



Pre-contact fish choice and foraging efficiency at Tula, American Sāmoa

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ABSTRACT

Marine foraging is an under-studied aspect of Sāmoan archaeology, although it clearly played a primary role in subsistence, with implications for settlement and demography. A pair of previous ichthyoarchaeological studies identified general stability in fish exploitation during ~1500–2000 year sequences. We present a foraging-theory-based analysis of fish remains from Tula Village, Tutuila Island. Our results identify a decrease in foraging efficiency, but there is no unequivocal evidence for resource depression. To frame this issue at a broader level, we re-analyse published data for Fatu-ma-Futi, Tutuila Island, and To‘aga, Ofu Island. Our results are consistent with previous analyses in suggesting little change in the prevalence of particular fish families and the contribution of large-bodied prey at these two sites. However, a degree of localised variability in dominant fish taxa is evident. Our analysis has implications for studies of resilience in nearshore marine environments, as well as methodological issues for data generated to examine foraging efficiency and resource depression.

Keywords: foraging theory, Polynesia, Sāmoa, zooarchaeology

RÉSUMÉ

La recherche de nourriture marine est un aspect peu étudié dans l'archéologie de Samoa bien qu'elle a clairement joué un rôle primordial dans la subsistance, avec des implications dans l'établissement et la démographie. Une paire d'études précédentes Ichthyo archéologiques identifièrent la stabilité générale de l'exploitation des poissons pendant séquences de ~1500–2000 années. Nous présentons une analyse basée sur la théorie de la recherche de nourriture des restes de poissons du village de Tula, dans l'île de Tutuila. Nos résultats mettent en évidence une diminution de l'efficacité du collectage, mais il n'y a pas de preuve sans équivoque de dépression des ressources. Pour encadrer cette question à un niveau plus large, nous avons analysé de nouveau les données publiées de Fatu-ma-Futi, de l'île Tutuila et de To‘aga, de l'île Ofu. Nos résultats sont cohérents avec l'analyse précédente en suggérant peu de changement dans la prévalence de certaines familles de poissons et l'apport des proies de grande taille sur ces deux sites. Cependant, il est évident un certain degré de variabilité localisée dans les taxons de poisson dominante. Notre analyse a des implications pour les études sur la résilience dans les milieux marins près des côtes, ainsi que des questions méthodologiques pour les données générées afin d'examiner l'efficacité de la recherche de nourriture et de la dépression des ressources.

Mots-clés: théorie butinage, la Polynésie, les Samoa, zooarchéologie

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INTRODUCTION

The presumed importance of marine animals in the Sāmoan diet is belied by the minimal amount of zooarchaeological research that this topic has garnered. Green and Davidson's (1969, 1974) extensive survey and excavation program in the western islands, which ushered in modern archaeology in the archipelago, largely failed to produce any vertebrate remains, presumably due primarily to the acidic volcanic soils at inland sites and the associated poor preservation of faunal material. The few zooarchaeological studies from the initial decades of research in the islands (Davidson 1969;

Janetski 1976, 1980) focused on mollusc remains, with analysis of vertebrate specimens hindered by poor preservation, screen-size recovery bias and a lack of reference material. Nagaoka's (1993) taxonomic study of the To‘aga, Ofu Island, vertebrate remains was the first of its kind for the archipelago. Although some descriptive analyses have been produced through cultural resource management-based investigations in subsequent years, the only other detailed studies have been conducted by Ishimura and Inoue (2006) for the Si‘utu site, Savai‘i Island, and Morrison and Addison (2009) for the Fatu-ma-Futi fish collection from south-central Tutuila Island.

Nagaoka's (1993) and Morrison and Addison's (2008, 2009) studies documented stability in the capture of marine invertebrates and bony fish over two millennia. Considering the time depth of occupation for Sāmoa (Rieth & Hunt 2008), a lack of variation in marine faunal assemblages due to human predation and/or climatic factors is surprising. However, with only two datasets, it is unclear if these patterns are representative of the larger archipelago. To further examine this issue, we present a foraging-theory-based analysis of a bony fish assemblage recovered from Tula Village, Tutuila Island.

TULA VILLAGE: DEPOSITION, CHRONOLOGY AND COLLECTIONS

Tula Village is on a coastal plain at the east end of Tutuila Island that is framed by the Saililagi, Lefutu and Lau'agae Ridges to the south, west and north respectively, with the ocean to the east (Figure 1). Vailoa Stream bisects the western half of the plain, but currently terminates before reaching the shore. The coastline is fronted by a fringing coral reef approximately 60 m offshore, which creates an inshore reef area of roughly 7.3 ha.

Previous archaeological investigations at Tula focused on the adjacent ridges and inland areas (e.g. Clark 1989), including the former village of Tulautā at the western end of the coastal plain (e.g. Frost 1978). Whereas these projects documented numerous surface features including house platforms, terraces and *tia seu lupe* (chiefly pigeon snaring mounds), excavations conducted in 2011 for a US Federal Emergency Management Agency (FEMA) project were the first to sample deposits within the more seaward portion of the Tula coastal plain (Rieth & Cochrane 2012). Excavations at two areas revealed 2–3 m of stratified cultural deposits approximately 90–130 m inland from the current mean high tide line.

Depositional sequences

Six test units were excavated at Tula (12 m²). A seaward excavation (TU 2) began as a 1 × 2 m unit, but at 260 cmbs it was restricted to 1 × 1 m and at 296 cmbs a shovel probe was excavated to 306 cmbs (total volume was ~5.0 m³). About 40 m further inland, a 1 × 3 m trench (TUs 7 and 8; 3.6 m³) and a 2 × 3.5 m block (TUs 9–11; ~14 m³) were excavated. Excavated sediment from TU 2 was water-screened with 3.2 mm mesh (1/8 inch), while sediment from TUs 7–11 was dry-screened using 6.4 mm mesh (1/4 inch). Collections from TUs 2, 7 and 8 are included in our analysis.

