Differential recovery of Pacific Island fish remains

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Abstract

The effects of differential recovery have been documented and discussed for almost a century. Screening experiments using comparative collections are one avenue for understanding recovery bias because they develop expectations about what is likely to be recovered. In this study, modern reference specimens of Pacific Island fish were screened through 1/4 inch (6.4 mm) and 1/8 inch (3.2 mm) mesh. Recovery rates are examined across taxa, body size, and element type. The experimental recovery rates are then compared to those from an archaeological fish assemblage from the Moturakau rockshelter, Aitutaki, Cook Islands, to examine how well the data derived from screening experiments are able to predict archaeological recovery patterns. The experimental data is able to accurately predict the taxa recovered in the Moturakau sample. The impact of differential recovery on a variety of interpretations utilizing archaeological fish remains is then discussed.
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Keywords: Recovery bias; Pacific Islands; Fish remains; Representative samples

1. Introduction

Studies on the effects of differential recovery have a long history in archaeological research and zooarchaeological analysis in particular [6,15,20,36,37,44]. The size of the mesh used to sieve archaeological matrices affects the nature of the material recovered. Specifically, sieves sample the archaeological record according to size, thus the size of the mesh used can affect the representativeness of the sample that is created [15,37,44]. Typically, there have been two means to examine the effects of recovery bias. Screening experiments on modern comparative collections have been used to develop expectations about which taxa are more likely to be recovered from a particular mesh size [40,42,44]. In general, these studies have shown that large sized mesh differentially recovers larger taxa so that smaller taxa may be underrepresented in sieved

samples. A more common approach to understanding recovery bias is to compare the recovery rates for particular archaeological samples that have been recovered using different sized mesh (e.g., 1/4 inch versus 1/8 inch mesh) [11,19,22,33,45,48] or by different recovery methods (e.g., hand collection, sieving or flotation) [7,16,24,36,38]. Like screening experiments, these types of studies evaluate the effects of differential recovery on taxonomic abundance and richness. In addition, they have also been used to understand the effects of recovery bias on skeletal element representation [11]. Such archaeological studies provide valuable insights into how recovery bias affects the representativeness of samples, however, the specific findings of these analyses are best applied to the assemblage at hand [14,33].

Each of these analyses provides different kinds of information about recovery bias. Screening experiments inform on what might be recovered or lost when using a particular recovery technique, while the archaeological studies provide the actual or observed recovery rates for a particular excavation. However, research has yet to

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examine how well the experimental screening data (expected) compare to the archaeological findings (observed). In this study, modern reference specimens of Pacific Island fish are screened through nested 1/4 inch (6.4 mm) and 1/8 inch (3.2 mm) mesh. Differential recovery rates across body size, taxa, and skeletal elements are examined. These experimental recovery patterns are then compared to those from an archaeological fish assemblage from the Moturakau rockshelter, Aitutaki, Cook Islands, to evaluate how well the experimental data predict the archaeological recovery of fish remains.

2. Differential recovery of modern fish reference specimens

Modern fish reference specimens from the osteological collections housed in the Department of Anthropology, University of Hawaii, and the Department of Anthropology, University of Auckland, were used in the screening experiment. Since identification of Pacific Island fish is typically only to family, this analysis examines the effects of screen size bias at the family level. From the two reference collections, 308 disarticulated specimens representing 23 families were initially analyzed. However, for some of the families, there were very few specimens. Thus, to capture intra-family variability and create reasonable samples across families and body size classes, I used only the 11 families that had at least 10 individuals per family, for a sample of 250 individual specimens. Table 1 lists the fish families, the diversity of taxa within each family, and the weight range of the specimens used in this analysis. The sample represents families commonly recovered from archaeological contexts in the Pacific.

The elements used in this analysis were limited to the five mouth parts (premaxilla, dentary, maxilla, articular, quadrate) typically used in Pacific Island fish analysis. For each specimen, the paired elements of the mouth

Table 1
The number, taxonomic diversity, and weight range of specimens used in the screening experiment by family

Family	N	No. of genera	No. of species	Weight range (g)
Acanthuridae	30	4	12	92–1406
Balistidae	18	8	10	36–2124
Carangidae	27	6	9	62–3000
Holocentridae	24	3	8	15–400
Labridae	16	6	9	30–1411
Lethrinidae	12	3	7	100–4000
Lutjanidae	32	5	11	23–4000
Mullidae	34	3	13	24–782
Pomacentridae	12	2	5	31–283
Scaridae	17	4	8	94–2345
Serranidae	29	3	10	74–1411

were screened ten times through nested 1/4 inch (6.4 mm) and 1/8 inch (3.2 mm) mesh for 10 s. The frequency with which the elements were retained in each screen, as well as those lost through the 1/8 inch mesh (<1/8 inch sample), was recorded. The percentage of each element recovered in the 1/4 inch, 1/8 inch, and <1/8 inch samples was then calculated. The 1/4 inch sample is analyzed for variability in recovery across taxa, body size, and skeletal elements.

2.1. Recovery bias across taxa and body size

The screening experiment demonstrates that the average 1/4 inch recovery rates vary across taxa. The 'total specimens' column in Table 2 represents the average 1/4 inch recovery for all elements for each family. Of the 11 families, Acanthuridae, Balistidae, Mullidae, and Pomacentridae have average recovery rates for the 1/4 inch sample that are lower than 50%, indicating that their remains were retrieved in the larger mesh less than half the time. Two families, Lethrinidae and Serranidae, have average recovery rates over 75%, while the remaining five families fall between 50% and 75% average recovery. Thus, across all elements and body sizes, acanths, balistids, mullids, and pomacentrids are more likely to be affected by differential recovery than other taxa (e.g., lethrinids and serranids).

Previous screening experiments on mammalian reference specimens have shown that recovery rates using sieves with different mesh size vary across taxa depending on the body size of the animal [41,42,44]. Typically, these experiments have used weight as a measure of body size for mammals. When the fish specimens used in this analysis were collected, body size was measured several ways: weight, total length (snout to tail tip), and standard length (snout to base of tail). All three measures correlate significantly with one another: weight to total length ($r = 0.866$, $p < 0.001$), weight to standard length ($r = 0.848$, $p < 0.001$), total length to standard length ($r = 0.975$, $p < 0.001$). Thus, each measure contains similar information on body size. Weight was chosen as the measure of body size for this analysis because it was the one measure consistently recorded across specimens.

