhancing comparative analyses in the human exploitation of fishes. While there is no universal protocol for recovering faunal remains from Pacific archaeological sites, we concur with Colley (1990) who emphasises the importance of transparency over standardisation in fish bone analysis.

The analytical limitations of reference collections must be acknowledged. Reference collections that include most of the range of possible taxa in an archaeological assemblage can provide more specific taxonomic identifications; however, the establishment and curation of extensive comparative collections is a time-consuming task. Ultimately, zooarchaeological identification criteria and protocol standards provide quality assurance, which is preferable to more specific taxonomic identification.

Pacific ichthyoarchaeologists, until quite recently, have used a narrow range of elements for identification of taxa, yet recent studies have clearly demonstrated that incorporating all archaeological fish remains adds significantly to tallies of species richness and diversity. aDNA and ZooMS facilitate species-level identifications, but the added expense and time required for these techniques must be justified in reference to research questions.

Archaeological fish remains should be quantified using a range of measures (e.g., MNI, NISP, weight, bone-to-meat weight measures, etc.), as this provides more complete reconstructions of the economic importance of different taxa, which allows for comparisons between all fish and faunal classes, assessments of fragmentation and postdepositional alterations, and more reliable regional comparisons of datasets. This allows analysts to assess the influence of quantification measures on determinations of species abundance, richness, and evenness that underpin reconstructions of human behaviour.

Taphonomy and site formation also should be more intensively studied in Pacific archaeological settings. This could include the impact of trampling and burning as well as the effects of depositional context and substrates, pH, and bone density on the preservation of fish bones found in Pacific archaeological sites. Understanding these processes will provide useful insights for interpreting zooarchaeological remains from tropical settings and globally.

Three key theoretical approaches have shaped discourses in Pacific Islands zooarchaeology: cultural ecology, behavioural ecology, and historical ecology. Given the emphasis on interdisciplinary research, frameworks of historical ecology have proven worldwide utility. Historical ecological

approaches are not only relevant to archaeological fishing studies but are useful for examining the spatial and historical dialogues between humans and the environment. Given the global concerns relating to the depletion of fisheries and the continued demise of long-term sustainability of marine biota across all oceans, archaeologists have a unique opportunity to provide century-to-millennial historical perspectives that can inform modern fisheries conservation and management practices.

Ichthyoarchaeology and Fisheries Management

Schwerdtner Máñez et al. (2014) proposed five key areas of research for a “global marine historical research agenda,” which include the characteristics of a pristine environment, the different drivers (e.g., climate change, human predation, etc.) that contribute to changes in the marine environment over time, the cultural significance of marine resources over time and between human groups, the circumstances that cause people to exploit or abandon particular marine habitats, and the ways that historical datasets can be incorporated into conservation and management agendas. In order for ichthyoarchaeology to contribute to these global aims, we suggest a number of important considerations. Archaeologists should engage with relevant parties (e.g., indigenous communities, resource managers, fisheries biologists, policy makers, etc.) to frame initial research objectives, which will ensure that the data produced (e.g., species specific, region specific, habitat specific, etc.) can be utilised by these researchers. The ability to complete timely, cost-effective, and species-level taxonomic identifications of archaeological fish bone is critical to ensure relevance to the widest audience. Archaeologists must acknowledge the limitations and utility of faunal data. For example, measures of relative abundance may not have the greatest relevance for conservation management, but data relating to anthropogenic influences on the presence or absence of species over long periods of time and varying spatial scales (e.g., island, archipelago, and region) may be extremely informative. Furthermore, we cannot overestimate the benefits of archaeology that has the unique ability to assess long-term change in human–environment interactions and to generate datasets that can address archaeological research questions as well as contribute to conservation and management agendas; topics may include aDNA and stable isotope analyses of ichthyoarchaeological remains, assessments of fish population structure, historic biogeography, and human impacts over millennial time spans. Finally, increasing dialogue between disciplines and developing collaborative, interdisciplinary projects are essential to the successful use of archaeological data in management and conservation planning and policy as exemplified in the Oceans Past Platform COST Action.