The seaward excavation (TU 2) exposed a stratigraphic sequence reflecting varying depositional energy environments spanning over two millennia. The basal layer (Layer VIII) represents a cobbly beach that formed prior to human settlement; the few artefacts collected from this deposit are interpreted as originating from the overlying cultural stratum. Three consecutive dark greyish brown or very pale brown loamy calcareous sand layers (Layers

VII–V) reveal subsequent periods of calcareous sand deposition and stability that allowed human occupation as evidenced by a hearth, plainware ceramics and other artefacts (for an analysis of the ceramics, see Cochrane *et al.* 2013). Two radiocarbon determinations from Layer VII (2230 ± 30 BP (Beta-308721; *Cocos nucifera* wood charcoal; $\delta^{13}\text{C} = -26.0\text{‰}$) and 2220 ± 30 BP (Beta-308720; *C. nucifera* endocarp charcoal; $\delta^{13}\text{C} = -26.6\text{‰}$)), one from Layer VI (2230 ± 30 BP (Beta-308719; *C. nucifera* wood charcoal; $\delta^{13}\text{C} = -26.1\text{‰}$)) and two from Layer V (2220 ± 30 BP (Beta-308717; *C. nucifera* wood charcoal; $\delta^{13}\text{C} = -25.1\text{‰}$) and 2220 ± 30 BP (Beta-308718; *C. nucifera* wood charcoal; $\delta^{13}\text{C} = -24.3\text{‰}$)) are statistically identical, indicating rapid deposition. These strata relate to coastal aggradation and progradation. Eventually calcareous sand deposition increased while cultural deposition decreased (Layers IV–II), which may relate to a shift in primary occupation on the plain. The sequence is capped by a recent fill (Layer I).

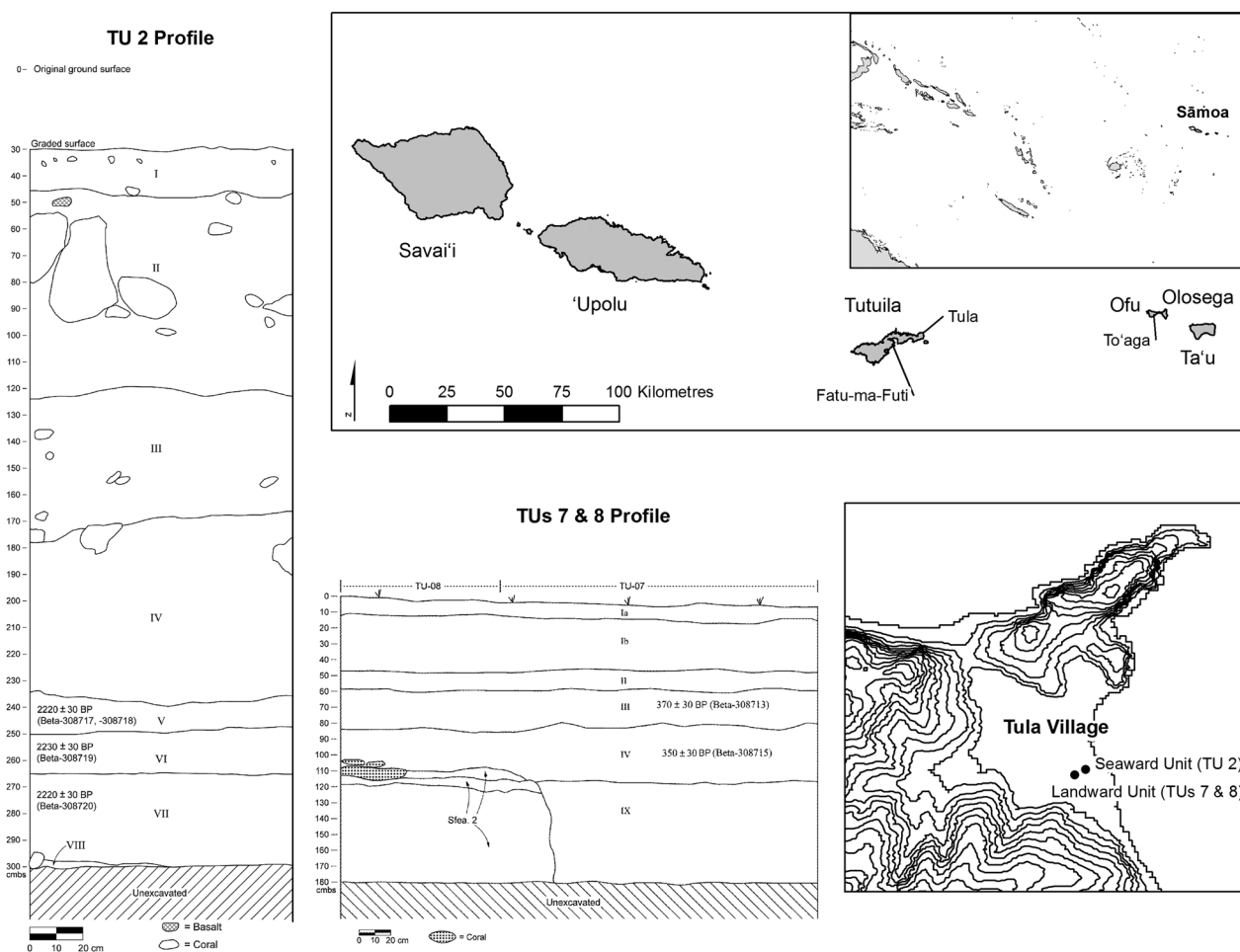
The more inland excavations (TUs 7–11) did not extend into pre-cultural strata. The lowest layer (Layer X), very pale brown calcareous sand, was sampled with a shovel probe and produced plainware pottery and a small amount of midden. Charred residue from a sherd produced a radiocarbon age of 2005 ± 15 BP (PRI-11-144-115q). The shovel probe limited observations of this stratum and it is unclear if this sherd was recovered from a primary or secondary location. Regardless, this age indicates occupation slightly later than the basal occupation layers at the seaward unit. The overlying strata (Layers IX–II) are dark calcareous sand, silty calcareous sand and gravelly sandy loam deposits containing basalt, shell and bone artefacts, midden and intrusive modern material. The uppermost stratum is modern fill (Layer I). Charcoal ages from the upper cultural strata are late and inverted (Layer VI, 280 ± 30 BP (Beta-308712; cf. *C. nucifera* wood charcoal; $\delta^{13}\text{C} = -24.2\text{‰}$); Layer IV, 350 ± 30 BP (Beta-308715; *C. nucifera* endocarp charcoal; $\delta^{13}\text{C} = -23.7\text{‰}$); Layer III, 370 ± 30 BP (Beta-308713; *C. nucifera* endocarp charcoal; $\delta^{13}\text{C} = -23.0\text{‰}$); Layer III and IV interface, 470 ± 30 BP (Beta-308714; *C. nucifera* wood charcoal; $\delta^{13}\text{C} = -22.6\text{‰}$)).