To determine if differential recovery is related to body size, the 1/4 inch mesh recovery rates for specimens were averaged for six weight classes within each family (Table 2). The two largest weight classes span a greater range than the smaller ones because the sample of specimens larger than 400 g was small. The division was arbitrary, however it creates classes that in effect reflect exponential increases in weight ranges. The average at the bottom of Table 2 lists the average recovery of specimens in each weight class across families. These data demonstrate that the larger the fish specimen is, the

Table 2
The average 1/4 inch recovery of individual specimens in the screening experiment sample by family weight and class

Family	Weight (g)						Total Specimens
	<100	100–199	200–299	300–399	400–999	1000+	
Acanthuridae	0.0	8.7	16.6	32.1	34.0	67.0	18.6
Balistidae	0.0	17.3	24.9	60.0	75.0	92.5	45.0
Carangidae	21.5	42.0	61.0	91.0	94.3	100.0	70.9
Holocentridae	26.5	56.2	82.0		100.0		51.3
Labridae	11.6	67.6	83.0		100.0	100.0	57.3
Lethrinidae		47.5	99.0		100.0	100.0	90.8
Lutjanidae	29.3	63.7	84.0	96.0	97.1	100.0	68.2
Mullidae	18.8	50.3	63.8	67.0	85.7		45.0
Pomacentridae	0.8	4.4	30.5				7.1
Scaridae	38.0	54.3	57.6		82.3	99.0	71.4
Serranidae	30.3	69.4	85.5	100.0	100.0	100.0	75.7
Average	19.6	43.8	62.6	74.4	85.4	91.7	

greater the likelihood that its mouth elements will be recovered in the 1/4 inch mesh.

This trend of increasing recovery across body size also holds for specimens within each family (Table 2). To examine intra-family variability, the recovery rates for each weight class were plotted for all 11 families (Fig. 1a–d). Since the weight categories are discontinuous, histograms would be the appropriate graphical representation. However, to better compare differences in recovery between families, line graphs were used. For a visual reference, a line is drawn at the 50% mark to delineate where elements had an equal chance of being recovered or lost through the 1/4 inch mesh. Data points that fall above the line indicate that those elements were more likely to be recovered than lost in the 1/4 inch mesh; those below were less likely to be recovered.

The fish families were categorized into four different groups (A–D) based on the shape of the recovery rate curve. For Group A, Lethrinidae (emperors) and Carangidae (jacks), the overall recovery rate of mouth elements is high (Fig. 1a). Of the 11 taxa analyzed, these two families have the highest 1/4 inch recovery rates (Table 2). The increase in recovery across weight classes is steep. Recovery of lethrinids specimens over 200 g and carangids specimens over 300 g is nearly 100%.

The recovery rates for Group B (Lutjanidae (snapper), Serranidae (sea bass), Holocentridae (squirrelfish), and Labridae (wrass)) are similar to lethrinids and carangids (Fig. 1b). Recovery is relatively high with an average of over 50% recovery for individuals larger than 100 g. The difference between Fig. 1a and b is the shape of the curves. Recovery rates for the four families
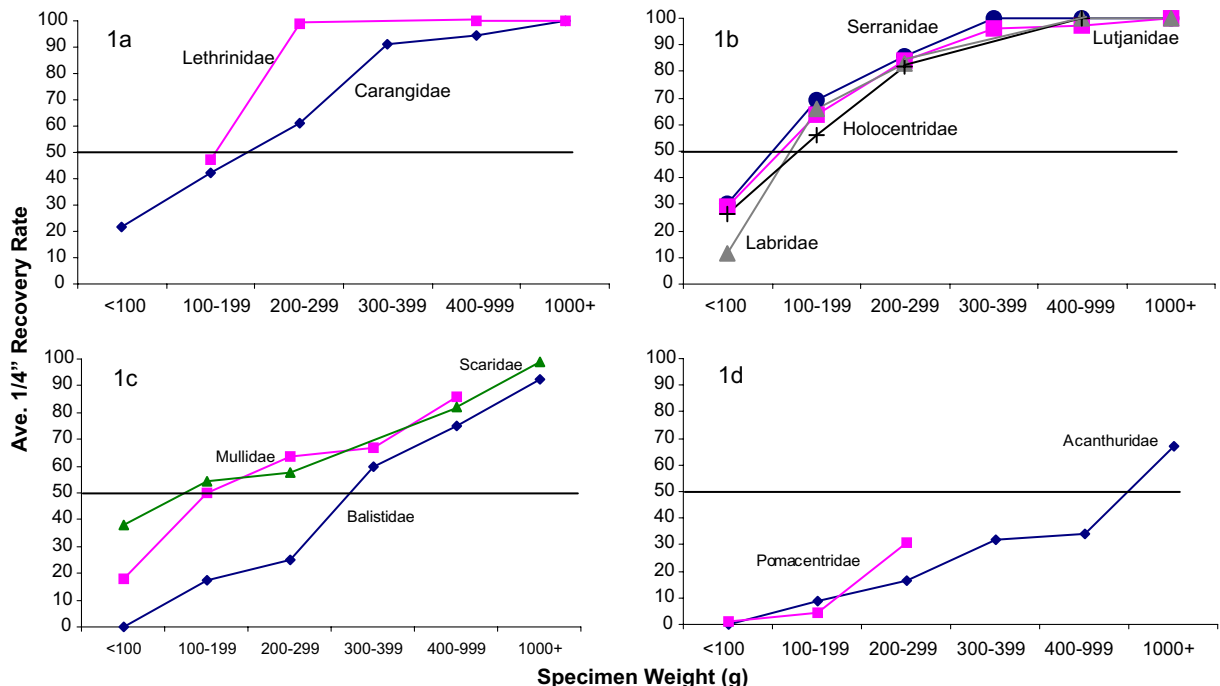

Fig. 1. The average 1/4 inch recovery rates for screening experiment data for each family across different weight classes.

represented in Fig. 1b, while steep, show a more gradual curvilinear pattern than seen in the lethrinid and carangid recovery rates, which plateau sharply. For lethrinids and carangids, increases in the recovery rate for specimens larger than 200 g and 300 g, respectively, are minimal. For the fish families in Fig. 1b, the increase in percent recovery across weight classes is greater for smaller specimens than for larger ones.

For Group C, Fig. 1c shows the recovery rates for the families Mullidae (goatfish), Scaridae (parrotfish), and Balistidae (triggerfish). Recovery curves for these families are more variable than in the previous two graphs. These curves have a lower slope indicating that recovery rates for these families are generally lower than the previous two groups. In addition, the curves are more linear across weight classes. Thus, rather than showing diminishing returns as body size increases, recovery for these families increase at a relatively constant rate across weight.

Of the 11 families examined, Acanthuridae (surgeonfish) and Pomacentridae (damselfish) in Group D have the lowest recovery rates (Fig. 1d). For pomacentrids, only 30% of the elements from the largest individuals were recovered. This family is small-bodied, and the sample of specimens is representative of the size range. Acanthurids, on the other hand, have greater size range than pomacentrids, yet their 1/4 inch recovery rate for large individuals is relatively poor.

The variable recovery rates for each group illustrate how 1/4 inch mesh can differentially recover taxa across body size and taxa. For families in Groups A and B, the increase in recovery across weight hits a point of diminishing returns, which can be gradual or quite steep. Thus, large sized mesh will likely recover a large proportion and a wider size range of these families. For Group C, the recovery rate appears to be relatively constant across weight. For these families, mesh size will have a greater effect on recovery rate and on the size range of individuals recovered. Finally, recovery of acanthurids and pomacentrids in Group D is markedly lower than for other families when large mesh is used.