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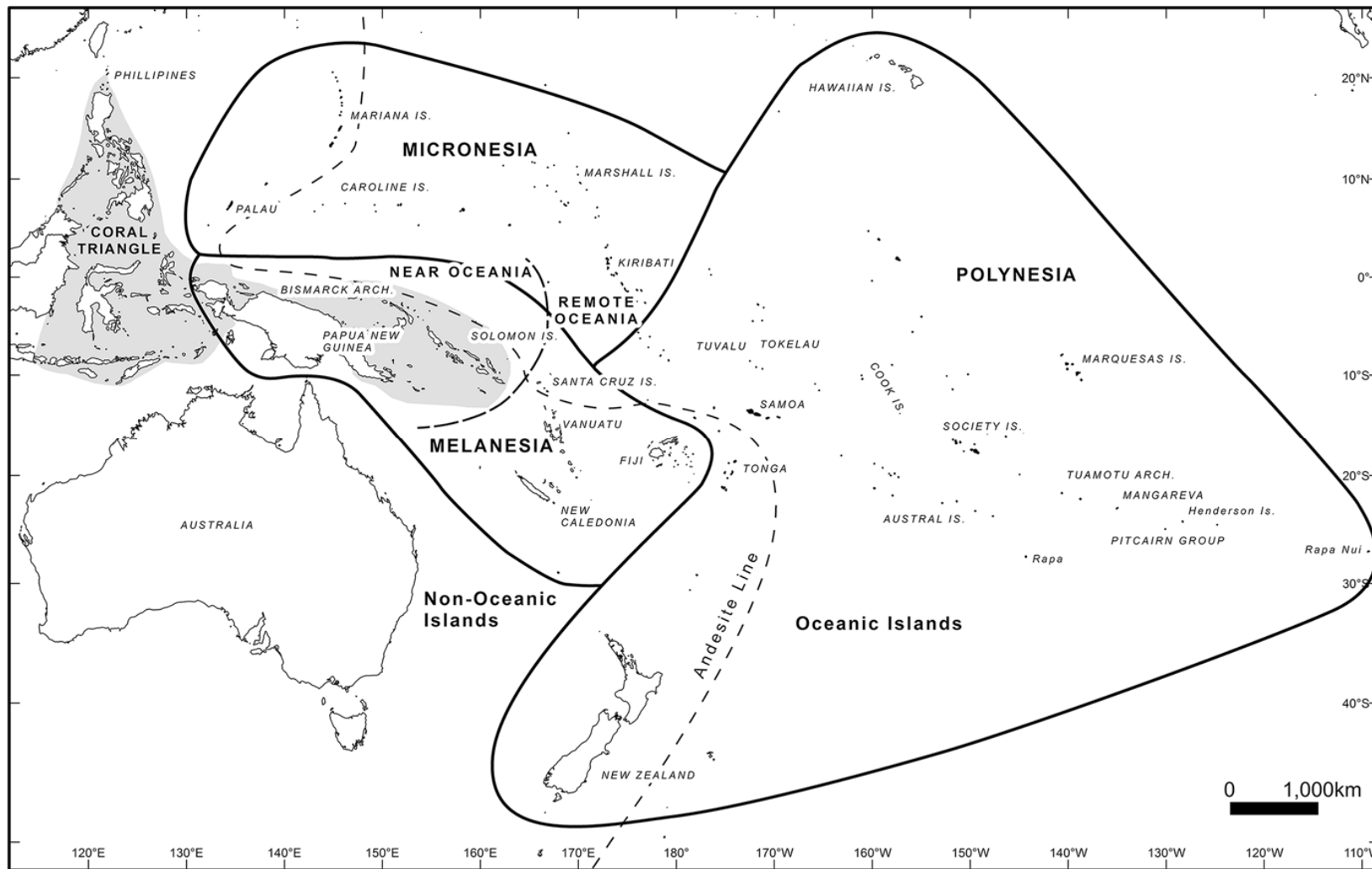


Figure 1. Map of the Pacific with islands and archipelagos mentioned in the text. The highest species diversity is within the Coral Triangle with a marked decline in taxa from west to east across the Pacific.