Bayesian chronological modelling

The radiocarbon determinations were calibrated with a multi-phase Bayesian model using Oxcal v. 4.23 (Bronk Ramsey 2009, 2013) and the IntCal13 Northern Hemisphere curve (Reimer *et al.* 2013) since Sāmoa lies within the South Pacific Convergence Zone, which merges with the Inter-Tropical Convergence Zone (McCormac *et al.* 2004: 1088). The “Sequence”, “Boundary”, “Phase”, “Span” and “Difference” commands were used in the model. The model code is provided as Online Supporting Information.

The model shows good agreement between the radiocarbon dates and phasing ($A_{\text{model}} = 107.1$). Modelled results are italicised in the text to distinguish them from unmodelled dates. The estimates provided by this model will change as new data are added or the model structure is

Figure 1. The locations of Tula Village, the Tula excavation areas and profiles, and the Fatu-ma-Futi and To'aga sites.



changed; however, based on the available information, this model provides the best current estimate for the site deposit chronology.

The model estimates initial occupation at Tula (TU 2, Layer VII) no later than 2347–2167 *calBP* (95.4%) (2317–2191 *calBP* (68.2%)). The end of deposition for Layer V (TU 2) occurred between 2309 and 2114 *calBP* (95.4%) (2218–2150 *calBP* (68.2%)).¹ Deposition of Layers VII and VI was up to 135 years (95.4%) (up to 53 years (68.2%)), with the duration of Layer V up to 89 years (95.4%) (up to 26 years (68.2%)). Later deposition at TUs 7–11 began at 540–323 *calBP* (95.4%) (453–375 *calBP* (68.2%)) (landward Layer VI), with traditional deposition ceasing sometime between 456 and 226 *calBP* (95.4%) (376–305 *calBP* (68.2%)). This later occupation spanned 0–261 years (95.4%) (0–106 years (68.2%)).² The basal deposits in the seaward unit and the upper strata at the more inland unit are separated by 1620–1907 years (95.4%) (1716–1827 years (68.2%)).

Bony fish collection

Vertebrate remains were sorted by T.M. Rieth in 2011 to the lowest taxonomic category possible and were quantified using NISP. Identifications relied on reference skeletons at

the International Archaeological Research Institute, Inc., and the University of Hawai'i–Mānoa archaeology laboratories. The International Archaeology reference collection contains specimens from 12 fish families and is used for initial identifications. The University of Hawai'i reference collection contains 261 individual specimens representing 46 fish families. Bony fish identifications were made using the five paired cranial elements and special bones. The identification of an expanded number of elements, particularly vertebrae (Lambrides & Weisler 2015), would undoubtedly improve identification and family representations. However, the identifications forming the foundation of the analytical results presented here were conducted prior to the common use of a more diverse range of cranial elements. Additionally, per the requirements of FEMA, the Tula artefact and midden collection was repatriated to the traditional landowners in 2012 and is no longer available for analyses. Consequently, we are aware that our analysis may not be sensitive enough to capture more subtle trends in the dataset, and a future research avenue will include recovery of a comparable assemblage from Tula and subsequent analysis using an up-to-date identification protocol (following Lambrides & Weisler 2016).

Vertebrate collections from these excavation units document use of the Tula marine environment during the earliest known settlement of the coastal plain and during the late pre-Contact period. The middle portion of the occupation sequence spanning ~1600–1900 years is currently lacking. Layers VII–IV (~2.1 m³) from TU 2 and Layers IV and III (~1.1 m³) from TUs 7 and 8 produced 7898 bony fish specimens (NISP), with 345 identified to 15 bony fish families (Table 1). The low number of specimens identified to family (4.6%) is due to high fragmentation and the recovery of a large number of small non-diagnostic specimens through water-screening with fine mesh. Bird (Aves), Pacific rat (*Rattus exulans*) and turtle (Chelonidae) were recovered from the seaward and inland units, with dog (*Canis familiaris*) and pig (*Sus scrofa*) only present in the later inland strata.