The difference in recovery rates across taxa is partially due to the feeding strategies of each family. For example, carangids, lethrinids, serranids, lutjanids are carnivorous and typically feed on fast moving prey [12]. Their mouths and mouth parts tend to be large and robust enough to capture their prey. On the other hand, most herbivores, such as acanthurids and pomacentrids, have relatively small, delicate mouths that are used to feed on algae or reef detritus. These taxa had the highest recovery rate of families from the <1/8 inch sample (Table 3). Thus, a significant proportion of elements from these two families can be expected to be lost even when using smaller mesh. While poor recovery of these two taxa is due to their corresponding small mouth elements, they are also less likely to be found in

Table 3
The average recovery rate for the screening experiment by mesh size for each family

Family	Premaxilla			Dentary			Maxilla			Articular			Quadrate			Average		
	1/4 inch	1/8 inch	<1/8 inch	1/4 inch	1/8 inch	<1/8 inch	1/4 inch	1/8 inch	<1/8 inch	1/4 inch	1/8 inch	<1/8 inch	1/4 inch	1/8 inch	<1/8 inch	1/4 inch	1/8 inch	<1/8 inch
Acanthuridae	9.5	67.5	8.8	17.1	65.5	0.7	5.0	48.6	42.2	5.4	4.0	54.2	55.3	35.0	0.2	18.6	61.6	19.7
Balistidae	55.0	21.7	0.0	60.3	16.4	5.6	24.9	38.2	32.6	19.4	46.4	17.5	63.3	12.8	0.0	45.0	44.0	10.9
Carangidae	51.3	36.5	2.8	95.6	22.2	0.0	58.7	49.1	0.0	73.9	16.5	0.4	74.8	20.4	0.0	70.9	28.5	0.7
Holocentridae	11.0	40.8	18.1	80.6	42.7	0.4	64.8	51.9	8.3	49.4	10.6	1.7	50.8	42.1	4.6	51.3	42.0	6.7
Labridae	72.8	40.0	5.6	58.4	48.5	0.0	46.0	62.8	3.8	45.0	37.9	8.2	60.9	43.2	0.0	57.3	38.1	4.1
Lethrinidae	91.7	8.3	0.4	92.5	9.2	0.0	84.6	15.4	0.0	92.1	8.8	0.0	93.3	10.0	0.0	90.8	9.1	0.1
Lutjanidae	43.9	39.7	3.9	80.8	26.9	0.0	57.9	55.0	3.2	74.7	22.7	0.0	83.9	23.5	0.0	68.2	30.4	1.4
Mullidae	10.3	64.3	8.7	59.9	32.8	0.0	20.3	78.4	5.1	60.9	22.9	2.1	71.3	29.2	0.0	45.0	50.7	4.3
Pomacentridae	7.1	52.9	33.8	5.8	50.4	24.6	0.5	46.4	17.7	11.3	50.4	25.8	10.5	49.5	5.5	7.1	71.2	21.7
Scaridae	98.2	35.9	0.0	77.6	34.1	0.0	49.7	34.4	2.6	34.7	43.5	6.8	96.8	32.1	0.0	71.4	26.7	1.9
Serranidae	53.8	23.8	0.0	87.9	39.7	0.0	85.3	57.4	0.0	67.4	19.1	0.0	78.3	35.2	0.0	75.7	24.3	0.0
Average	41.1	51.8	7.1	67.2	31.3	1.7	35.0	53.1	12.1	62.1	29.7	8.4	69.6	30.1	0.4	55.0	39.2	5.9

archaeological assemblages because of differential preservation. Both taxa have mouth elements that are very thin and delicate, thus these elements are less likely to survive than those of other taxa. Also, in the case of pomacentrids, the overall small body size of individuals within the family also reduces the probability of recovery.

2.2. Recovery bias across skeletal elements

As previous studies have shown, recovery rates also vary across skeletal elements [11,36,40,42]. The variability in recovery across elements is likely due to their size and shape. Some shapes are more likely to be retained in screens than others. To describe skeletal element shape, zooarchaeologists have used the methodology developed within sedimentology to describe particle shape [17]. Shape is classified based on the length, width, and thickness of the object. Objects with equal thickness, width, and length are spherical or cubic. Disc-shaped objects tend to have relatively equal length and width, but are relatively thin. Blades tend to be about twice as long as they are wide and twice as wide as they are thick. Rods are long with relatively small thickness and width. The shapes that are most likely to be retained in sieves are those where at least two dimensions (e.g., length and width) are larger than the mesh size. Thus, when length is held constant and is larger than the given mesh, spherical or cubic shaped objects are likely to be recovered since all three dimensions are relatively equal and are greater than the mesh size. Discoidal shapes for which length and width are relatively equal will also be retained. Shapes for which only length is larger than the mesh size, such as rod- or blade-shaped objects, are least likely to be recovered.

Although some families have specialized and modified mouth parts, for most families, the shape of each mouth element tends to be standardized. The dentary, articular, and quadrate typically are triangular. They can be classified as discoidal in shape because length and width are somewhat comparable but thickness is relatively small. Maxillae tend to be rod-shaped, that is narrow and thin relative to length. Thus, given their shapes, dentaries, articulars, and quadrates should be retained more often than maxillae. Premaxillae are more complex because they tend to be L-shaped. They can be classified as discoidal since overall length and width are relatively equal, and as a result should be retained during sieving. Premaxillae can also be classified as a combination of two rod shapes. Thus, they may not be retained if the thin and narrow end of the element gets caught in the mesh and falls through. Given their complex shape, premaxillae may be as or more likely to be retained than maxillae in 1/4 inch mesh, but less likely to be recovered than the lower jaw elements.

Figs. 2a—e illustrate the average experimental recovery rate from the 1/4 inch mesh for each element by family, and are based on the data in Table 3. The horizontal line again marks the 50% recovery rate. The mean value represents the average recovery for that element across all families. In general, the lower jaw elements (dentary, articular, quadrate) tend to have higher average recovery rates than the upper jaw elements (premaxilla, maxilla), as was predicted based on the shapes of these elements. Premaxillae (Fig. 2a) have a higher recovery rate than maxillae, thus the shape that may best describe premaxillae in terms of potential recovery is discoidal rather than rod-shaped. The variability in recovery for each element is likely due to morphological variability across families. For example, balistids and scarids have articulars that have been highly reduced to mainly the surface that articulates with the quadrate. Thus, they are often small and their recovery rate is low relative to other families (Fig. 2d). Quadrates, on the other hand, are typically the mouth element that shows the least amount of modification or specialization across families. This element has a relatively high recovery rate, achieving at least 50% recovery across all families except for pomacentrids (Fig. 2e). Pomacentrid quadrates are recovered less frequently because most individuals are smaller than 300 g, and their quadrates are quite small.

