

The Historical Role of Bonefishes (*Albula* spp.) in Polynesian Fisheries

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Abstract

This paper is a tribute to Yosi Sinoto, a pioneer in the study of indigenous Polynesian fishing technologies and East Polynesian prehistory. It builds on his research by considering the historical role of bonefishes (*Albula* spp., family Albulidae) across Polynesia. Bonefishes are relatively large, schooling, nearshore species which, on several grounds, constitute high-return resources as defined by foraging models, especially in relation to Polynesian fishing technologies. Ecological, life history, and sportfishing data is compiled in support of this claim, while their role in indigenous fisheries is assessed with linguistic, ethnographic, and archaeological evidence. The latter shows that, despite being naturally distributed across the region, and recognized by a common Polynesian referent (*kiokio* or a close cognate), only two Polynesian localities (Cook and Hawaiian Islands) provide unambiguous historical evidence for well-developed *Albula* fisheries; their historical importance also is suggested on Tubuai (Austral Islands) where they have declined. In Tokelau and in the Tuamotu Islands they play a modest role in contemporary fisheries, while the evidence compiled here suggests more incidental use elsewhere in Polynesia. Three hypotheses are examined to explain the disjunction between the high-return potentials of bonefishes and the available evidence for their traditional importance: 1) ethnographic and archaeological preservation and/or collection biases are factors; 2) bonefishing was once more widely practiced but has declined as a result of harvesting pressures, climate change, or other processes; and/or 3) geographic variability in conditions favoring bonefish abundance (e.g., habitat, food sources) have led to a discontinuous and uneven pattern of cultural use across Polynesia. The available evidence suggests that all three factors may be relevant.

1 Introduction

When archaeologist Dr. Yosi Sinoto embarked on his studies of prehistoric Polynesian fishing, indigenous fishery research was uncommon and archaeological fish bone analyses often were limited to taxonomic lists. Dr. Sinoto's concerted efforts to develop fishhook typologies appropriate to archaeological materials and research questions departed from earlier museum-based studies which focused on overall fishhook forms (e.g., Anell 1955). He showed that line-lashing devices were chronologically sensitive, along with hook shape, thereby informing on settlement chronologies and inter-island connections

(Emory et al. 1959; Sinoto 1962, 1967, 1968, 1970, 1991; see also Green 1960, 1961). Dr. Sinoto also has carried out experimental research using traditional fishing gear (e.g., Sinoto 2007), gathered ethnographic information on fish names and fishing technologies (e.g., Randall and Sinoto 1978), and was an early supporter of archaeofish studies (e.g., Goto 1986; Leach et al. 1984; Sinoto and McCoy 1975:179). This paper draws on his research in these varied domains, while examining a specific resource, bonefishes or *Albula* spp. of the family Albulidae, a physically and behaviorally distinctive fish (Figure 1) that in some Polynesian settings achieved social if not dietary prominence.



Figure 1. A 3.4 kg bonefish caught as part of Aitutaki's catch-and-release fly-fishing program by Rosie Manins. Archaeological excavations on Moturakau Islet (in background) reveal that bonefish have been part of Aitutaki's subsistence economy for centuries (Allen 1992). Photo by bonefish guide Rua Davey, November 2013; image courtesy of Rosie Manins.

Bonefishes are widely distributed across the Pacific, of relatively large body size, and often congregate in shallow inshore waters, sometimes in very high densities (Beets 2000; Friedlander et al. 2008; Pinca et al. 2009, Figure 2.12; Randall 2005:25). In the parlance of foraging theory, these features combine to make bonefishes a high-return resource (i.e., high energetic returns relative to the costs of prey location, capture, and processing) (following Broughton 1999; Nagaoka 2002). They are major contributors to some Pacific artisanal fisheries, as on Tarawa Atoll where historically they have contributed 45% of the catch (Beets 2000, Table 1), and on at least one island they have been fished for centuries, Aitutaki, southern Cook Islands, (Allen 1992, 2002). However, as described herein, bonefishes are not well represented in Polynesia's archaeological faunal assemblages (e.g., Allen in press), figure poorly in many island ethnographies (this study), and make limited contributions to contemporary subsistence fisheries (Dalzell et al. 1996; Gillet 2010). This study sought to resolve these apparently contradictory patterns, focusing on the cultural historical region of Polynesia.

Initially, the biology, ecology, and life history of bonefishes are reviewed to identify traits that would enhance (or constrain) their value as a food resource and to identify characteristics that might alter their abundance over time, especially vulnerabilities to harvesting or climate change. This is followed by a brief review of web-based sources

related to the growing Pacific bonefish sportfishery. Although anecdotal in nature, these sources extend the limited scientific literature on the distribution and abundance of Pacific bonefish populations. A review of Pacific linguistic references for bonefishes is used to gain insights into Polynesian awareness of these distinctive fishes, and possible historical connections between island communities. This is followed by a survey of early Polynesian ethnographic and material culture studies, supplemented by indigenous fishery accounts. Archaeological records also are considered where available. The emerging picture is one of widespread awareness of bonefishes, but a pattern of exploitation that is spatially discontinuous and variable in intensity. The latter appear unrelated to cultural historical relations and, even where highly-valued, bonefishes make rather modest contributions to local artisanal fisheries today. In the final section, three hypotheses are considered in an effort to explain these patterns within Polynesia:

- 1) Ethnographic and archaeological records are biased by preservation and/or recovery techniques, and do not accurately portray traditional patterns;
- 2) Bonefishing was once more widely practiced but has declined in some areas as a result of harvesting pressures, climate change, or other factors;
- 3) The discontinuous and uneven patterning in traditional bonefishing practices reflects natural distributions, which is in turn most likely the result of geographic variability in appropriate habitat conditions.

2 Natural Distribution, Ecology, and Life History Traits

Bonefishes are a globally dispersed family with a complex and poorly resolved taxonomic history (e.g., Adams et al. 2014; Bowen et al. 2008; Hidaka et al. 2008). Two Pacific species are of interest here, the widely distributed *Albula glossodonta* and the endemic Hawaiian *Albula virgata* (Friedlander et al. 2008; Harding 2010). *A. glossodonta*, or roundjaw, is found from the Hawaiian Islands and French Polynesia in the east to the Seychelles in the western Indian Ocean, and from southern Japan in the north to Lord Howe Island, Australia in the south (Froese and Pauly 2005). Based on the available genetic evidence, only *A. glossodonta* is present in the southern Cook Islands (J. Robins et al., unpublished data), at Palmyra Atoll, Kiritimati (Line Islands) and on Tarawa Atoll

(Friedlander et al. 2008). *A. vulpes*, a name found in older publications, is no longer valid in the Pacific.

Bonefishes occur in both marine and brackish water environments, and in a variety of shallow, nearshore habitats (Adams et al. 1999:5; Harry 1953; Myers 1989; Randall 2005:25). A carnivorous family, *Albula* often root in shallow water areas with sandy substrates for invertebrates, especially crabs, shrimps, and worms (Friedlander et al. 2008). Juveniles tend to school in the protected shallows of lagoons, especially on atolls, but also can be found in shallow surf zones, as in Hawai'i (Friedlander, pers. com., 2014). Large mature adults sometimes forage on sand flats during high tide, but also occur in smaller groups or singly in deeper waters, often in reef passes or on seaward reef flats (e.g., Pinca et al. 2009). These differing distributions figure into indigenous Polynesian capture technologies, making them amenable to both mass harvesting (nets, weirs) and angling (see below).

Pacific bonefishes are considered some of the largest *Albula* in the world and for Polynesian fishers were a comparatively large nearshore food fish (e.g., Pinca et al. 2009, Figure 2.12). Hawaiian *A. glossodonta* give insights into size potential of the taxon, with a maximum observed size of 73.7 cm (fork length) (Friedlander et al. 2008, Table 2.8). Myers (1989:58) reports individuals up to 90 cm (standard length) and 8.6 kg, while McCormack (2007) indicates specimens collected on Aitutaki in the 1980s weighed up to 12 kg. Otolith annuli counts of Palmyra *A. glossodonta* indicate a maximum age of 11 years (n=33, Friedlander et al. 2008:33), while maximum ages of 17 to 21 years have been determined in the closely related *A. vulpes* of Venezuela (n=91, Posada et al. 2008) and Florida (n=112, Larkin 2011). It is not known whether these differences relate to taxonomic differences, local ecological conditions, or sample sizes.

Despite being widely distributed across the Pacific, the abundance of *Albula* appears to vary considerably. In some locations they reach enormous densities (e.g., Tarawa Atoll; Beets 2000), while in others they are relatively uncommon (e.g., Mangaia and Rarotonga, Cook Islands; Pinca et al. 2009). Their abundances are partly tied to the availability of suitable habitat, in particular extensive shallow water sandy reef flats such as those found on atolls. However, other shallow water environments also support bonefishes, including mud flats, sea grass beds, etc. (Adams et al.

2014; Anderson et al. 2007) and in some cases suitable habitat seems to be a necessary but not sufficient basis for sizable populations (see Hamon and Blanc 2009; Roberts 2013). Overall, there is little systematic information on bonefish abundances across the region and factors other than habitat could be important.