Remains from certain strata were aggregated to create four analytical zones (Tula-AZs 1–4). Aggregation was justified by the radiocarbon dating and increased the sample size for the oldest and youngest analytical units. Specimen accumulation rates based on the maximum estimated depositional spans range from 2.9 specimens per year (Tula-AZ 4) to 44.1 specimens per year (Tula-AZ 2). A depositional rate cannot be calculated for Tula-AZ 3 due to the lack of associated radiocarbon dates.

METHODS FOR MEASURING PREY CHOICE, DIET BREADTH AND FORAGING EFFICIENCY

Foraging theory provides a framework to predict under what conditions changes may be expected in subsistence activities and offers methods for measuring these activities (Stephens & Krebs 1986). To assess potential variation in the use of prey taxa at Tula, the bony fish collection is examined for taxonomic diversity and the relative importance of specific taxa. We use the prey choice model, which is based on the expectation that high-ranked prey will always be taken upon encounter (Stephens & Krebs 1986: 23; Winterhalder 1981) and as the encounter rate of these prey declines, lower-ranked prey may be incorporated into the diet. It is important to note that declining foraging efficiency may be the result of a number of processes that influence the encounter rate between foragers and higher ranked taxa. Environmental variability, prey and predator life history strategies, predation pressure and technological innovation are some of these processes. Following Charnov (1976), when foraging efficiency declines, an increase in diet breadth (i.e. increased diversity of taxa) and an increasing number of exploited patches (e.g. habitats) may also occur, and these patterns may signal resource depression. Based on these theoretical expectations, we examine the Tula bony fish assemblage for changes in diet breadth and foraging efficiency.

Calculation of NTAXA, rank order and abundance indices

The number of taxa (NTAXA), in this case bony fish families, present in the Tula collection is used as a measure

of diet breadth (e.g. Broughton & Grayson 1993; Grayson & Delpech 1998; Morrison & Addison 2008; Nagaoka 2001, 2002). Increases in the NTAXA value denote a greater diversity in diet. To complement NTAXA, we also consider rank order. Although some fish families present in the Tula collection include pelagic and reef taxa, all families are classified as inhabitants of the reef patch for our analysis. This is in part due to the coarse resolution (family-level) of the identifications, but also accounts for the fact that many pelagic fish may be found and captured in nearshore environments (e.g. Randall 2005: 609–11). Foraging efficiency was measured using abundance indices (AI). The indices compare the proportion of high-ranked and low-ranked taxa, using body size as a proxy measure of energetic return (e.g. Allen 2012; Broughton 1999; Broughton *et al.* 2011).

We calculated mean body length for each fish family using the maximum reported species-level lengths provided by Randall (2005) (see Table 1). We chose to use maximum lengths under the assumption that these may be better measures of fish sizes prior to the effects of modern commercial fishing in the Pacific. The mean lengths for the Tula fish families range from 150.5 mm (Cirrhitidae) to 1290.0 mm (Scombridae), with no inherent break in the continuum (when arranged with bin sizes of 49 mm). This poses an analytical challenge in defining “large” versus “small” fish that has ramifications for measuring foraging efficiency with archaeological assemblages (discussed further below). To evaluate the effect of using different cut-off lengths for making this determination, we calculated AI using 300 mm (≥ 300 mm = large; < 300 mm = small) following Butler (2001) and also 400 mm (≥ 400 mm = large; < 400 mm = small). The equation for the large fish AI is as follows:

$$\text{large fish index} = \frac{\sum \text{NISP (large taxa)}}{\sum (\text{NISP large taxa} + \text{small taxa})}$$

Admittedly, the use of a mean length for categorising prey body size glosses intra-genus, inter-species, age and sexual variation. As a heuristic approach, however, mean estimates should capture general size relationships.

RESULTS

Diet breadth and rank order abundance

NTAXA decreases through time (Figure 2a); however, these results correlate with sample size (Spearman's rank correlation coefficient; $r_s = 1$, $p = 0.000$). Therefore, we cannot say with confidence that there was a constriction in diet breadth by the late pre-Contact period or if the trend is merely due to sample-size bias. Four of the fish families absent in Tula-AZ 4 (Mullidae, Muraenidae, Scombridae and Scorpaenidae) are represented by individual specimens in Tula-AZs 1–3, highlighting the effect of small sample size in the exclusion of rare taxa. Acanthuridae, Balistidae,

Table 1. Bony fish (NISP) recovered from excavations at Tula.

Taxa	Analytical Zone 1 (TU 2, L. VI and VII)	Analytical Zone 2 (TU 2, L. V)	Analytical Zone 3 (TU 2, L. IV)	Analytical Zone 4 (TUs 7 and 8. L. III and IV)	Total	Mean length (mm)
Acanthuridae	24	29	12	8	73	316.3
Balistidae	2	6	2	3	13	382.7
Cirrhitidae				1	1	150.5
Diodontidae	8	11	1	4	24	530.0
Holocentridae		7	1	2	10	244.8
Labridae	2	11	6	3	22	257.9
Lethrinidae	10	31	10	2	53	615.0
cf. Lethrinidae		5			5	—
Lutjanidae	2	5	3		10	607.7
cf. Lutjanidae	2	1			3	—
Mullidae	1				1	361.5
Muraenidae	1				1	816.8
cf. Muraenidae		1			1	—
Scaridae	30	61	14	1	106	487.7
Scombridae		1			1	1290.0
Scorpaenidae		1			1	139.6
Serranidae	3	3	2	2	10	516.8
cf. Serranidae		2		1	3	—
Sphyraenidae	1	4	2		7	990.0
Subtotal	86	179	53	27	345	
Unidentified Osteichthyes	1624	3746	1449	734	7553	
Total	1710	3925	1502	761	7898	
Accumulation rate (specimens per year)	12.7	44.1	?	2.9	—	—