In sum, the screening experiment shows that recovery of Pacific Island fish remains can be affected by individual body size, the general body size of individual families, as well as the shape of particular skeletal elements. Fish with comparatively robust mouth elements, particularly those with carnivorous feeding strategies, are more likely to be retained in 1/4 inch mesh than members of herbivorous taxa. In addition, the upper jaw elements are less likely to be recovered in 1/4 inch mesh than lower jaw elements because of their shape.

2.3. Screening experiment limitations

While the screening experiments have pointed out several expected biases, it is important to note that these findings show the ideal expected recovery rate. There are several limitations of such datasets that must be considered when using experimental results to derive archaeological expectations. For example, in the experiments the material is screened for a relatively short time and without the benefit or hindrance of matrix. Thus, methodologically, they do not accurately mimic field conditions that may affect recovery of elements. In addition, the experimental data are based on reference specimens at hand, which ranged from 12 to 34 individuals per family. Although the sample used in this analysis covers a wide range of sizes and species, it
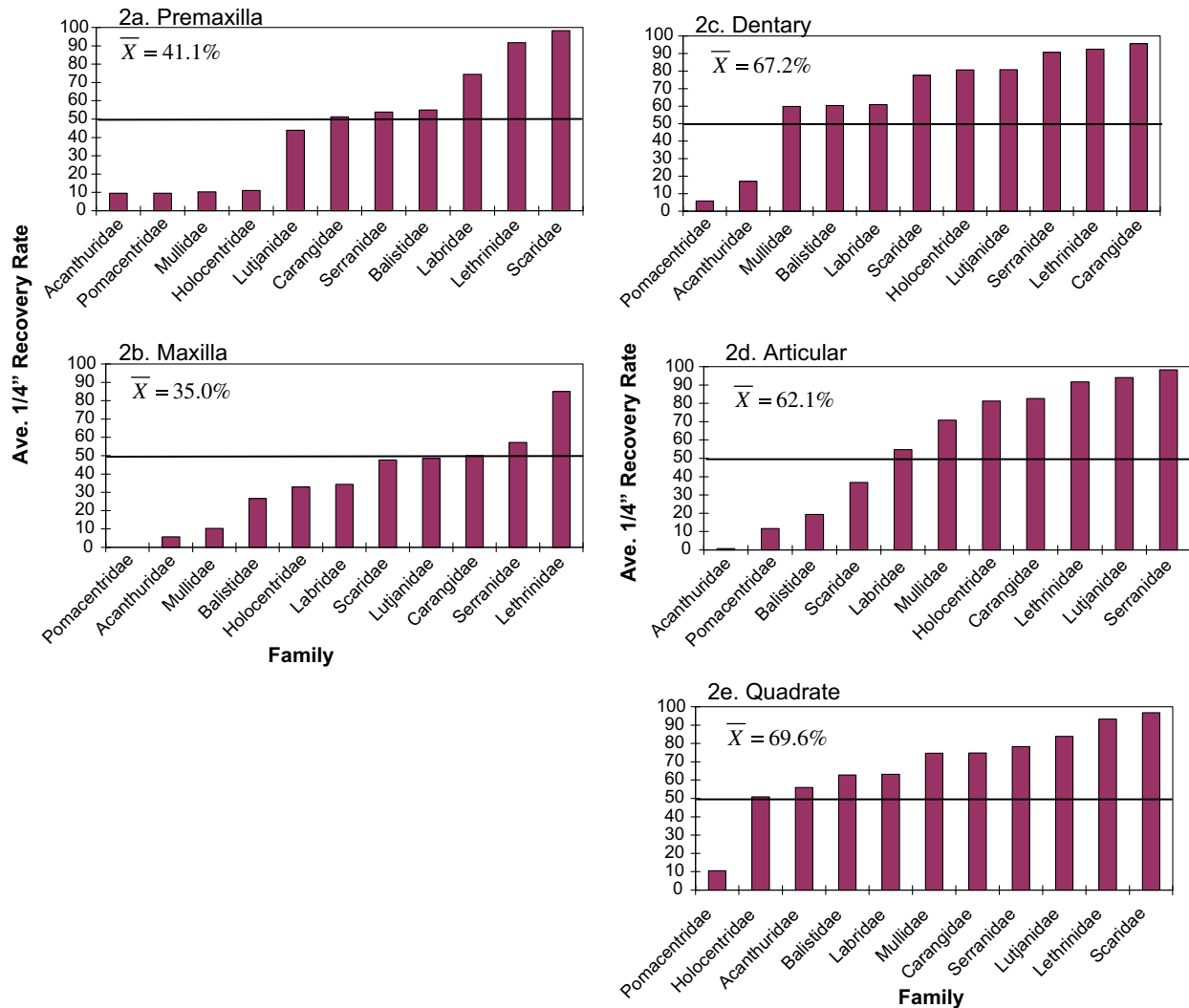
Fig. 2. The average 1/4 inch recovery rates for screening experiment data for each skeletal element by family.

may not be representative of intra-family variability in body and element size.

Another limiting factor of these experimental data is that special bones were not used in the analysis. In the analysis of Pacific Island fish remains, special bones are skeletal elements, such as spines, scales, and vertebrae that are generally not diagnostic for all taxa [25]. Such bones are often modified or specialized, and can be large, dense, and distinctively shaped. Thus, for some families, special bones might be better preserved, recovered, and identified than mouth elements. Indeed, some researchers have determined that special bones can greatly increase the number of identified specimens over mouth elements. For example, in French Polynesia, the ultimate vertebra of tuna is a large, robust and distinctive special bone, the identification of which greatly increases the relative abundance of that taxon in archaeological assemblages [18,28]. Thus, some of the taxa that were not experimentally recovered in the 1/4 inch mesh using mouth elements might be better

represented in samples when special bones are recovered and identified.

The most important difference between the experimental data and those derived from archaeological contexts is the degree of fragmentation. In screening experiments, whole skeletal elements are used. However, archaeological specimens are often fragmented. Fragmentation can greatly affect recovery such that the dimensions of identifiable portions of elements are significant factors in addition to the size of elements [12,14,41,45]. In general, fragmentation reduces the expected recovery rate, thus screening experiment data should be viewed as estimates of maximum recovery rate for each taxon or element. Given these limitations of the experimental dataset, the data should be treated as ordinal level data [20,30]. They are useful for determining that certain taxa are more or less likely to be recovered, but not the degree to which they will be recovered. The latter is a function of a faunal assemblage's taphonomic history, as well as recovery.