Some bonefish life history traits could potentially adversely affect their ability to sustain long-term intensive harvesting. Most important in this respect is their propensity for spawning aggregations. These typically occur in shallow waters (10-15 m) at "pre-spawning staging sites" prior to offshore migrations (Johannes and Yeeting 2000:10). These aggregations tend to occur in relatively shallow waters, at the same localities and often at regular points in the annual and lunar cycle (around the full or new moon), making bonefishes dense and predictable resources (*sensu* Dyson-Hudson and Smith 1978) and, by extension, exceptionally vulnerable to fishers (Johannes and Yeeting 2000; see also Caillart et al. 1994; Hamon and Blanc 2009:12; Johannes and Hviding 2000). On Tarawa Atoll, traditional management strategies recognized fish vulnerabilities during these events and only allowed fishing to commence after their seaward migrations had begun, (Johannes and Yeeting 2000). Also problematic is that females typically obtain larger sizes than males, which may make them the preferred targets of fishers (Friedlander et al. 2008:49). On balance, two other life history traits may provide a degree of resilience. These include their relatively early sexual maturity (Friedlander et al. 2008:50), identified by Adams et al. (2014) as between 3.5 to 4.5 years and 42 to 49 cm, and their protracted spawning season which could aid recovery from over-harvesting (Friedlander et al. 2008:50).

In recent times, bonefish have been on the decline in many Pacific localities, as a result of commercial fishing, environmental disturbances and exotic fish introductions. These include populations on Tarawa Atoll, Aitutaki Island, the Hawaiian Islands, Tikehau Atoll, Fanning Island, and possibly elsewhere (Anderson et al. 2007; Adams et al. 1999; Beets 2000; Caillart et al. 1994; Friedlander et al. 2008; Lobel 1980). On Tarawa, the annual commercial take was once between 1 and 5 million fish, but marked declines have resulted from habitat disturbances and over-harvesting, with only one of several original spawning runs persisting (Beets 2000; Johannes and Yeeting 2000). In Hawai'i bonefishes abundances were once sufficient to support a commercial fishery,

with an estimated 134 mt landed in 1900. By 2001, however, the commercial catch had declined to 1.2 mt (Friedlander et al. 2008:45). In artisanal fishery contexts, as on Aitutaki and Tikehau, the recent introduction of gill nets has been especially problematic. Their length, small mesh size, and some applications (e.g., leaving for extended periods, use in splash drives, etc.) can be overly efficient, leading to adverse long-term impacts (Adams et al. 1999; Anderson et al. 2007; Johannes and Yeeting 2000:4; Ram-Bidesi 2011). These recent harvesting impacts need to be considered in any historical assessment of bonefishing patterns.

Climate change also could have affected bonefish abundances over the period of Polynesian settlement. Experienced contemporary sportfishers suggest that during overly warm conditions, bonefishes retreat to deeper waters (<http://www.anglingdestinations.com>). This is consistent with reports from Kiritimati where fishers report that bonefishing is less productive during warmer El Niño years (in Friedlander et al. 2008:50). Adams et al. (2014) identify several ways that global warming might adversely affect bonefishes, including habitat change and disruption of preferred food sources. There also is evidence that albulids are sensitive to cold, particularly if the onset is sudden and extreme (Larkin 2011:32; <https://www.bonefishestrapontrust>).

3 Insights from Sportfishing

Globally, bonefishes are renowned for their speed, difficulty of capture, and tenacity once hooked and the comparatively large Pacific bonefishes are rapidly gaining worldwide attention from sportfishers (Figure 1, Table 1; Anderson et al. 2007). While anecdotal in nature, on-line newsletters, fishing interest sites and sportfishing blogs offer insights into bonefish distributions, abundance, and size that are broadly indicative of regional patterns (Table 1; Figure 2). Widely recognized commercial bonefish sportfisheries (typically using fly fishing tackle and catch-and-release protocols) are found on Palmyra Atoll, Kiritimati Island, the Hawaiian Islands and Aitutaki. Around 1,000 flyfishers visit Kiritimati annually, bringing in an estimated 2.5 million USD (Yeeting 2010). Efforts are underway to develop bonefishing on Nonouti, one of the southern Gilbert Islands where there is good habitat, a substantial fish population, and traditional bonefishermen who can

serve as guides. More recently, local entrepreneurs and sportfishing blogs have promoted bonefishing in the Tuamotus and New Caledonia (see Table 1). It is unclear whether high bonefish densities are limited to these sportfishing locales, or if other sites have yet to be discovered. On Tokelau, for example, bonefishes play a modest role in the contemporary subsistence fishery (Elders from Atafu Atoll 2012) but do not seem to have attracted the attention of sportfishers.

4 Linguistic Evidence

Indigenous names for bonefishes offer insights into historical associations between islands and potentially reflect the importance of bonefishing in the past. The University of Auckland web-based Polynesian Lexicon Project or POLLEX-online (Greenhill and Clark 2011), has ten entries where an association with *Albula* spp. has been determined. All are cognates of the indigenous Cook Island name, *kiokio*. In two cases *kiokio* is associated with other fishes (East Uvea and Tikopia), and in another four instances (Manihiki-Rakahanga, Tongan, Vaeakau-Taumako, and West Uvea) with undetermined taxa. Samoan is distinctive in use of the referent *ava*, a name more commonly associated with milkfish (*Chanos chanos*). Additional sources help flesh-out the POLLEX database (Table 2) and Rensch (1999; see also Hooper 1994) provides further details on intra-archipelago variations. In a few cases, marine checklists support the linguistic analyses, as for example Randall et al. (2003) for Tonga, and Randall and Sinoto (1978) for Rapa.

*Kio-kio unambiguously reconstructs to Polynesian but there is some evidence for tracing it back to Proto-Malayo-Polynesian *kuRaw (“edible marine fish”). Blust (in Osmond 2011:36) identifies a few Western Austronesian forms, while within Oceanic *kuRaw regularly becomes *kuRo (bony fish, probably *Albula*). There are a few cognates outside of Central Pacific languages with various meanings, but only the Nyelâyu (New Caledonia) term *yhu* refers specifically to *Albula* (Osmond 2011:36). This evidence suggests that recognition, naming, and probably use of bonefishes predates Lapita settlement of Polynesia (around 2800 B.P.).

Casual observations by Pawley (2011) suggest that the Oceanic fish names with the highest retention rates tend to be those of economically important taxa. Given the wide distribution of the referent *kiokio*

Table 1. Selection of on-line sites and sources with information on Pacific bonefish sportfishing.

Archipelago (Island)	Source	Website comments
Cook Is (Aitutaki)	http://www.fishing.net.nz/asp_forums/aitiutaki-bonefishes_topic47208.html Hamon and Blanc 2009:19; Pinca et al. 2009	Average 3-4 kg; up to 6 kg
Cook Is (Penrhyn)	http://www.flylife.com.au/library/articles/34/34.html ; McCormack 2007	4 to 8 fish per day; average size up to 2 kg. McCormack indicates very common
Hawaiian Islands	http://diybonefishing.com/united-states/oahu-hawaii-2/ ; Hamon and Blanc 2009:12	3 kg on average, >4.5 kg individuals “not rare”
Line Is (Kiritimati/Christmas Is.)	https://pacificflyfishers.com/blog/tags/bonefishes/ ; Hamon and Blanc 2009:11	Very good density; sizes sometimes small (<1 kg); considered among top five destinations worldwide
Line Islands (Palmyra)	Friedlander et al. 2008	
New Caledonia	http://flyodyssynewsletters.blogspot.co.nz/search?q=New+Caledonia	Specimens 3-4 kg on average but up to 4.5 kg. Reputedly in lower abundance than other Pacific sites
Society Is (Tetiaroa Atoll)	http://www.anglingdestinations.com/Recent.php?action=adv&RECADV_ID=16 ;	Size large (estimated up to 4.5 kg), abundance moderate
Tuamotu Islands (Anaa)	http://www.flylife.com.au/library/articles/34/34.html	Specimens 2 to 3 kg on average but up to 4.5 kg or more; abundance high, catches 4 to 16 per day; considered best spot in French Polynesia to date
Tuamotu Is (Fakarava Atoll)	http://www.anglingdestinations.com/Recent.php?action=adv&RECADV_ID=16 ; also Hamon and Blanc 2009:12	Average size 3 to 3.5 kg, abundance moderate to low
Tuamotu (Rangiroa Atoll)	http://www.tahiti-haumana-cruises.com/tahiti-haumana-cruises-fishing-and-fly-fishing.php ; also Hamon and Blanc 2009:12	Web site reports some “breaking the magical 10 lb barrier”; reputedly an exceptional locality
Tuamotu Is (Tahanea Atoll)	http://www.anglingdestinations.com/Recent.php?action=adv&RECADV_ID=16	Average size 2.2 to 2.7 kg, abundance low