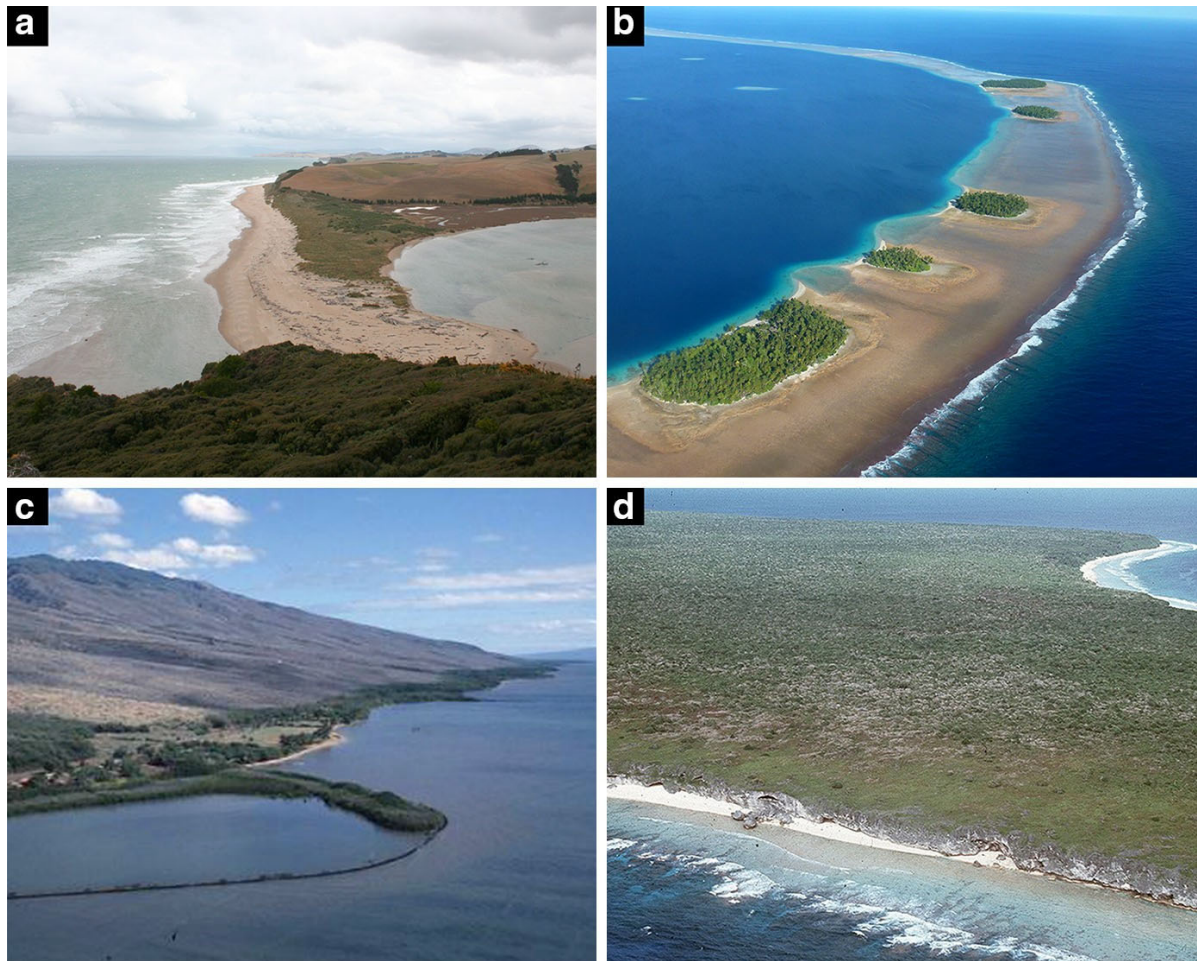


Figure 2. Coastal environments of the Pacific Islands. (A) Island-arc or continental island with the Shag River Mouth 14th century AD archaic site (centre of frame) situated along the east coast of the South Island, New Zealand showing the estuary to right and sandy marine shore (photo: M. Weisler); (B) A portion of Ebon Atoll, Marshall Islands with small islets atop the reef platform ringing the central lagoon to left (photo: M. Harris); (C) The south, leeward shoreline of the high volcanic island of Moloka'i, Hawaiian Islands with a 1-km-wide fringing reef and prehistoric walled fishpond (photo: M. Weisler); (D) Makatea (raised limestone) Henderson Island, Pitcairn Group with typically narrow reef platform (here, only 30 m wide) and near-uniform island elevation of 33 m (photo: courtesy Sir Peter Scott Commemorative Expedition to the Pitcairn Islands, used with permission).