3. Comparing the experimental to the archaeological

Screening experiments have been used to illustrate which taxa or elements are more likely to be recovered in various mesh sizes. However, the accuracy of these predictions for archaeological contexts has not been tested. To test if the experimental data can accurately predict recovery of archaeological fish remains, recovery rates from this screening experiment are compared to the actual recovery of archaeological fish remains from the Moturakau site in Aitutaki, Cook Islands. The Moturakau fish assemblage constitutes one of the largest samples excavated in the Pacific Islands with over 11,000 identified specimens. The archaeological matrix from the site was sieved using nested 1/4 inch and 1/8 inch mesh screens [1,2,4]. In earlier research I compared the recovery rates of the Moturakau fish samples recovered from the two mesh sizes [33]. The rank order abundance of fish taxa, the number of taxa represented, and the kinds of taxa represented differed significantly between the 1/4 inch and 1/8 inch samples. In addition, this research demonstrated that obtaining large 1/4 inch faunal samples does not negate the effects of recovery bias since the likelihood of recovery is based on size rather than relative abundance of material in the deposit.

Since recovery bias is known to have affected the 1/4 inch sample from the Moturakau fish assemblage, it is an ideal sample to test whether or not experimental data can accurately predict archaeological recovery patterns. Recovery rates for the Moturakau assemblage were calculated by taking the percentage of remains recovered in the 1/4 inch mesh relative to the total sample collected through both 1/4 inch and 1/8 inch sieves (Table 4). The method of calculating archaeological recovery rates differs slightly from those derived through the screening experiments. Experimental recovery rates are based on a known number of skeletal elements in the total sample. Thus, a complete recovery rate of 100% is calculated by adding up the data from the 1/4 inch, 1/8 inch, and <1/8 inch samples. For archaeological data, however, recovering all elements from a site is not possible, therefore, the total sample for the Moturakau archaeological dataset is comprised of just the remains that have been recovered in the 1/4 inch and 1/8 inch mesh. Thus, it may be that calculating the experimental data using the same methodology as was used for the archaeological data is more appropriate.

To test whether the method of calculating 1/4 inch recovery rates significantly affects the experimental data, the datasets derived using the two calculation methods were compared to one another. The two methods produced data that are statistically identical to one another ($r = 1.00$, $p < 0.001$). The average recovery was different for only six data points (one element each for six families). The largest difference was an increase of

Table 4
The number of identified specimens recovered in the 1/4 inch and 1/8 inch mesh for the Moturakau assemblage

Family	Element	1/4 inch	1/8 inch	Total
Acanthuridae	Premaxilla	5	11	16
	Maxilla	1	21	22
	Dentary	8	17	25
	Articular	1	0	1
	Quadrate	6	23	29
Balistidae	Premaxilla	13	16	29
	Maxilla	2	14	16
	Dentary	10	7	17
	Articular	1	10	11
	Quadrate	9	31	40
Carangidae	Premaxilla	23	11	34
	Maxilla	26	13	39
	Dentary	20	2	22
	Articular	23	6	29
	Quadrate	56	13	69
Holocentridae	Premaxilla	23	33	56
	Maxilla	6	16	22
	Dentary	22	18	40
	Articular	27	15	42
	Quadrate	11	6	17
Labridae	Premaxilla	53	79	132
	Maxilla	26	16	42
	Dentary	39	41	80
	Articular	40	21	61
	Quadrate	40	38	78
Lethrinidae	Premaxilla	17	5	22
	Maxilla	2	0	2
	Dentary	20	3	23
	Articular	9	2	11
	Quadrate	6	1	7
Lutjanidae	Premaxilla	41	62	103
	Maxilla	32	34	66
	Dentary	31	42	73
	Articular	43	21	64
	Quadrate	57	29	86
Mullidae	Premaxilla	24	36	60
	Maxilla	31	27	58
	Dentary	17	36	53
	Articular	41	22	63
	Quadrate	63	58	121
Pomacentridae	Premaxilla	5	5	10
	Maxilla	0	8	8
	Dentary	1	6	7
	Articular	0	2	2
	Quadrate	0	1	1
Scaridae	Premaxilla	152	48	200
	Maxilla	136	21	157
	Dentary	149	29	178
	Articular	78	75	153
	Quadrate	103	44	147
Serranidae	Premaxilla	209	251	460
	Maxilla	178	219	397
	Dentary	225	248	473
	Articular	257	125	382
	Quadrate	441	184	625

2% for pomacentrid premaxillae, while the other five were changes of less than 1%. The reason for the similarity is that the elements of a specimen were either recovered in the 1/4 inch and 1/8 inch mesh and not in

the $<1/8$ inch sample, or they were recovered in the 1/8 inch and $<1/8$ inch samples, but not in the 1/4 inch. The elements of very few reference specimens were recovered in all three samples. So when the $<1/8$ inch sample was removed from the calculations, the 1/4 inch recovery rate did not significantly change. Thus, in this case, the calculation method does not affect the outcome of this analysis. Previous screening experiments typically calculate 1/4 inch rates as a percentage of the total known number of elements recovered. Since the goal of this research is to test the utility of screening experiment data in general, then the data used here are derived using this standard methodology.

To examine the relationship between the experimental and archaeological samples, Spearman's rank order correlation (r_s) was performed between the 1/4 inch recovery rates for the screening experiment and the Moturakau sample (Fig. 3). The data are limited to the 11 families and five mouth elements used in the screening experiment. The data are graphed in scatterplots, where each data point represents the average 1/4 inch recovery rate for a mouth element of a particular family in the screening experiment and in the Moturakau assemblage. For example, the average 1/4 inch recovery rate for serranid premaxillae used in the screening experiment sample is compared to the percentage of serranid premaxillae recovered in the 1/4 inch sample of the Moturakau assemblage. The relationship between the experimental and archaeological datasets is statistically significant ($r_s = 0.63$, $p < 0.001$), indicating that the archaeological recovery rate can be predicted from the screening experiment data at the ordinal level.

The screening experiment demonstrated that some fish families are more susceptible to recovery bias than others. To determine if the screening experiment can be used to predict which fish families are more likely to be recovered, the experimental and the Moturakau recovery rates for each family were compared. As Fig. 4 shows, the relationship between the two datasets is
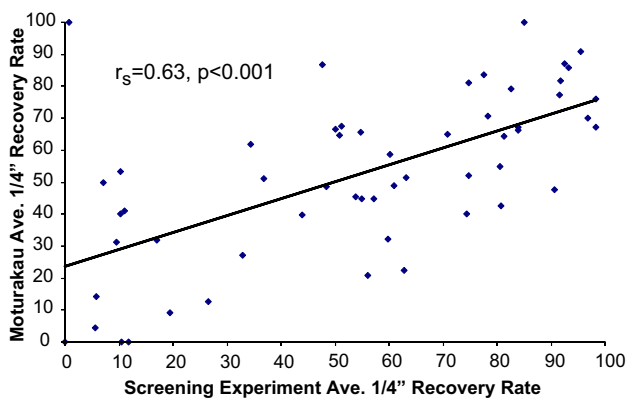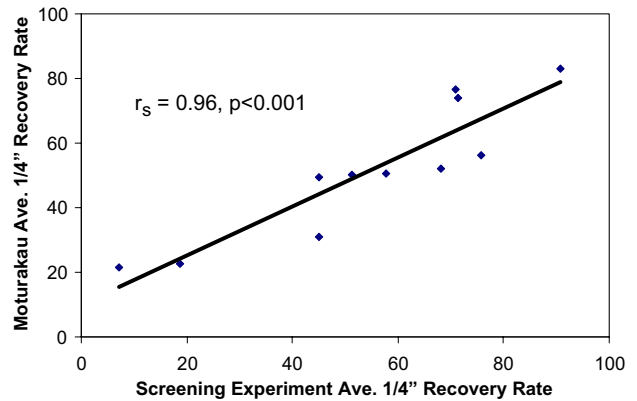