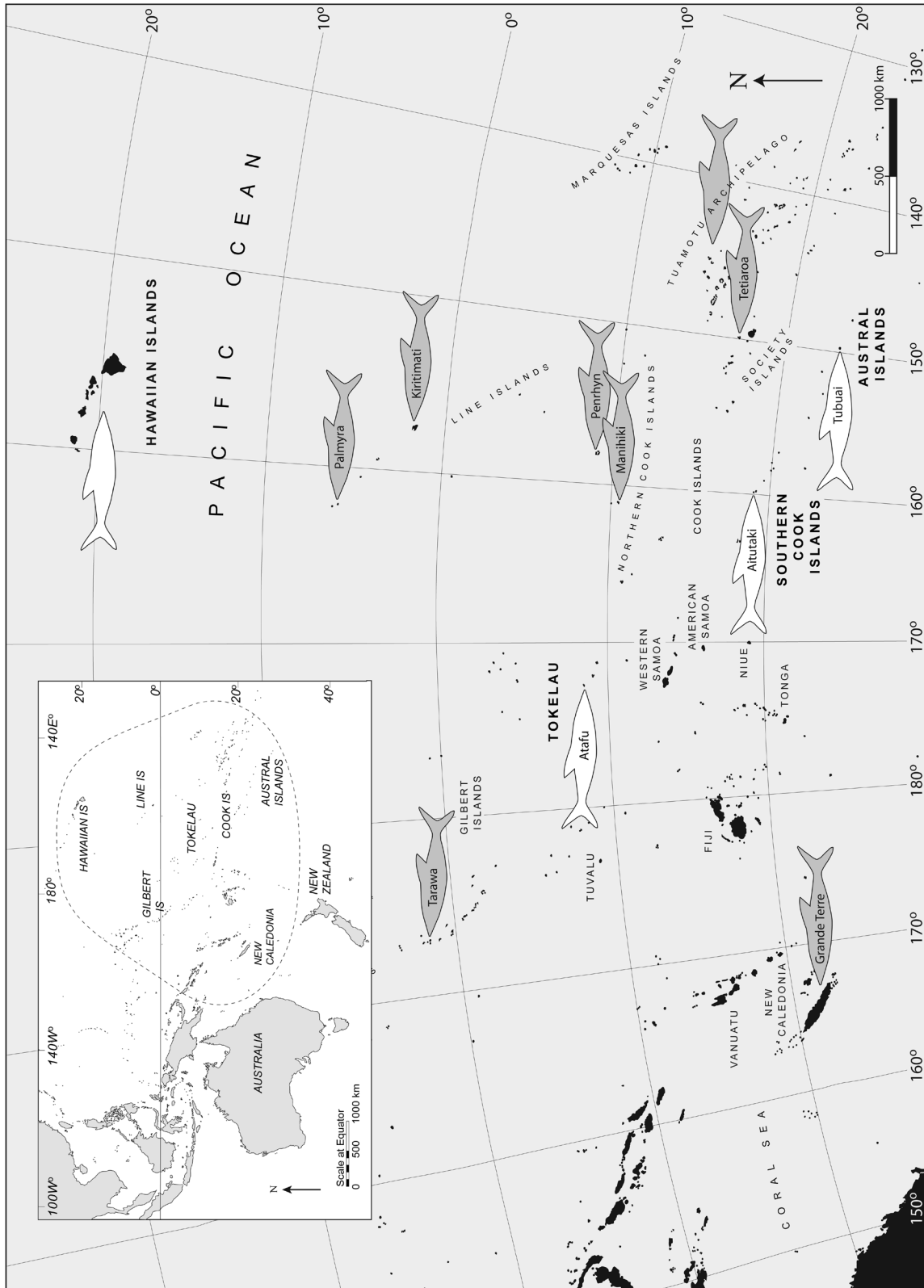


Figure 2. Established and emerging bonefish sportfishery sites (grey fish) and locations of important indigenous fisheries discussed in text (white fish).

Table 2. Pacific Island terms for *Albula* spp. Entries marked with an asterisk (*) are from the Polynesian Lexicon Project-Online or POLLEX (<http://pollex.org.nz/entry/kio-kio/>).

Language	Reflex	Original source	POLLEX
Hawaiian	<i>‘Ō‘io</i>	Hooper 1994; see also Titcomb 1972	*
Fijian (Bauan)	<i>Yawakio</i>	Osmond 2011:36	
Fijian (Lau)	<i>Kikio</i>	Osmond 2011:36	
Mangarevan	<i>Kiokio</i>	Fourmanoir et al. 1974	
Manihiki-Rakahanga	<i>Kiokio</i>	Hiroa 1932	*
Marquesan (northern)	<i>Kiokio</i>	Hooper 1994	*
Marquesan (southern)	<i>‘Io‘io, kiukiu</i>	Rensch 1999	
Nyelāyu (northern New Caledonia)	<i>Yhu</i>	Ross et al. 2011	
Penrhyn	<i>Kiokio</i>	Shibata 2003	*
Pukapuka	<i>Kiokio tai</i>	Beaglehole & Beaglehole 1991; also Beaglehole & Beaglehole 1938	*
Rapan (Austral Is)	<i>‘Io‘io</i>	Randall & Sinoto 1978:295	
Rapa Nui	None identified	Randall & Egana 1984	
Rarotongan	<i>Kiokio</i>	Buse 1996	*
Rarotongan	<i>Kiokio or Kiukiu</i>	Savage 1980:105	
Rotuman	? <i>Uo</i>	Osmond 2011:36	
Samoaan	<i>Ava</i> (also refers to <i>Chanos chanos</i>)	Wass 1984:4; also Rensch 1999:18	
Tahitian (Windward Society Is)	<i>‘Io‘io</i>	Lemaître 1973; also Randall 1973	*
Takuu	<i>Kiokio</i>	Moyle 2011	*
Tokelauan	<i>Kiokio</i>	Simona 1986	*
Tongan	<i>Kiokio</i>	Randall et al. 2003:6, Vaea & Straatmans 1954; Rensch 1999	
Tuamotuan	<i>Kiokio</i>	Stimson 1964	*
Tuamotuan (Raroia)	<i>Kiokio, pati</i> (adults); <i>nifa</i> (juveniles)	Harry 1953	
Tuamotuan (Rangiora)	<i>‘Io‘io</i>	Rensch 1999	
Tupuaki (Tubuai)	<i>O‘io</i>	Aitken 1930:12	*
Tuvaluan	<i>Kiokio</i>	Besnier 1981	

and its close cognates, we might expect bonefishes to have been an important fish in many traditional Polynesian subsistence economies. However, as shown below, this does not appear to be the case on present evidence, raising questions about whether 20th century observations are representative of earlier fishing practices. It is possible that bonefishes were simply a distinctive and hence widely recognized fish. It is also possible that their economic importance has declined as a result of natural and/or cultural changes.

5 Ethnographic and Archaeological Overview

To further assess traditional bonefishing practices, several classic Pacific Island ethnographies and material culture studies were consulted and, when available, were augmented by contemporary fishery accounts (Table 3). A number of these material culture studies were carried out by Te Rangi Hiroa and, given his early exposure to bonefishing on Aitutaki (Hiroa

Table 3. Summary of information sourced from early Polynesian ethnographies and material culture studies.

Archipelago	Island	Bonefishes Capture Technologies ¹			Relative importance ²	Ethnographic source
		Line fishing	Nets/sweeps	Weirs		
Cook Is.	Aitutaki	yes	?	yes	high	Hiroa 1927
	Rakahanga-Manihiki	yes	?	?	moderate?	Hiroa 1932
	Pukapuka	?	yes	yes	moderate?	Beaglehole & Beaglehole 1938
Fiji Is.		?	?	?	minimal ³	Deane 1921
Hoorn Is.	Futuna	?	?	?	minimal?	Burrows 1936
Hawaiian Is.		yes	yes	?	high	Hiroa 1964, Kaha'ulelio 2006; Malo 19
Kapingamarangi		?	?	?	minimal?	Hiroa 1950
Lau Is.		?	?	?	minimal?	Hocart 1929; Thompson 1940
Gambier Is.	Mangareva	?	?		minimal?	Hiroa 1938
Marquesas Is		?	?	?	minimal?	Handy 1923
Rapa Nui (Easter Is.)		?	?	?	minimal?	Métraux 1974
Samoan Is.		?	?	?	minimal?	Hiroa 1930
Society Is.		?	?	?	minimal?	Handy 1932; Henry 1928
Tokelau		yes	yes	?	moderate	Macgregor 1937
Tonga Is.		?	yes	?	low?	Gifford 1929; Vaea & Straatmans 1954:
Tuamotu Is.	Anaa	yes	yes	?	moderate?	Emory 1975
Austral Is.	Tubuai	yes	yes	?	high?	Aitken 1930

1 A question mark indicates no specific mention made of bonefishes and thus uncertainty regarding their use.

2 Relative importance (high, moderate, low, or minimal) is a subjective evaluation of the available evidence and may not reflect true historical circumstances, as discussed herein.