Diodontidae, Labridae, Lethrinidae, Scaridae and Serranidae are present throughout the sequence, although their rank order varies. Most noticeably, Scaridae is the top-ranked taxon in Tula-AZs 1–3 but drops to the lowest rank in Tula-AZ 4. Similarly, Lethrinidae, which is second or third rank in the lower analytical zones, attains the second to last rank in the upper analytical zone. Although diet breadth may not have changed significantly, the relative importance of individual fish does appear to have varied from the early to late periods. As with NTAXA, rank order should be re-evaluated if greater sample sizes are attained.

Further, specimen accumulation rates increase from Tula-AZs 1 to 2 and decrease from Tula-AZs 2 to 4. Although time-averaging could be affecting our NTAXA results, differential time-sampling-whereby rarer taxa are more likely to be present in assemblages that accumulate over a greater period of time-does not appear to be the case (Grayson & Delpech 1998). Tula-AZ 2 formed during the shortest period yet has the greatest NTAXA.

Foraging efficiency

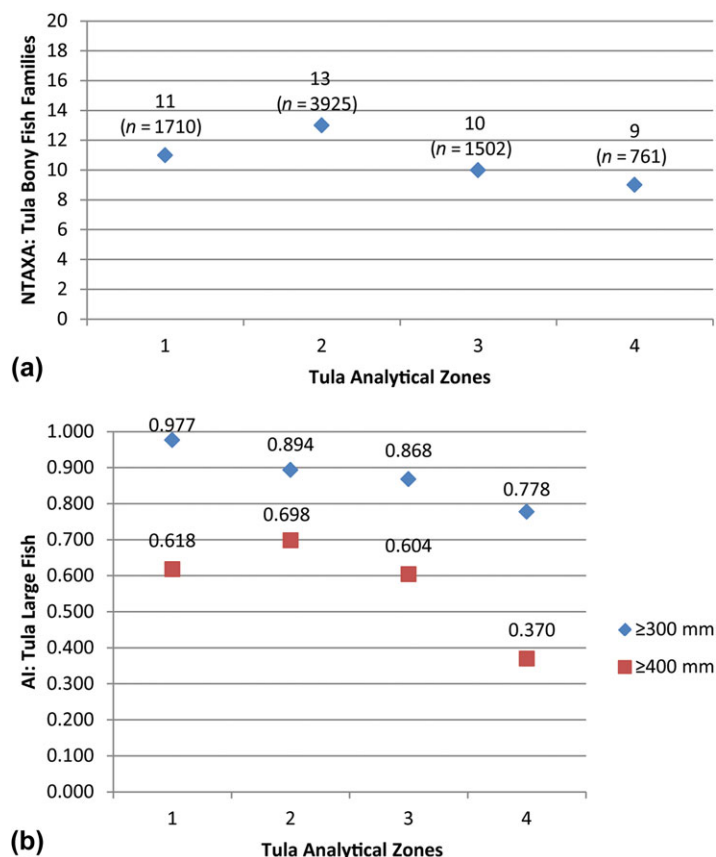
Figure 2b presents the AI values for the analytical zones using the 300 mm and 400 mm cut-off lengths. As suggested above, relative size classification has an effect on foraging efficiency values. For example, if the large fish class is defined as ≥ 300 mm, there is a constant decrease in foraging efficiency from a near-absolute dominance of large-bodied taxa in Tula-AZ 1 (0.977) to a greater proportion of small-bodied taxa in Tula-AZ 4 (0.778), although the proportion of large fish still remains relatively high (the trend is not correlated with sample size

(Spearman's rank correlation coefficient; $r_s = 0.8$, $p = 0.2$). Using ≥ 400 mm, there is an increase in foraging efficiency between Tula-AZs 1 (0.618) and 2 (0.698), followed by a slight decrease in Tula-AZ 3 (0.604) and a precipitous decline to Tula-AZ 4 (0.370). However, like NTAXA, this trend is correlated with sample size (Spearman's rank correlation coefficient; $r_s = 1$, $p = 0.000$). Setting aside the absolute AI values, the analyses reveal two common trends. First, the variation in the contributions of large fish between Tula-AZs 1–3 is relatively minor. Second, relative to AI values for Tula-AZ 1, foraging efficiency declined by Tula-AZ 4 (the late pre-Contact period) and this trend is robust regardless of the cut-off criteria used for fish size classification.

DISCUSSION: COMPARISONS WITH TO'AGA AND FATU-MA-FUTI

Although fish NTAXA does not document an expanding diet breadth at Tula, AI for large-bodied prey suggest a temporal decrease in the prevalence of high-ranked taxa and this is revealed regardless of the cut-off criteria used to classify fish. A detailed late Holocene environmental record is lacking for Sāmoa, so potential natural factors affecting the abundance of large-bodied fish are unknown, although our results suggest that human predation played some role. As suggested by Rieth and Cochrane (2012: 331–6), a decrease in high-ranked fish taxa may be correlated with a reverse trend for marine molluscs, with the Tula population focusing on high-value shellfish as returns on large fish declined. Additionally, later in the Tula sequence, pig and

Figure 2. NTAXA of bony fish families (and sample size) at Tula (a) and AI values for large inshore fish using 300 mm and 400 mm cut-off lengths for defining large taxa (b).



dog show up in the midden collections, animals that could have further offset nutritional losses from fishing.