Fig. 4. The relationship between the average 1/4 inch experimental data and the Moturakau archaeological data by family.

statistically significant ($r_s = 0.96$, $p < 0.001$). The screening experiment predicts that taxa such as lethrinids, carangids, and lutjanids are more likely to be recovered in the 1/4 inch mesh than other taxa like pomacentrids and acanthurids. And indeed, for the Moturakau assemblage, those taxa are more and less likely to be recovered in 1/4 inch mesh.

The experiments also suggest that individual skeletal elements will be differentially recovered. From the experimental data, the maxillae and premaxillae are expected to have a relatively low recovery rate in the 1/4 inch mesh, and the lower jaw elements should be the most commonly recovered elements. To examine whether this pattern holds for the Moturakau data, the recovery rate for each element by family is plotted (Fig. 5a–e). The average percent recovery across all families for each element was calculated. Like the experimental data, the lower jaw elements have a higher average recovery rate than the upper jaw elements. Thus, the screening experiment appears to predict which elements in general are more likely to be recovered.

To determine if the screening experiment is able to accurately predict recovery rates for elements by family, rank order correlations comparing the experimental to the Moturakau data are performed separately for each of the mouth elements. The relationship between the experimental and archaeological data is statistically significant for dentaries and quadrates (Fig. 6c,e). For articulars, the relationship is not significant (Fig. 6d), however it likely is affected by the presence of an outlier. Given the experimental data, the 1/4 inch recovery rate of 100% for acanthurid articulars in the Moturakau assemblage is much higher than expected of 0.8%. The high recovery rate is due to the small sample size of Moturakau acanthurid articular. Only a single specimen was identified for the entire assemblage, and it was recovered in the 1/4 inch mesh. When this outlier is extracted from the analysis, the relationship between the screening experiment and Moturakau data becomes
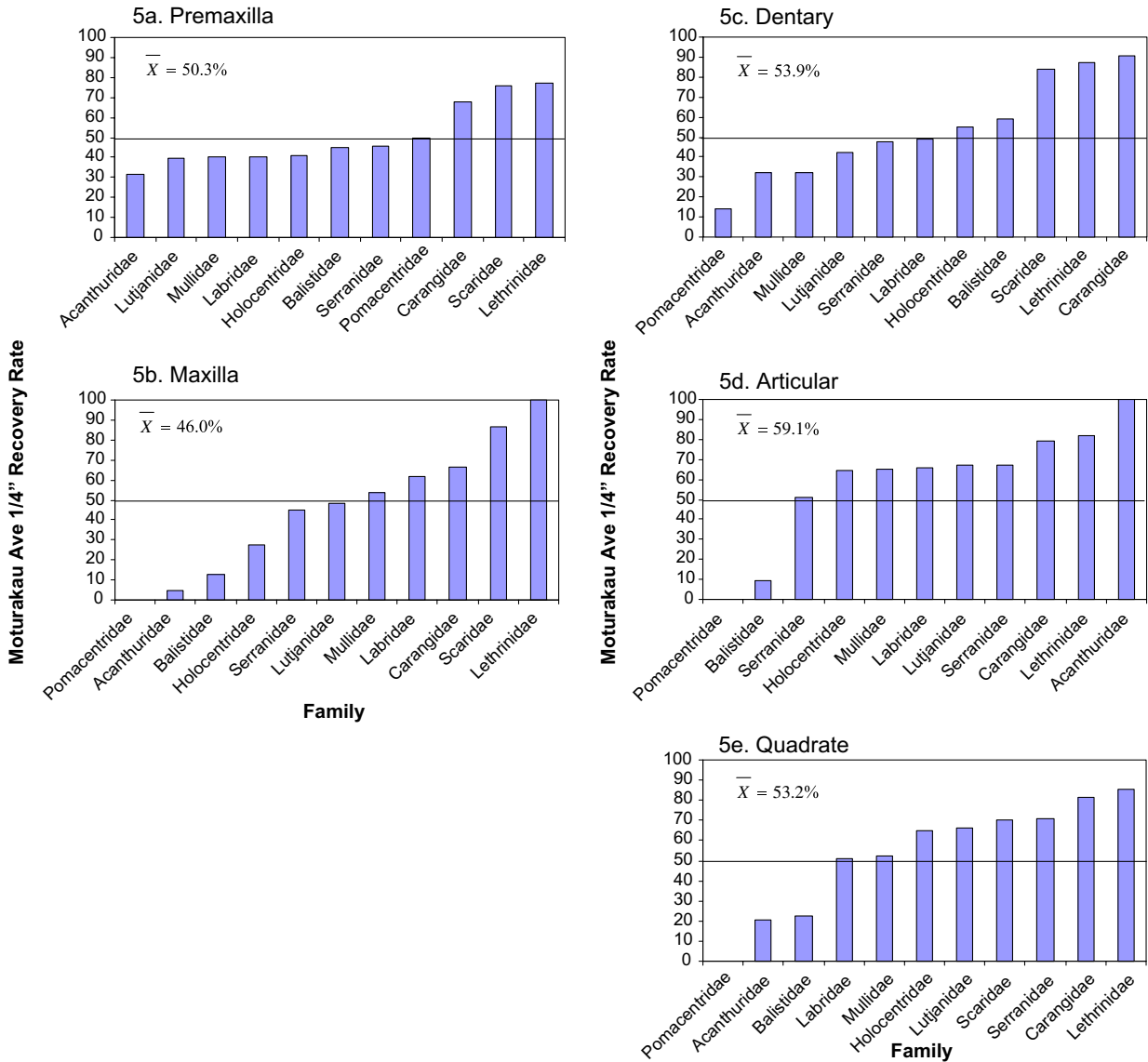

Fig. 3. The relationship between the average 1/4 inch recovery rates for the experimental data and the Moturakau archaeological data.

Fig. 5. The average 1/4 inch recovery rate for the Moturakau assemblage for each skeletal element by family.

statistically significant ($r_s = 0.89$, $p < 0.001$). Thus, for the lower jaw elements, the screening experiment data appear to accurately predict the recovery rates for the Moturakau data at a rank order level.