3 Identified as a food fish by the Fiji Fisheries survey (1983), as cited in Zug et al. (1988).

1927), we might expect he would have commented on their use elsewhere. In Table 3, the relative importance of bonefishing (Column 6) is a rough interpretation, based foremost on specific mention of the taxon and second on the frequency with which bonefishes were noted and/or the reporting of multiple capture technologies. For the most part the information on bonefishing gleaned from these studies was minimal. However, four localities stand out as places where bonefishing was prominent and are reviewed in some detail below: Cook Islands (especially Aitutaki), Tubuai Island, Hawaiian Islands, and Tokelau.

Studies specifically dedicated to traditional fishing practices also were consulted. These typically are more recent than the foregoing ethnographies and thus may have been affected by external influences. For Polynesia these included Kirch and Dye (1979) for Niuaotupapu (Tonga), Elders of Atafu Atoll (2012) for Tokelau, Rolett (1998) for the Marquesas, and Titcomb (1972) for Hawai'i. Ono's (2010) study of contemporary Malaysian and prehistoric Lapita

fishing practices also was consulted. Amongst these sources, bonefishes are only mentioned for Tokelau and the Hawaiian Islands. Additionally, bonefishing is reported for Palau (Johannes 1981) and the Solomon Islands (Johannes and Hviding 2000).

In Dalzell and colleagues' (1996) review of contemporary Pacific Island reef fisheries, bonefishes figure in only three out of 15 localities: Kiribati (16.5%), Tikehau Atoll (2%), and Fiji (0.01%) (their Table 3). They also are mentioned in passing for the Cook Islands, where they were identified as on the decline. A subsequent Food and Agriculture Organisation report (Gillett 2010) also suggests a relatively minor role for bonefishes, with *Albula* contributing 1.36% of the landings in a survey of 15 Pacific Island locations. Out of the 22 fish groups identified as economically important, Albulidae ranked 13th.

Turning to more specific accounts, the classic Fijian ethnographies are mute as to bonefishes importance (e.g., Deane 1921; Thompson 1940).

They are mentioned in a contemporary study of Viti Levu subsistence and artisanal fisheries but no details are given (Rawlinson et al. n.d.; see also Zug et al. 1988). In Tonga, a brief report by Vaea and Straatmans (1954) categorized bonefishes as a “deep sea fish”, but they also observed that they were caught using traps and leaf sweeps, suggesting capture in shallow water environments. No specific reports of bonefishing could be found for Samoa. On Pukapuka they are one of several species caught in semi-permanent stone and impermanent coconut-leaf weirs (Beaglehole and Beaglehole 1938:57), while a Manihiki-Rakahanga study (Hiroa 1932) identified shell fishhooks designed specifically for bonefishes. On Kiritimati, they comprised 7% of the 1995 artisanal catch made by recent Micronesian settlers (in Friedlander et al. 2008:49).

In the Tuamotus, bonefishes on Anaa Atoll were traditionally driven into shallows and captured with scoop nets (Emory 1975:193). A 1990s fishery study on Tikehau Atoll identifies them as one of 14 taxa that contributed around 85% of the total landing derived from permanent stone fish traps (Caillart et al. 1994). Albulids in particular were described as of “medium abundance, species often fished but representing less than 5% of the annual total catches” (Table 10, page 18). During the study period (1983 to 1987) the annual total kg of landed albulids declined from 12,292 to 5,099 kg, while the overall total weight of fishes (all taxa) increased. The authors note that, in general, the use of stone traps involves targeting adult fishes engaged in seasonal spawning aggregations, which could adversely affect their abundances (Caillart et al. 1994:20). Although no other ethnographic accounts were found, sportfishing reports (Table 1) identify populations of bonefishes in other Tuamotuan atolls as well. Anecdotal evidence suggests that in some localities they may be common but overlooked by local residents as a food source, as for example on Rangiroa (V. Wichman, pers. com. 2014); whether this is a long-standing historical pattern or a recent development is not known. Finally, for the other Polynesian islands listed in Table 3 little to no information specific to bonefishes was uncovered, leaving their use and importance uncertain.

Outside of Polynesia, bonefishing on Tarawa Atoll (Gilbert Islands) warrants a mention given their exceptional abundance in this locality (Beets 2000; Johannes and Yeeting 2000). Apparently they occur in such high densities that they occasionally strand

on the reef at low tide. Early 20th century accounts suggest they once comprised nearly half of the local fish intake. Unofficial commercial estimates point to enormous catches in the past, but numbers and fish sizes have been declining (Beets 2000; Johannes and Yeeting 2000; Friedlander et al. 2008:50). Weirs figure importantly in traditional capture technologies, and more than 150 have been strategically placed on the outer reef flats with the aim of capturing bonefishes returning from spawning events. Monthly catches average around a thousand fish, although as many as 2,000 fish might be trapped in a single night (Johannes and Yeeting 2000).

Across Polynesia, archaeological remains of bonefish are even rarer than ethnographic records. In a recent review of prehistoric fishing in the central islands of East Polynesia, Aitutaki was the only island where Albulidae remains were identified (Allen in press). Albulid remains also have been found in a small number of Hawaiian sites (McElroy et al. 2006; Weisler 1993) and seven *Albula* otoliths were recovered from Oundjo (Site 26) on Grand Terre, New Caledonia (Weisler 2002). In an extended ethnographic and archaeological study in the Lau Islands, involving excavation at some 15 sites and recovery of 15,417 identifiable fish specimens (NISP), only one albulid remain was found and bonefishes did not even rate a mention in the former (Jones 2009; Jones and Quinn 2009, Table 5).

6 Aitutaki, Southern Cook Islands

Aitutaki Island, an “almost-atoll” (following Stoddart and Gibbs 1975) in the southern Cook Islands, provides the best historical record of Polynesian bonefishing practices. Today bonefishes are not only a valued food (Pinca et al. 2009), but also the focus of intensive conservation efforts and an emerging world-class sportfishery, as captured in the documentary film *Itu's Bones: A Story About Bonefishes* (On the Fly Productions). Aitutaki consists of a 16 km² volcanic mainland, with another 2 km² partitioned across several coralline islets (Stoddart and Gibbs 1975). The roughly 54 km² lagoon is relatively shallow, with a maximum depth of around 10 m. Human arrival dates between the 11th to 13th centuries AD, but may have been a century or two earlier given regional chronologies and the absence of vulnerable native fauna in the island's earliest sites (Allen and Wallace 2007; Allen and Morrison 2013).

6.1 Contemporary Bonefishing

Aitutaki's sandy shoals and mudflats provide good habitat for schooling bonefishes, while large individuals are more common in the reef passes (Pinca et al. 2009, Figure 2.12). The taxon is among the three largest food fishes recovered from reef passes and they are prized by the local community even though they are not a major contributor to the local fishery. A 2007 fishers survey found they represented 3.5% (457 kg) of the annual lagoon catch, while another 20 kg were secured in reef passes where they made up 10% of the annual catch (Pinca et al. 2009, Appendix 2.1.1).

Although little is known about bonefish densities in the past, Whitford and Guinea (1983, in Adams et al. 1999) report they were once common. A professional fisherman operating in the 1970s reported catches of around 80 fish per day, ca. 1.5 kg each, while fishing at an intensity of two-to-three times a week (Adams et al. 1999:24). The introduction of gill nets, however, took a considerable toll. A single event in 1978 is associated with local population collapse, when an estimated 3,600 fish, weighing around six tons, were captured in a single set carried out during a spawning aggregation near Rapota Islet (Adams et al. 1999:24). Underwater visual census counts in the 1990s, adjacent to prime habitat areas near Rapota and Tapuaetai Islets (Figure 3), recorded 0.09 and 0.03 fish/m² respectively (Whitford and Guinea 1993 in Adams et al. 1999); this can be compared to Aitutaki's most abundant food fish family at present (Acanthuridae) which reaches densities of 0.20 fish/m² (Pinca et al. 2009). In 2008 another gill-netting harvest resulted in an estimated 1,000 fish, which ranged from 6 to 9 kg in size (On the Fly Productions).

Bonefishes once occupied an important place in Aitutaki's annual cycle of lagoon fishing, filling a gap between runs of other food fishes (Adams et al. 1999). Bonefish season extends from July to October, falling between that of yellow fin tuna (*Thunnus albacares*), which ends in May, and milkfish (*Chanos chanos* or *ava*) which begins in August. Bonefish also may have been valued because of their potential for preservation. Local informants report that when baked in an underground oven for a couple of days they can keep for up to a week (On the Fly Productions).

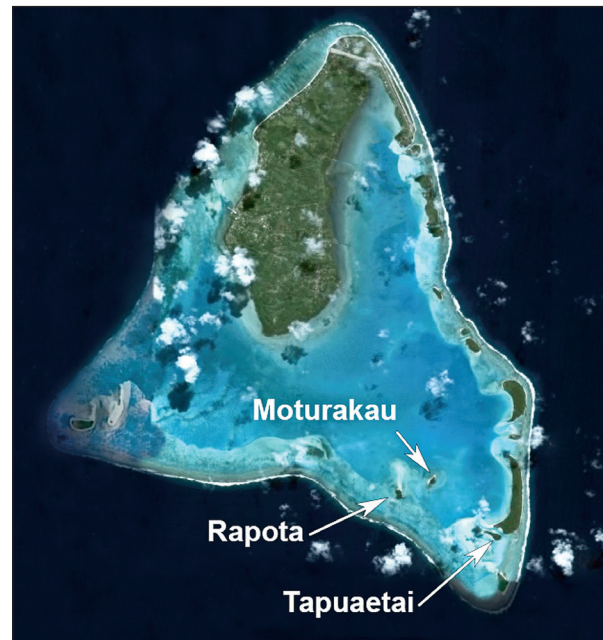


Figure 3. Aitutaki Island. Bonefish congregate along the lagoon-side of the eastern islets, and on the sand flats near the volcanic islets of Rapota and Moturakau at the southeast end of the lagoon (NASA satellite image, June 2007, sourced from Wikimedia Commons).