At an archipelago level, the history of marine exploitation in Sāmoa has not been examined. Potential variation in past subsistence practices relating to the dynamic interplay of humans, the environment and climate remains largely unexplored. Addressing this issue requires large, well-provenienced, reliably dated faunal collections from each of the Sāmoan islands and across multiple time periods. As Lambrides and Weisler (2016) have pointed out, appropriate recovery methods, identification protocols and quantification procedures should be presented in a transparent manner for all collections. In addition to these archaeological requirements, localised environmental characteristics and climate histories are required. Currently, the extant Sāmoan archaeological and environmental records fall short of these data requirements. However, as an initial step towards a more comprehensive investigation, we compare the Tula results with faunal data from Fatu-ma-Futi (Morrison & Addison 2009) and To‘aga (Nagaoka 1993).

Nagaoka (1993) reported temporal stability in the bony fish from To‘aga, while Morrison and Addison (2009) identified stability in the mean trophic level of fish families exploited through the ~1500 year sequence at Fatu-ma-Futi. These analyses have been the most detailed zooarchaeological studies for Sāmoa, suggesting a degree

of resilience in fish populations for the archipelago. Nagaoka (1993: 207) provided general hypotheses for this pattern, stating that “Some possible causes [for stability] include the exploitation of naturally abundant taxa from a temporally stable environment, a lack of change in subsistence practices, or a combination of both factors.” In contrast, the Tula results raise the possibility of a decrease in the encounter rate of some large-bodied fish over the course of two millennia. In the following paragraphs, we discuss the Fatu-ma-Futi and To‘aga bony fish assemblages in greater detail and re-analyse the datasets to allow for comparison with the Tula assemblage.

Fatu-ma-Futi, Tutuila

Fatu-ma-Futi Village is on a narrow coastal shelf towards the western edge of the Pago Pago Harbor entrance, along central Tutuila. Approximately 70 m² was excavated within the village by the American Samoa Power Authority. A full presentation of the excavations and laboratory results has not been completed, but Addison *et al.* (2008) provide a summary of the initial excavations, while Morrison and Addison (2008, 2009) present analyses of the invertebrate and fish remains from a 4 m² subset of the overall excavated area. The series of excavated deposits spanning the past ~1500 years include burials, house pavements, lithic artefacts and midden. A total of 6221 fish specimens were

Table 2. Bony fish (NISP) recovered from excavations at Fatu-ma-Futi (data from Morrison & Addison 2009).

Taxa	IV	III	II	I	Total
Acanthuridae	9	202	95	9	315
Balistidae	6	26	26		58
Belonidae	2		2		4
Carangidae	2	18	13	2	35
Cirrhitidae		2			2
Diodontidae	4	10	3		17
Holocentridae	2	8	7	2	19
Labridae	2	91	34	1	128
cf. Labridae		1	1		2
Lethrinidae		26	10	1	37
cf. Lethrinidae	1	2	1		4
Lutjanidae	1	13	3		17
Mugilidae			1		1
Muraenidae		4	4		8
Pomacentridae	1	1			2
cf. Pomacentridae		2			2
Scaridae	14	201	76	7	298
Scombridae		1	1		2
Scorpaenidae		3			3
Serranidae	4	112	38	1	155
Subtotal	48	723	315	23	1109
Unidentified Osteichthyes	407	2360	2270	75	5112
Total	455	3083	2585	98	6221

sorted, with 1109 identified to 18 bony fish families (Morrison & Addison 2009) (Table 2). Following Morrison and Addison (2009), our analysis organises the assemblage by strata (Layers I–IV).

Sediment was water screened using 3.2 mm mesh (Morrison & Addison 2009: 181). A.E. Morrison

completed the identifications using the reference collections at the University of Hawai‘i–Mānoa and the Bernice P. Bishop Museum archaeological laboratories. The results were quantified by NISP and MNI, using the five paired cranial elements and special bones.

To‘aga, Ofu Island

To‘aga is a narrow sand coastal flat along the south coast of Ofu Island. Kirch and colleagues (Kirch & Hunt 1993) conducted extensive excavations across the flat over multiple field seasons. They established a geomorphological model for a prograding shoreline with successively older, and more deeply buried, deposits further inland from the modern high-tide line. Plainware sherds, lithic and shell artefacts, and midden were recovered. Of the 9524 total fish specimens, 862 bones identified to 19 bony fish families are considered here (Nagaoka 1993: 190–1, table 13.2) (Table 3).