For the upper jaw elements, the relationship between the experimental and archaeological datasets is statistically significant only for maxillae (Fig. 6b). For premaxillae, the slope of the trend line is nearly flat (Fig. 6a), indicating that the archaeological recovery of premaxillae is relatively similar across taxa. The premaxillae for 8 out of 11 taxa in the Moturakau assemblage were recovered at a rate between 30% and 50%, while the corresponding values for the experimental data varied from 9.5 to 74.4%. Thus, the screening experiment data were not able to accurately predict the archaeological recovery for premaxillae.

Differences between the expected and observed data are likely due to taphonomic factors that affect recovery such as degree of fragmentation and identifiability. As discussed above, the experimental data are based on whole elements, thus the impact of fragmentation on recovery is not taken into account in predictions made from these data. The relationship between the experimental and archaeological data is likely to be strongest for assemblages that are well-preserved with low rates of fragmentation, such as the Moturakau dataset. However, even for the Moturakau sample, there are differences between the predicted and actual recovery rates, such as for the premaxillae, which may be the result of element fragmentation. Element breakage can decrease the size of the bone or alter its shape, and thus decrease its likelihood of being retained in 1/4 inch mesh. For
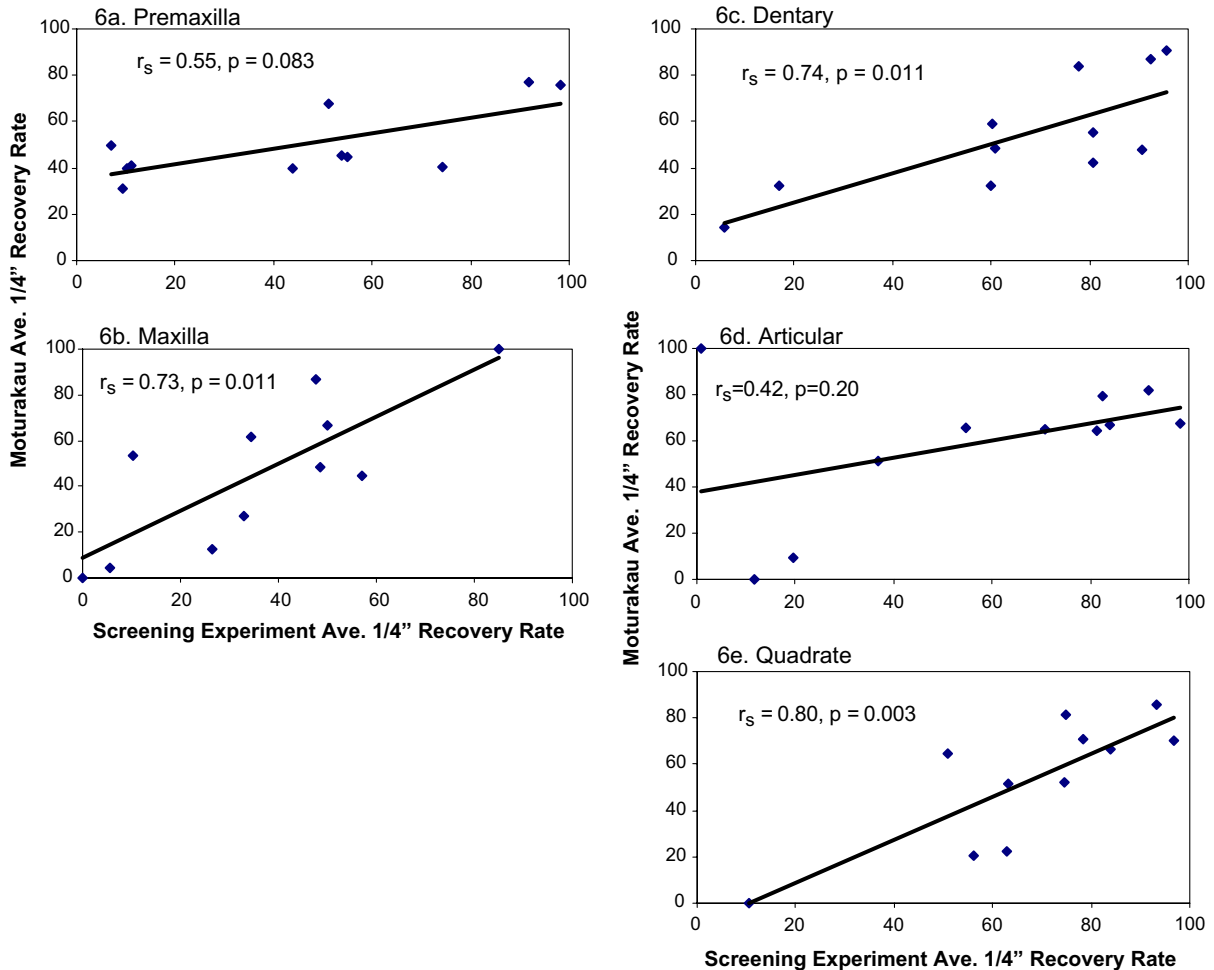
Fig. 6. The relationship between the average 1/4 inch experimental data and the Moturakau archaeological data for each skeletal element.

example, premaxillae may have been fragmented such that their shape changed from discoidal to rod-shaped, allowing the fragments to more easily fall through the mesh. In such a case, the archaeological recovery of premaxillae would be lower than expected given the experimental data.

Fragmentation not only can affect recovery by creating smaller element fragments, but it can affect element identifiability [32]. Some elements are more identifiable than others even when fragment size is small because of the nature of the diagnostic portion of the element [45]. For example, dentaries and premaxillae are toothed elements, which can often be identified from small fragments especially when tooth patterns are taxonomically distinctive. Other elements may require larger fragments that contain diagnostic portions, such as articular surfaces, in order to be identified. Studies that measure the size of diagnostic portions of elements from modern or archaeological specimens can help determine expected recovery rates of element fragments.

Fragmentation patterns in fish assemblages should be documented to determine if bone breakage is playing a role in recovery. Taphonomic measures, such as percent whole (% whole) or the ratio of number of identified specimens to minimum number of elements (NISP:MNE), are typically used to record element completeness or fragmentation patterns in mammalian assemblages [29,30,31,46]. These measures can determine the nature of fragmentation that may provide insights into its effect on recovery. For example, since the screening experiments use complete skeletal elements, the NISP:MNE ratio is 1:1 with a % whole of 100% for that dataset. For archaeological assemblages, the greater the NISP:MNE ratio and the smaller the % whole value are, the more fragmented the specimens are. Thus, it is expected that at higher fragmentation rates it is less likely that archaeological recovery rates will correspond to the screening experiment expectations. In the Pacific, archaeological fish analyses rarely use these measures to document fragmentation patterns or other taphonomic factors. The data are lacking even for the Moturakau assemblage.