6.2 Ethnographic Accounts

Contemporary observations are extended by Te Rangi Hiroa's (1927) early 20th century study. Metal bonefish hooks were one of two main types reported by Hiroa (1927:307), the other being an ironwood hook used for barracuda (*Sphyraena* spp.). Allen was given two metal hooks in the 1980s which were identified by the owner as specifically designed for bonefishing (Figure 4). Bonefish hooks also are reported from the northern Cook Islands with Hiroa (1932) picturing a shell example (Figure 4). The head form differs from the historic Aitutaki specimens, but in common with them, the point is nearly the length of the shank and strongly incurving, and the overall form is a U-shape. At 5.6 cm length and 3.6 cm width, this shell *matau kiokio* is smaller than the ethnographic metal specimens, which measure about 7 cm. Two archaeological pearl-shell hooks from Aitutaki (Allen 2002) are similar in shape to the northern Cook example, but smaller (Figure 5). While their functional association with bonefishing cannot be definitively demonstrated, they share a common shape with the ethnographic forms and they were stratigraphically associated with *Albula* otoliths.

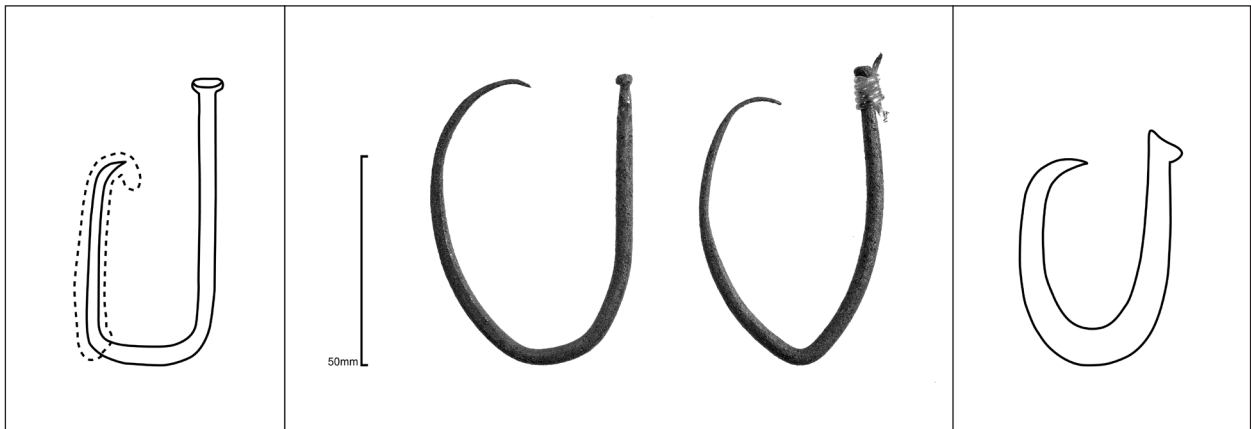


Figure 4. Specialized *kiokio* (bonefish) hooks. On left, a metal hook from Aitutaki with bait area indicated by dotted line (Hiroa 1927, Figure 268, no scale provided); in middle, metal hooks collected on Aitutaki by Allen in 1989; on right, bonefish hook of shell collected by Hiroa (1932) in the northern Cook Islands (size indicated in his text).



Figure 5. Possible *kiokio* (bonefish) hooks of pearl-shell from archaeological excavations on Aitutaki.

Bonefish hooks were used for angling from canoes in shallow waters. Initially, *kiokio* schools were identified by the way they discolored the water, presumably stirring up the sandy bottom in the course of feeding (Hiroa 1927; see also Malo 1971:211). Following this:

The canoe gets to the windward [of the school] and drops anchor quietly. A twenty fathom line is used, with a hook at either end and no sinker. A short length of *hau* [*Hibiscus*] pole, split at the top, is fixed in the mast hole of the thwarts or to the side of the gunwale. The middle of the line is hooked over the split in the short pole, thus giving two separate lines. Using both thwarts, the fisherman has four lines. Ground bait is first thrown out to attract the fish. When a fish takes

the bait, the running line makes a sound that attracts the fisherman's attention. If two lines are engaged at the same time, the one which seems to have the greatest strain is attended to (Hiroa 1927:306).

Stone weirs also were used in bonefish capture (Hiroa 1927:298-306). Important weirs were named, owned by particular families, and passed down from one generation to the next. These stone wall enclosures were designed to trap fish on the out-going tide. To this end they were laid out on the shallow reef flats, along reef channels leading to the outer reef and the open ocean (Figure 6). Weir construction was preceded by careful study of the reef channel flow dynamics, as well as fish behaviors (Hiroa 1927). The trapped fish were dispatched with a spear, or scooped up by hand nets. Hiroa (1927:298-299) describes a weir named Taketake in some detail (Figure 6). Positioned at Tautu Village on the lagoon side of the mainland, the weir was constructed from loose coral boulders, with walls about 60 cm thick. Coconut leaves and tree branches extended from the lagoon ends of the enclosure (dotted lines A-R and D-R), serving to direct fish into the main passage (indicated by the arrow). The weirs were not passive enterprises but involved lookout men positioned at key places. The job of the fisherman at Point X was to make sure that schools of fish entered the trap, while the man at Point Y inserted a *hopai* net when the school collected at the far end of the trap. These facilities were especially important during *kiokio* season. Hiroa (1927:300) also notes, without elaboration, that they were sometimes used at night, especially on *mutu*, the

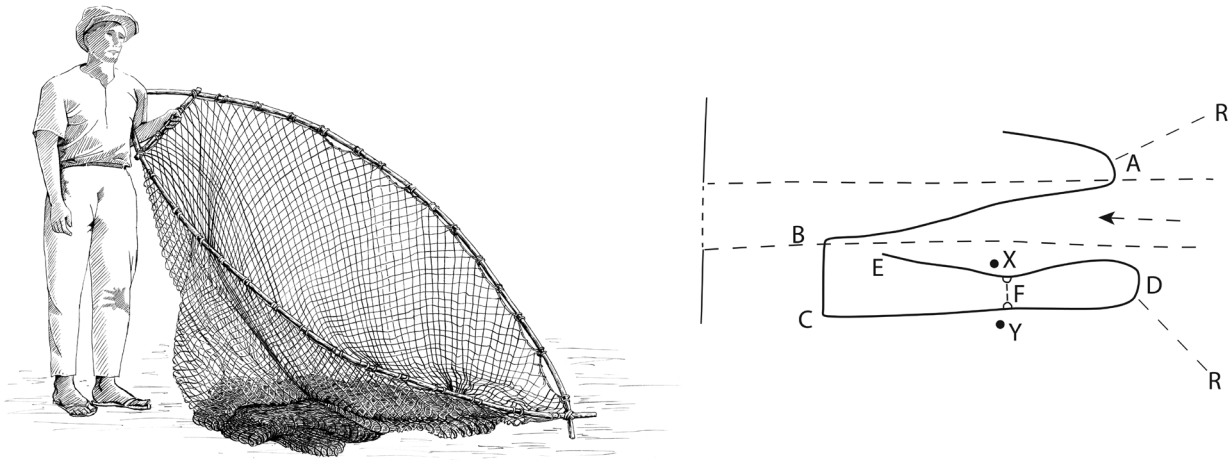


Figure 6. *Hopai* net used on Aitutaki for bonefishing (left) and Taketake Weir, an Aitutaki *pa kiokio* (right). The dotted lines indicate the reef channel (*ava*) and the arrow points towards the open sea; fish are trapped on the falling tide. Fisherman and net illustration by B. Sefton based on Hiroa (1927) Figure 250 (photograph), weir sketch based on Figure 259.

last night of the lunar month. In these instances the lookout fisherman stood at point E and waited for the feel of fish gliding past his thighs.

6.3 Archaeological Perspectives

Excavations in a rockshelter on diminutive Moturakau Islet (see Figure 3) exposed a sequence of cultural activities spanning several centuries (from ca. the 11th -13th century onward) and an enormous quantity of fish remains (Allen 2002; Allen and

Morrison 2013). The assemblage of 27 fish taxa is dominated by parrotfishes (Scaridae) and rockcods/groupers (Serranidae). Bonefishes are represented by both jaw elements and sagittal otoliths (Figures 7 and 8), but the former are uncommon. This is perhaps not unexpected for elements like the fragile *Albula* dentary or the small premaxilla, but the robust quadrate and articular also are poorly represented, suggesting low abundances are not necessarily the result of poor preservation.