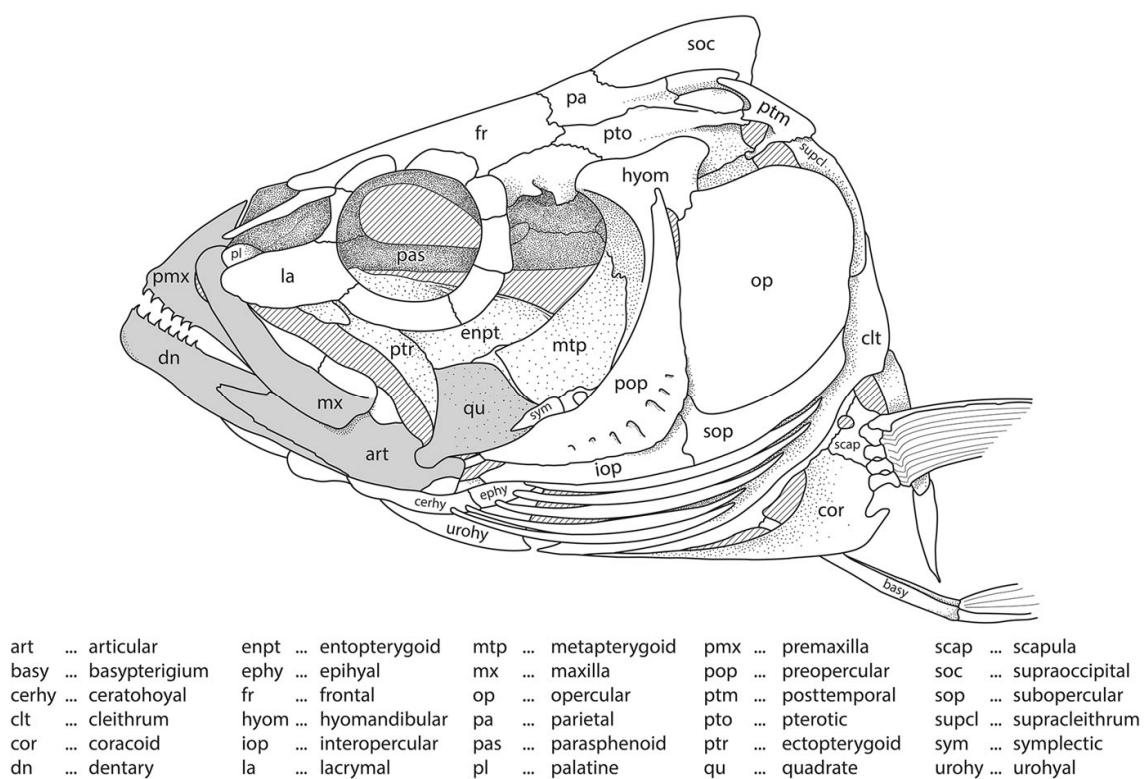


Figure 3. Cranial elements used for identification to lowest taxon. Dark-shaded elements are the routinely used five paired bones, while all the other cranial elements are now more commonly used for identification. This is a generalised diagram of the cranium to illustrate the position of elements (after Gregory 1959: 87).

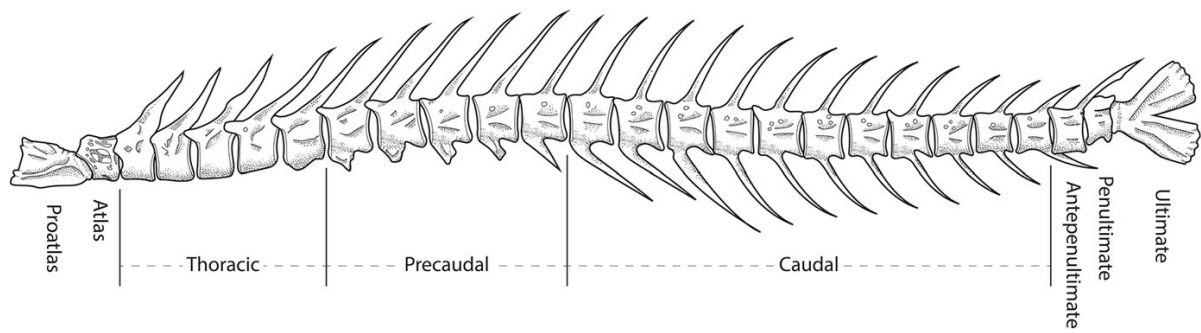


Figure 4. A generalised diagram of the vertebral column illustrating the position of vertebrae types (after Cannon 1987: 21).