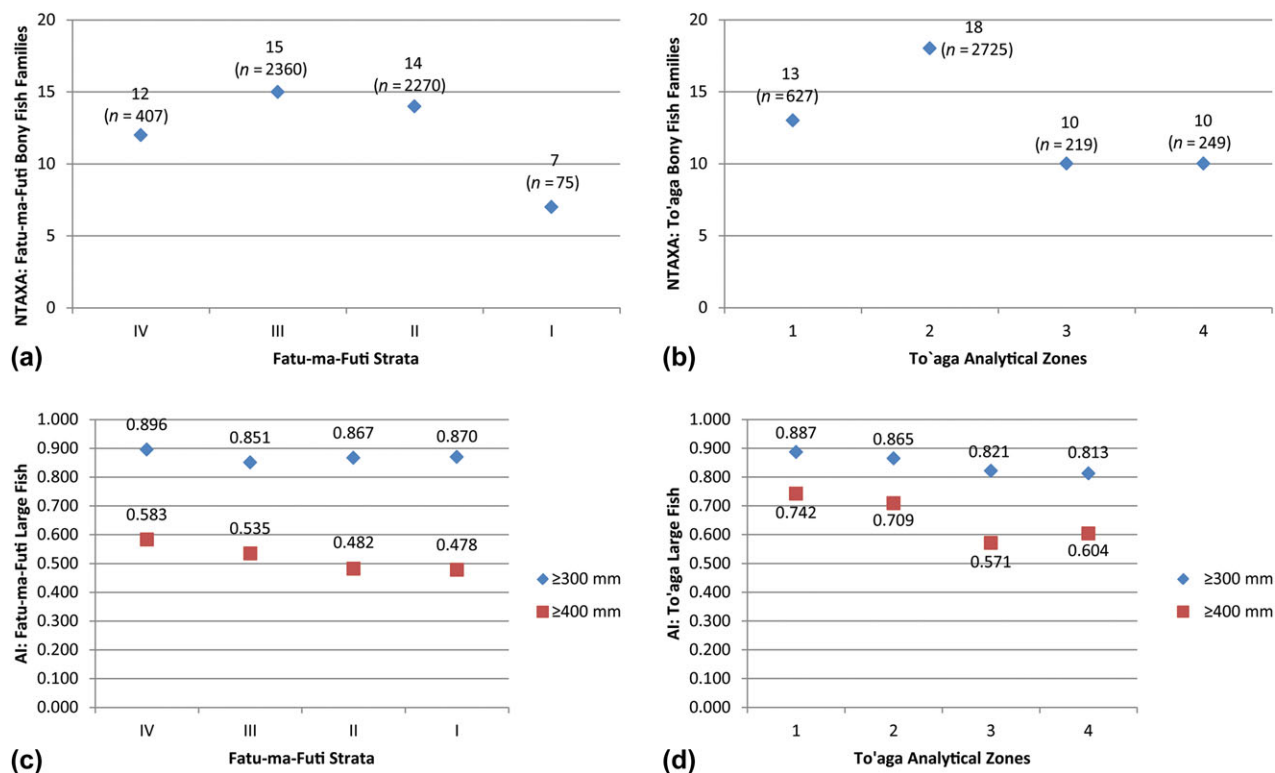
Most of the To‘aga material was collected by dry screening using 6.4 mm mesh, with some bulk samples sieved using –2, –1, and 0 ϕ mesh (Nagaoka 1993). Fish remains were identified by L. Nagaoka using the Bernice P. Bishop Museum reference collection and the collections of P.V. Kirch, M.S. Allen and L. Nagaoka. The results were quantified using NISP, with the five paired cranial bones and special bones used for identifications.

We considered Kirch and Hunt’s (1993: 56, 67–8, 77–8) geomorphological/depositional stages and created a Bayesian model to recalibrate the relevant radiocarbon dates to establish four analytical zones (To‘aga-AZs 1–4) that maximise sample sizes. Individual calibration models were created for the 1987, Transect 5 and Transect 9

Table 3. Bony fish (NISP) recovered from excavations at To‘aga (data from Nagaoka 1993).

Taxa	Analytical Zone 1	Analytical Zone 2	Analytical Zone 3	Analytical Zone 4	Total
Acanthuridae	12	65	3	9	89
Aulostomidae	3	12			15
Balistidae	2	19	4		25
Belonidae		1	1		2
Bothidae				1	1
Carangidae	6	25	2		33
Congridae	3	8			11
Diodontidae	108	206	4	9	327
Holocentridae	20	59	3	3	85
Kyphosidae		1		1	2
Labridae	2	21	2	6	31
Lethrinidae		7		2	9
Lutjanidae	1	17	2	3	23
Mullidae		1			1
Muraenidae	7	34			41
Ostraciidae	14	7			21
Scaridae	2	37	2	3	44
Scombridae		2			2
Serranidae	14	70	5	11	100
Subtotal	194	592	28	48	862
Unidentified Osteichthyes	496	2133	191	201	3021
Total	690	2725	219	249	3883
Accumulation rate (specimens per year)	0.6	2.7	0.4	0.09	–

Figure 3. NTAXA for bony fish families (and sample size) and AI values for large inshore fish using 300 mm and 400 mm cut-off lengths at Fatu-ma-Futi (a, c) and To'aga (b, d).



excavations (see the Online Supporting Information). Strata from these excavation areas that produced fish collections and that had comparable date estimates were aggregated as follows: To'aga-AZ 1 (1987 Layer IIC; Transect 9 Layer IV; cultural deposition postdates ~ 3700 – 2700 calBP and predates ~ 3000 – 2200 calBP (age estimates are 2-sigma and rounded to the nearest 50 years)); To'aga-AZ 2 (1987 Layers IIB and IIA; Transect 9 Layers IIIB and IIIA; deposition began ~ 3250 – 2200 calBP and ceased sometime before ~ 2700 – 2000 calBP); To'aga-AZ 3 (1987 Layer IIA-1; deposition began sometime around ~ 2450 – 2050 calBP and ceased by ~ 2400 – 1550 calBP); To'aga-AZ 4 (Transect 5 Layer II; deposition began ~ 3100 – 1550 calBP and ceased by ~ 1750 – 300 calBP). Analytical zone start and end dates are maximum estimates that encompass the individual date ranges for contributing strata. The range for To'aga-AZ 4 is particularly broad because it is based on a single determination that is not constrained by other ages or stratigraphic information.