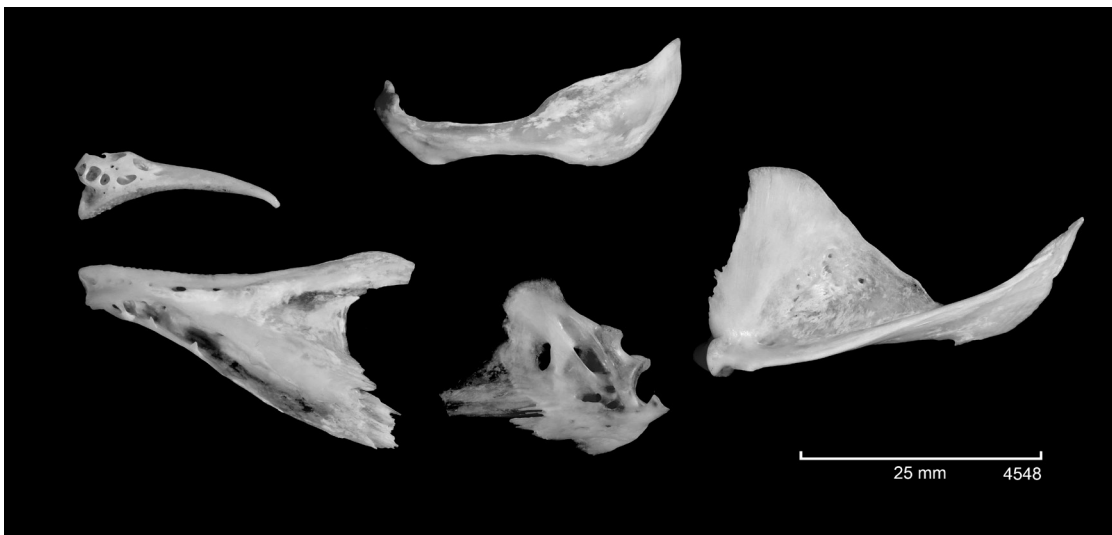


Figure 7. Reference specimen of *Albula* sp. (accession AU4548), paired jaw elements (left side, lateral views) in approximate anatomical position when fish's head is pointing left. Left to right: upper row, premaxilla and maxilla; lower row, dentary, articular and quadrate (photograph by T. Mackrell).

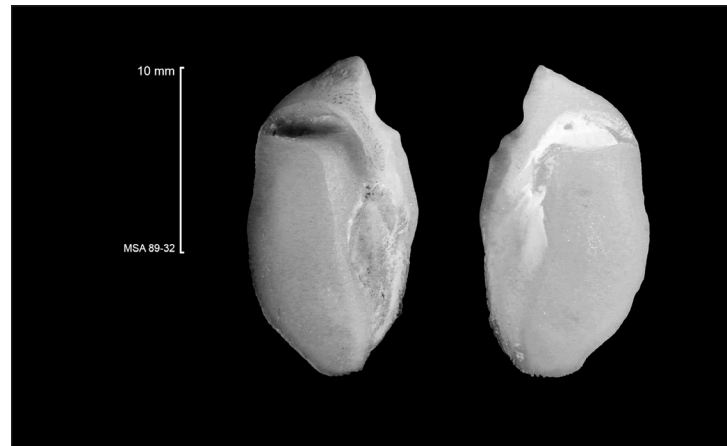


Figure 8. Two sides of a sagittal otolith from a reference *Albula* sp. from Aitutaki (accession MSA 89-32; photograph by T. Mackrell).

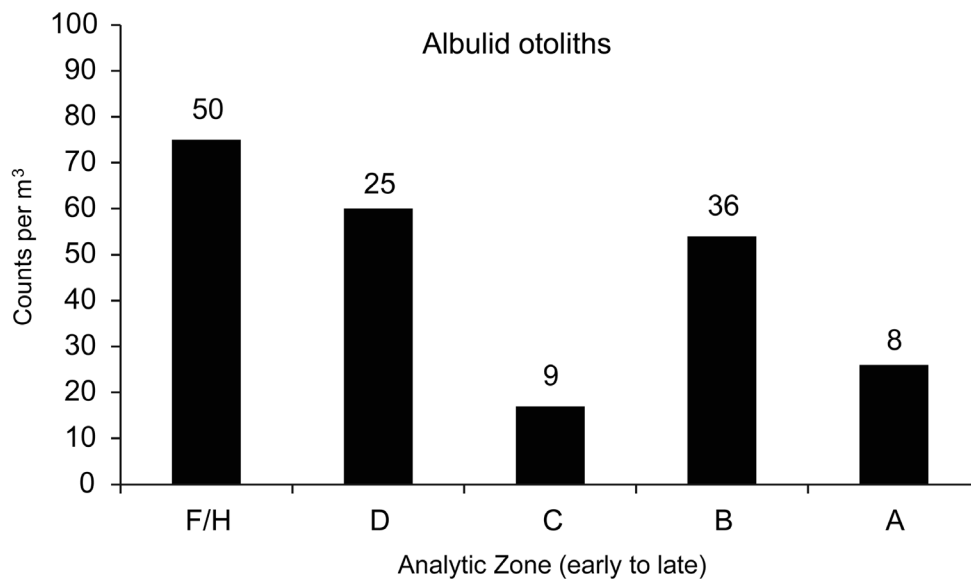


Figure 9. Otolith density (counts per m³) by analytic zone, with absolute numbers (counts) indicated above bars. Remains from Zone E, a non-cultural marine stratum, are excluded (data from Allen 1992).

Despite the abundance of bonefish remains, the relative importance of bonefishes in Aitutaki's prehistoric subsistence economy is difficult to estimate. This is because while head elements were rare for bonefishes, other fish taxa were rarely represented by otoliths. At Moturakau, bonefish jaw elements represent 2.5% of the large fish taxa (Allen 2002) and less than 1% of the overall fish bone assemblage; this is considerably less than the contemporary

estimates indicated above. Otoliths, however, were more common and Figure 9 tracks their density over time (counts per m³) for a 2 m² sample where all fish bone was analysed in detail. The results suggest that bonefishing was most important early in time (Zone F/H, dated to c. 14th century AD) (Allen and Morrison 2013). This occupation was followed by a major marine event, a significant storm or possibly a tsunami (Zone E). During the subsequent Zones D and C,

bonefish remains were reduced relative to Zone F/H, as is the case with fishes overall (Allen 2002). Zone B, thought to be post-contact in age, sees some recovery in bonefish numbers, in contrast to fish abundances overall, followed by declines in the recent period. On-going research, involving otolith sectioning and annuli counting, isotopic analyses of annual rings, and comparisons with other climate proxies, is aimed at evaluating the underlying cause(s) of these temporal trends, including the possibility of harvesting pressures and climate change (Allen et al. 2011)

7 Tubuai, Austral Islands

Bonefish also were important on nearby Tubuai, a volcanic island with a barrier reef in the Austral Islands. Ethnographer Aitken (1930:58) writes that on one occasion a three-hour wait at the fishing grounds was rewarded by the capture of a single fish and "... my companion was well pleased. The fish, an oi'ō... was once very highly prized, and was large enough to serve even a Tubuai family." He further observed: "a man fishing for oi'ō will never try simultaneously for any other sort of fish, but will cast two lines, then wait for hours, rebaiting his hooks when necessary. He will be pleased if he secures one fair-sized fish, and entirely satisfied with two or three, even though he may have spent the entire day catching them" (Aitken 1930:59).

Long drag-nets (*rau ere*) also were used for bonefishing in shallow waters, the largest measuring slightly over one half-mile (0.8 km). Typically 85 to 100 people might help deploy these nets and locals suggested that as many as 200 might be involved. Aitken (1930:61) notes that large numbers of fish were secured at the same place at the same time in the past, possibly a reference to pre-spawning aggregation sites. Informants observed that bonefishes were considerably more abundant in earlier times and Aitken concluded (1930:62): "It is certain, at any rate, that upon some former occasions vastly greater hauls have been made than those I have seen." In distributing fishes from these large *rau ere* harvests, a special effort was made to allocate each household at least one portion of a bonefish, "the most highly regarded of the local fish" (Aitken 1930:62).

Although Aitken's account is cryptic, it highlights the economic and social value of bonefishes. Moreover, at least two capture technologies are identified, including one which may have targeted

pre-spawning aggregations. Finally, the suggested declines in abundance parallel the Aitutaki situation where the archaeological sequence provides direct evidence for changing abundances. Although no archaeological fisheries studies are available for Tubuai, albulids are lacking in assemblages from nearby Rurutu Island (Weisler et al. 2010).

8 Hawaiian Islands

Historically, bonefishes or *ō'io* of the Hawaiian Islands were abundant enough to support a large commercial fishery (Friedlander et al. 2008). Unsurprisingly, bonefishes also were pursued by native Hawaiian fishermen. Despite their fine bones, they were "... an exceedingly popular food fish, flesh is delicious, white; liked raw when its many fine bones are supple and slip down the throat without any trouble" (Titcomb 1972:119). Hawaiian *ō'io* were sufficiently valued as to appear in a Hawaiian fisherman chant, along with another twenty-odd fish and sea creatures (Titcomb 1972:52). David Kaha'ulelio (2006) describes early 20th century practices in some detail and they are mentioned by native historian David Malo (1971:79, 211) and, more recently, by Hiroa (1964:298-9). An 1837 Hawaiian newspaper account reports that schools of bonefishes, along with tuna, hawksbill turtles, octopus, goatfish and other marine resources, were placed under *kapu*, or restriction, by Hawaiian chiefs (*ali'i*) (Solomona (?)1838). A second account, some twenty years later, identified *ō'io* as a species controlled by *konohiki* (Spencer 1857), headmen who managed resources for Hawaiian chiefs in traditional land units known as *ahupua'a*. These accounts suggest bonefish were a delicacy.

Native Hawaiians recognized four bonefish growth stages: *nehu* (roughly fry), *pua'ō'io* (finger length), *amo'omo'o* (like small strips of tapa), and *ō'io* (forearm length). Paralleling the Aitutaki evidence, Kaha'ulelio (2006:141) explains that leaf sweeps (*lau kapalili*) and nets (*pāloa*) were most efficient in shallow lagoon areas where the younger fish tended to school, whereas hooks were needed in deeper waters and beyond the reef for catching large individuals. Fishermen using nets worked from canoes in shallow waters, with a shore-based master fisherman orchestrating the hunt. The Hawaiian *ō'io* net was quite large, reportedly between 80 to 150 fathoms (144 to 270 m) in length and 2 to 3 fathoms (3.6 to 5.4 m) deep (Hiroa 1964).

With respect to angling, Kaha‘ulelio (2006) indicates that very large hooks were involved. Another technique, known as *mamali ‘ō‘io*, involved small hooks of varied forms used with bait chum immediately off the reef at sunset. Malo (1971:79) observed, “The names of the different kinds of hooks used in ancient times would make a long list...” but among those he details is “...the kue (a very much incurved hook, used to take the oio, etc.)...” Kaha‘ulelio noted that the bonefish hooks of a Kaua‘i fisherman, “bent” at the back and bottom and with a straight point, differed from his own and those of other Maui fishers, suggesting regional variation even within a specialized hook type. Remarkably, Kaha‘ulelio estimated catches of about 40 fish an hour. His secret, he explains, is to catch the fish in the lower jaw, which causes the fish to rotate; once belly-up it no longer has the strength to fight. If the hook catches in the upper jaw he suggests you might as well release it and start over, as the fish will “dash to and fro, pulling with all its might...” (Kaha‘ulelio 2006:145).

Specialized hooks like those outlined above may offer a means of identifying bonefishing in the archaeological record. The Aitutaki metal examples (Figure 4) have long points that nearly equal the shank in length and the gape is relatively narrow, a feature required for snagging and holding fast-moving fishes. The Hawaiian *kue* hook also was “much incurved” (Malo 1971:79), while a Tuamotuan form known as *numi* and associated with *kiokio* by at least one informant, similarly features a lengthy point and strongly incurving tip (Emory 1975:199). There is, however, a trade-off, alluded to by Kaha‘ulelio (2006), between holding and removing a fish, with a narrow gape requiring more effort to remove the fish once landed. Another attribute shared by the foregoing examples is overall hook shape, specifically a narrow U-shape form. The bends, in contrast, are variable, as are widths of the shank, bend and point, although presumably too delicate a hook would be ineffective and prone to breakage. The Kaua‘i hook described by Kaha‘ulelio (2006), with its angled shank, angled bend, and straight point, may have been problematic with respect to holding the fish, and the angled shank may have made the hook too wide for the mouths of these fishes; unfortunately no illustrations are provided. This small sample of known bonefish hooks highlights attributes that were required for capturing fast-moving prey in general and could help identify archaeological localities where bonefishes were once a target.

Despite the plentiful evidence for significant populations of bonefishes, and historical evidence for traditional Hawaiian bonefishing practices, only a few archaeological sites have produced albulid remains. Weisler (1993, Table 5) recovered 9 otoliths from three sites on Moloka‘i, including both the endemic *A. virgata* and the more widely distributed *A. glossodonta*. A much larger assemblage (n=260) derives from a probable late prehistoric context at Bellow’s Beach, O‘ahu where McElroy et al. (2006:172) suggest they were an assemblage dominant, along with parrotfishes (Scaridae), wrasses (Labridae), and leatherjackets (Monacanthidae). Another site on the Waimānalo Plain produced a single albulid bone (McElroy et al. 2006:173). Thus despite unambiguous ethnographic evidence for the importance of bonefish, they are archaeologically poorly represented.

9 Tokelau

Tokelau is an interesting case because of the range of evidential sources. Neither the early ethnographic study of Macgregor (1937), nor the 1996 historical ethnography of Huntsman and Hooper, make mention of bonefishing, although other fish are considered. Similarly, they are not mentioned in Zyllich et al.’s 2011 assessment of contemporary Tokelauan subsistence fisheries, and detailed catch records for the three atolls, collected over a two-week period, include only a single bonefish (Huntsman and Hooper, unpublished data). In contrast, a compendium of traditional fishing practices by community elders identifies several bonefish capture strategies (Elders from Atafu Atoll 2012:28, 51, 65-6). Although there is no specific hook for bonefishes on Atafu, they are targeted with both hand-lining and rod fishing, depending on the tide. Other important factors include the time in the lunar cycle, line breaking weight (12 kg), hook size (no. 12 or 13), and bait (red hermit crabs). During high tide, bonefishes are caught from the beach using a rod or hand-line, while hand-lining from canoes is done during low tide when they congregate in sheltered sandy coves. *Lauloa* or net fishing on the reef at night takes place during high tide conditions, with bonefishes being one of several targets (Elders from Atafu Atoll 2012:51).

Surprisingly, *Albula* remains have not been archaeologically identified for Tokelau, despite two recent zooarchaeological studies. On Fakaofu Atoll, archaeological sediments were systematically processed

with 3 mm mesh sieves, a large number of specimens identified (NISP=3085), and 16 families represented but bonefish was not among them (McAlister 2002). In a second study on Atafu Atoll, samples were again processed with 3 mm sieves, a wider range of elements used for identification (NISP of 1655), and 22 families identified, but not *Albulidae* (Ono and Addison 2012). The Tokelau example is again illustrative of potential ethnographic and archaeological biases, with only the more focused study of indigenous fishery knowledge detecting bonefish use.

10 Discussion and Conclusions

The argument developed here is that the biology, ecology, and life history traits of bonefishes combine to make this taxon a high-return prey for Polynesian fishers, one which could be efficiently harvested using a variety of traditional technologies. Further properties which might have favored bonefish use include the timing of their runs in relation to other fishes and their reputed suitability to preservation by extended cooking. The wide natural distribution of bonefishes and their consistent Polynesian referent (*kiokio* and cognates) further suggests that most indigenous Polynesian communities recognized them as distinctive. Following the logic of Pawley (2011), we might infer a degree of economic importance as well. Supporting evidence comes from Hawai'i where they were a fish worthy of chiefs (Solomona [?] 1837; Spencer 1857), from Tubuai where they were highly valued and allegedly a single fish could feed a family (Aitken 1930), and from Aitutaki where they are a delicacy and have been a dietary contributor for centuries. Elsewhere, as on Tokelau (Elders of Atafu 2012; Ono and Addison 2012) and in the Tuamotu Archipelago, more modest importance is indicated. In a regional study of Pacific artisanal fisheries they ranked 13th (1.36%) in importance (Gillet 2010, Table 3), contributing far less than the top ranked families which included *Lethrinidae* or emperors (13.32%), *Acanthuridae* or surgeonfishes (10.91%), and *Lutjanidae* or snappers (9.19%). Archaeologically they are only well represented on Aitutaki Island and in the Hawaiian Archipelago. Overall, despite a concerted effort to identify bonefishing traditions across Polynesia, their historical and contemporary use appears discontinuous and uneven.¹ The three hypotheses offered at the outset are now examined in more detail using the larger dataset assembled herein.

10.1 Preservation and Recovery Biases: *Ethnographic and Archaeological*

Initially it is worth considering whether the apparent patterns are accurate representations of the past, or affected by preservation and recovery biases, both ethnographic and archaeological. The ethnographies surveyed here generally date from the early to mid-20th century (Table 1) and were undertaken to document broad cross-sections of island lifeways, traditions, and socio-economic practices. Fishing is routinely considered but the focus often is on the associated material culture rather than the fish themselves. The specific prey species often are not mentioned, or only local names provided. Sometimes there is in-depth coverage of a few high-profile marine taxa, such as bonito, flying fish, turtles, sharks, or *Ruvettus* (oilfish), but typically little mention is made of the common reef fishes which probably were the mainstays of many island diets. It seems that these more spectacular species are disproportionately emphasized relative to their actual economic contributions (see also Leach 2006:34). Comparison of the ethnographic account of Macgregor (1937) with that of Elders from Atafu Atoll (2012) underscores the potential for information loss in the absence of targeted indigenous knowledge studies (see also Johannes 1981).