Duration estimates for the To'aga analytical zones are considerably less precise than for Tula due to the larger error ranges for the radiocarbon ages and the horizontal distribution of dates. To'aga-AZ 1 spans up to 1250 years (95.4%); To'aga-AZ 2 spans up to 1012 years (95.4%); To'aga-AZ 3 spans up to 620 years (95.4%); and To'aga-AZ 4 spans up to 2650 years (95.4%). In consequence, accumulation rates are substantially lower than Tula, ranging from 0.09 to 2.7 specimens per year.

Variation in prey choice and foraging efficiency within the archipelago

We calculated NTAXA, rank order and AI values for Fatu-ma-Futi and To'aga following the methods described above. As with Tula, NTAXA as a measure of diet breadth is correlated with sample size for both sites (Fatu-ma-Futi Spearman's rank correlation coefficient; $r_s = 1$, $p = 0.000$; To'aga Spearman's rank correlation coefficient; $r_s = 0.95$, $p = 0.05$) (Figures 3a and 3b) and the results therefore must be interpreted cautiously. Taxonomic diversity and the relative importance/rank order of particular fish at To'aga is the most variable. Unlike the Tutuila collections, Serranidae is a dominant prey throughout the sequence. In contrast, Fatu-ma-Futi, like Tula, documents the predominance of Acanthuridae and Scaridae (first- or second-rank taxa). Although diet breadth constricts through time for all collections, the prevalence of dominant taxa remains relatively stable.

Foraging efficiency at Fatu-ma-Futi is high and stable if large fish are categorised as ≥ 300 mm (Figure 3c). When body length is increased to ≥ 400 mm, the proportion of large fish decreases significantly and there is a slight decline in efficiency. To'aga reveals comparably high AI values and a negligible decrease using the ≥ 300 mm length cut-off (Figure 3d). With the greater body length (≥ 400 mm) cut-off, AI values decrease and a more pronounced decline in foraging efficiency is evident. None of these trends are correlated with sample size (Fatu-ma-Futi ≥ 300 mm, Spearman's rank correlation coefficient; $r_s = -0.8$, $p = 0.2$;

Fatu-ma-Futi ≥ 400 mm, Spearman's rank correlation coefficient; $r_s = 0.4$, $p = 0.6$; To'aga ≥ 300 mm, Spearman's rank correlation coefficient; $r_s = 0.6$, $p = 0.4$; To'aga ≥ 400 mm, Spearman's rank correlation coefficient; $r_s = 0.8$, $p = 0.2$).

CONCLUSION

As an exploratory analysis of marine foraging at Tula and two other sites within the Sāmoan archipelago, a few substantive observations can be made. First, diet breadth constricts through time at Tula, Fatu-ma-Futi and To'aga, although this pattern appears to be related to decreasing sample sizes. While this pattern should be interpreted cautiously, these results are not consistent with the expectation of widening diet breadth associated with resource depression. Second, geographical variation in dominant taxa is suggested by the prevalence of Serranidae at To'aga (Ofu Island) compared to Scaridae and Acanthuridae at Tula and Fatu-ma-Futi (Tutuila Island). Although a comparison of the natural abundance of fish species associated with these reef ecosystems has not been made, it seems likely that ecological factors may explain these patterns. Third, when defining large fish as ≥ 300 mm in mean body length, the three collections produce relatively high AI values, but only Tula shows an appreciable decline in foraging efficiency. Categorising large fish as ≥ 400 mm results in decreased AI values for all collections and trends for moderate (Fatu-ma-Futi and To'aga) to significant (Tula) declines in the contribution of large fish. Overall, none of the sites satisfy all expectations for resource depression; however, Tula does reveal the most significant change, which warrants further research. These results suggest a degree of localised variability in marine exploitation at Tula that contrasts with measures of stability for Fatu-ma-Futi and To'aga (following Nagaoka 1993; Morrison & Addison 2009).

Lastly, our analysis has raised certain analytical and methodological issues. Creating ordinal or interval body size categories requires explicit justification, and the use of modern body length estimates—as we have done—is potentially susceptible to shifting baseline effects (Paulay 1995). However, by using maximum modern lengths we may moderate this effect (i.e. maximum lengths may better approximate past fish populations prior to the advent of commercial fishing), though this requires testing. We are in agreement with other researchers that direct measurements of elements is preferable (see Lambrides & Weisler 2016 for a regional synthesis; see also Giovas *et al.* 2016 for a recent case study). However, in our case and similar studies that rely on re-analyses of previously published data, it may not be possible to directly measure elements. An additionally important point concerns the use of the cranial elements and special bones as opposed to an expanded set of cranial elements and vertebrae. We acknowledge that new identification protocols have been established since the original identifications were conducted; however, an

assessment of the influence of these different protocols on the Tula assemblage will require additional fieldwork and analyses. Finally, ethnographic studies aimed at examining cultural variation in species preference, habitat use, and fish capture sizes may aid in the production of meaningful analytical size classifications and help to provide a stronger basis for future studies of archaeologically derived foraging patterns.

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NOTES

1. These results differ somewhat from the chronology presented in Cochrane *et al.* (2013), which relied on the BCal calibration software. The BCal and Oxcal model structures are generally comparable, so differences relate to the underlying software programming.
2. Beta-308714 was identified as an outlier in a first iteration of the model and was subsequently removed.

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this paper at the publisher's website:

Tula Bayesian Calibration Model Code
 To'aga 1987 Excavations Bayesian Calibration Model Code
 To'aga Transect 5 Bayesian Calibration Model Code
 To'aga Transect 5 Bayesian Calibration Model Code
 Table correlating Kirch's (1993) depositional stages, ¹⁴C dates, the To'aga Analytical Zones created for this analysis, and the date estimates.