Bonefishes also are poorly represented in Polynesia's archaeological sites, even in island settings where they are of known importance (e.g., Hawai'i and Tokelau). Although some of their head bones are small (e.g., premaxilla) or fragile (e.g., maxilla, dentary), others are sufficiently robust that they would be anticipated to survive under most circumstances (see Figures 7, 8, 10, 11). Remains from Moturakau, Aitutaki indicate the potential for bone recovery with 31 bones being identified from a 2 m² sample. However, otoliths are much better represented, suggesting preservation or cultural processing biases. It also is possible that the atypical morphologies of some *Albula* bone elements have stymied identification. The figures provided herein may aid future identifications and possibly consideration of a larger array of head elements would prove profitable. *Albulid* otoliths, in contrast, are not only dense and robust, but also large and distinctive. They should preserve well and be recovered, even with coarse mesh screens. However, they may be confused with shell fragments if broken.

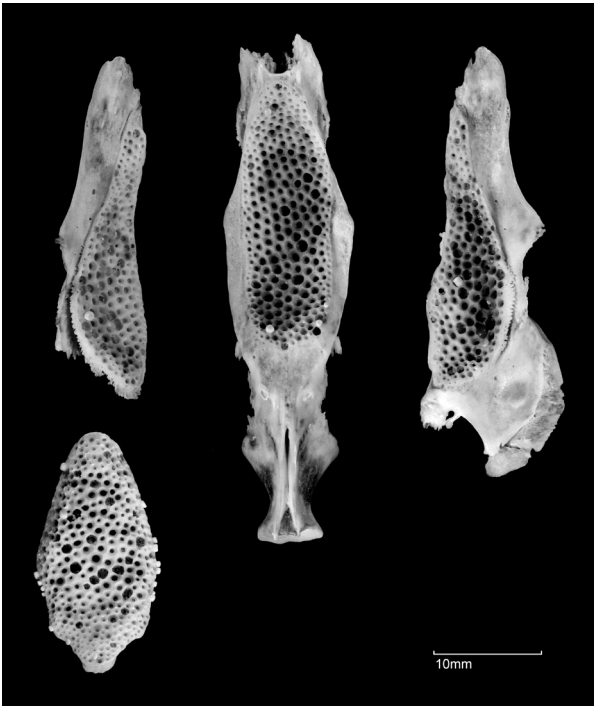


Figure 10. Other distinctive *Albula* sp. bones (accession AU4548). Ventral views of toothed elements: parasphenoid (central specimen) and two other toothed elements with the metapterygoid attached to far right example. Dorsal view of basibranchial tooth plate (lower left); note the teeth are largely missing (photograph by T. Mackrell).

10.2 Temporal Change in Bonefish Abundance

A second hypothesis was that bonefishing may once have been more widely practiced but has declined over time, as a result of harvesting pressures, climate change, or other factors, such as the introduction of exotic fishes like tilapia (e.g., Lobel 1980). Long-term historical trends are more difficult to evaluate given the rarity of archaeological remains of bonefishes. The Aitutaki example alone indicates several centuries of exploitation, but also a long-term decline (Allen 2002). The brief Tubuai account (Aitken 1930) hints that bonefishes may have declined there as well, with harvesting pressure possibly being a factor. As described above, their life history traits make bonefishes vulnerable to intensive harvesting but whether impacts would be discernible under traditional fishing regimes is uncertain. There is robust evidence for adverse impacts arising from contemporary harvesting practices and environmental influences, as for example on Tarawa (Beets 2000), in Hawai'i (Anderson et al. 2007; Friedlander et al. 2008), on Aitutaki (Adams et al. 1999) and in the

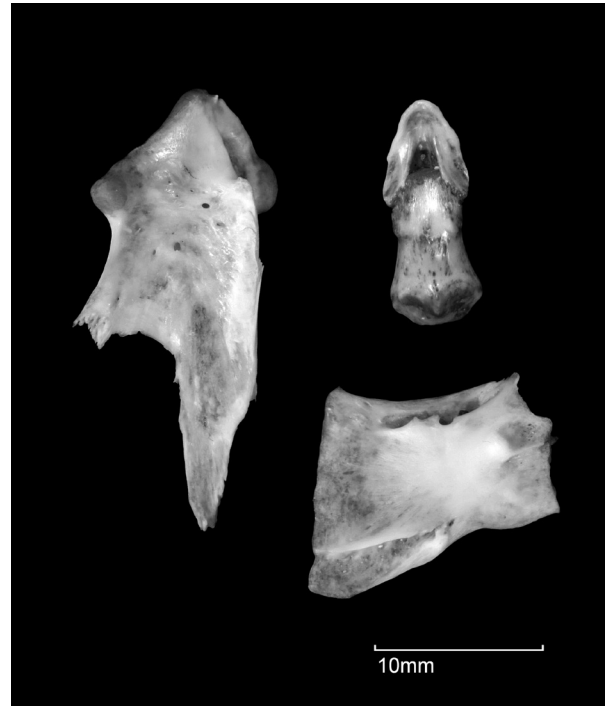


Figure 11. *Albula* sp. hyomandibula (left side, lateral view), undetermined but distinctive element (possibly from the hyoid apparatus-gill arch region) and ceratohyal (left side, lateral view). Note that none of the elements are in anatomical position (accession AU4548; photograph by T. Mackrell).

Tuamotus (Caillart et al. 1994). Climate variability also could be a factor, a possibility that is being assessed on Aitutaki where the bonefish otoliths are being examined for variability in age and size in relation to variability in sea surface temperature.

10.3 Geographic Variability in Suitable Habitat

The third possibility is that spatial variability in conditions which favor the abundance of bonefishes has led to a discontinuous and uneven pattern of exploitation and socio-economic importance. Friedlander (pers. com. 2014) suggests "they are not abundant throughout their range." Hamon and Blanc (2009:12) note that French Polynesia has some "magnificent flats but bonefish populations are not evenly spread out among the islands." Ichthyologist Harry (1953:50) reported that bonefishes occur only in specialized environments on Raroia Atoll, where they are restricted to brackish water pools. Limited published information on the abundance and ecology of Pacific bonefishes, however, makes evaluation of this third hypothesis difficult. A recent

archipelago-scale fishery study allows for at least a preliminary assessment.

In 2007, the Pacific Regional Oceanic and Coastal Fisheries Development Programme (PROCFish/C/CoFish) analysed artisanal fisheries across four southern Cook Islands using a uniform set of observational and recording protocols (Pinca et al. 2009). Additional controls arise from the islands' close proximity, extending from 18 to 21° south latitude and 157 to 163° west longitude, and relative consistency in large-scale conditions of climate, currents, finfish biogeography, and the like. The specific study islands were varied with respect to marine habitats and included, from north to south, the atoll of Palmerston, the almost-atoll of Aitutaki, the high island of Rarotonga with its narrow fringing reef and small lagoon, and Mangaia, a makatea island. In comparing the fisheries results, my expectation was that bonefish would be best represented in the two atolls where extensive shallow water sand flats are available.

As expected, the study reports that bonefishes were only represented in the artisanal fisheries of Aitutaki where they comprise between 3.5% (lagoon) and 10% (reef passes) of the catch (Pinca et al. 2009, Appendix 2.1.1). Moreover, bonefishes were not recorded for any island in the underwater visual surveys but this could be a methodological bias related to “detectability.” Anecdotal support for the identified patterning comes from the Cook Islands Biodiversity & Natural Heritage website (McCormack 2007) where bonefish are indicated as “absent” from Miti‘āro, ‘Ātiu, Ma‘uke (all makatea islands), and Rarotonga, with no data for Mangaia. Overall, Cook Island bonefish distributions are best explained by the availability of good habitat; however, their absence from the Palmerston Atoll fishery is unexpected. Although far from conclusive, this study highlights variability in bonefish distributions within a single archipelago, where many large scale environmental factors and analytical protocols can be held constant, but marine environments are highly varied.

10.4 Conclusions

This review provides few definitive answers and raises many questions about a potentially valuable Pacific Island food resource. The apparent patterns identified here, discontinuous and uneven usage of bonefishes, raise questions of broad anthropological significance. How can we identify and better control for collection biases associated with ethnographic and

archaeological data? Do human subsistence practices conform to foraging theory predictions regarding the use of high return resources? While many studies suggest they do, when this is not the case, what are the underlying drivers? If we can identify the historical processes that have led to spatial and temporal variability in bonefish use, then we may gain insights into the how and why of patterning in use of other fishes as well. On current evidence, it seems likely that all three of the hypotheses outlined above (collection biases, temporal changes in bonefish abundance, and regional variation in availability) have some validity and have affected current understandings of the historical role of bonefishes in Polynesian fisheries. Additionally, widespread use of a common linguistic referent for the distinctive *kiokio* may be a signal that they were once more widely used and valued.

Acknowledgements

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Note

1. Based on field observations, Alan Friedlander (pers. com. 2014) suggests there are additional instances of bonefishes contributing to Pacific fisheries which are undocumented in the literature.

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