However, the relationship between experimental data and the effects of fragmentation can be turned

around to make a shortcoming into a useful tool that can inform on an assemblage's taphonomic history. For the screening experiments, their taphonomic history is very favorable in terms of recovery, preservation, and identifiability because the specimens are whole, well-preserved, and are of known quantity. It can then be argued that the closer the archaeological dataset is to the experimental one, the less severe is its taphonomic history, as was the case with the Moturakau assemblage. The opposite should also hold true. The more dissimilar the archaeological assemblage is to the expectations generated by the screening experiment, the more likely that the assemblage has a taphonomic history that is significantly different from the ideal experimental dataset. For example, the recovery of Moturakau premaxillae differed significantly from the experimental data. Thus, the archaeological premaxillae seem to be more affected by other taphonomic factors such as differential preservation, fragmentation, or identifiability than other elements in the assemblage.

Another example of how deviation from the ideal may hold information about an assemblage's taphonomic history can be seen in the Arrawarra I fish assemblage from a site located in coastal New South Wales, Australia [45]. The site deposits were sieved through a series of nested screens (6 mm, 3 mm, 1 mm), and thus provided a well-recovered assemblage. The data presented in Vale and Gargett's [45] analysis of the assemblage focused on the fish remains from the 6 mm and 3 mm samples. The authors found that smaller mesh did not increase the number of taxa as was expected given previous experimental and archaeological studies. Fragmentation rates were not calculated for this assemblage, however, it appears that the rate of identifiability was very low, suggesting that the assemblage was highly fragmented. The number of identifiable specimens for the 6 mm and 3 mm samples was 415. Although the authors do not specify the total number of specimens identified as fish for just the 6 mm and 3 mm samples, 60,000 fish specimens were reported as identified for all three mesh sizes. Even if a significant proportion of those unidentified remains came from the 1 mm mesh, the identifiability rate of the 6 mm and 3 mm is still quite low. Given the high number of unidentifiable specimens, it is likely that the assemblage is highly fragmented. Thus, the taphonomic history of the Arrawarra I site deviated significantly from that of the screening experiments. So it should not be surprising that the recovery data from the site is radically different from experimental expectations. This case illustrates that not only can screening experiment data be used to compare recovery rates of an expected dataset to an actual dataset, but they can also be used to compare two taphonomic histories, an ideal to an archaeological one.

4. Summary of findings

The screening experiment demonstrates that recovery of Pacific Island fish remains through 1/4 inch mesh varies across body size, taxa and skeletal element. In general, the larger the individual is, the greater the likelihood is that its remains will be recovered. Recovery rates also depend on the fish's feeding strategy. Taxa with large, robust mouth elements often characteristic of carnivorous fish will more likely be recovered in 1/4 inch mesh than taxa with smaller, delicate mouth parts, such as herbivorous fishes. In addition, the size and shape of a fish's skeletal elements can affect recovery. Thus, zooarchaeologists can use the experimental data at the ordinal level to predict that certain taxa, skeletal elements, and body sizes are more or less likely to be represented in samples collected using 1/4 inch mesh.

The experimental data accurately predict archaeological recovery rates across families and for most skeletal elements at the ordinal level. Thus, screening experiments can provide useful rank order information about recovery, particularly when assemblages are well-preserved and have relatively low rates of fragmentation. Since experimental data are based on whole elements, element fragmentation likely affects the predictive ability of screening experiments. Some elements for particular taxa are expected to be more susceptible than others to the effects of increased fragmentation because of the element's size, shape, and identifiability. Further experimental and archaeological studies are required to fully understand how fragmentation affects differential recovery of Pacific Island fish remains. However, differences between an archaeological assemblage and expectations generated by the experiments can be used to suggest that aspects of the archaeological taphonomic history, such as differential preservation or fragmentation, are significantly different from the ideal taphonomic history of the experimental data.

5. Effects of recovery bias on interpretations

It is clear that the mesh size that archaeologists employ has significant consequences on the robusticity of data to answer a variety of important questions. As this study and others have shown, the size bias created by differential recovery can affect the kinds of taxa and skeletal elements recovered. These biases in turn affect the ability of zooarchaeologists to accurately address questions, such as changes in taxonomic diversity and abundance of exploited fauna, identifying the procurement methods utilized, understanding the effects of predation pressure, and identifying processing methods. While the examples presented below specifically reference studies on fish remains, the issues raised are

relevant for all faunal classes, and indeed to any archaeological material recovered via sieving.

5.1. Effects on taxonomic abundance and diversity

Researchers use species abundance and diversity measures to understand change in diet or exploitation patterns. Differential recovery can affect relative abundances of taxa as well as numbers and kinds of taxa recovered [14,20,33]. Thus, richness and diversity measures on affected assemblages may be an artifact of recovery bias rather than a representation of past subsistence practices. In particular, foraging theory studies use body size as a proxy for prey rank [8,9,13,23,35,39,47], thus these studies are more vulnerable to size-related differential recovery. For example, richness measures such as the number of taxa present (NTAXA) are used to track changes in diet breadth [10,21,34]. Diet breadth is expected to increase to include a wider range of low-ranked or small-bodied taxa if foraging efficiency declines significantly. As has been documented in both screening experiments and in analyses of archaeological data, the use of larger mesh size preferentially selects for larger bodied taxa, and thus also affects the number of taxa recovered. Therefore, the use of 1/4 inch mesh might not recover smaller taxa that were being exploited which may result in an apparent lack of change in diet breadth through time.

Additionally, foraging theory studies use indices that measure the proportion of taxa of different body sizes to document changes in foraging efficiency caused by resource depression [8,9,34]. The relative abundance of large-bodied taxa is often compared to that of small-bodied taxa to measure changes in the relative abundance of high- to low-ranked taxa. An increase in the proportion of low-ranked or small-bodied prey indicates that foraging efficiency is declining and may be the result of resource depression. Since body size is important to these indices, then recovery bias can affect the validity of these measures. The effects of differential recovery on such indices have been discussed elsewhere [14,24]. In particular, Cannon [14] models the effects of recovery bias on foraging indices that incorporate North American mammal remains. He concludes that these indices will not be affected by differential recovery if "the degree of fragmentation or the average specimen size of each taxon is the same between" samples [14:212]. Thus, if Cannon's recovery model holds for Pacific Island fish, then analyses based on data collected via 1/4 inch mesh need to document specimen fragmentation and fragment size as discussed above to demonstrate that recovery bias has not affected taxonomic abundance.

To date, studies on Pacific Island fauna that use foraging indices are derived from assemblages collected using small mesh sieves (e.g., 1/8 inch or smaller [3,13,35]). Based on results of the screening experiments presented above, only a small proportion of specimens was not recovered in either the 1/4 inch or 1/8 inch mesh for most families, with the notable exceptions of acanthurid and pomacentrid specimens (Table 3). Thus, Pacific Island fish analyses using data collected with 1/8 inch mesh are likely to be less affected by recovery bias. However, even when smaller sized mesh is used, fragmentation patterns should be examined to determine if bone breakage is playing a significant role in recovery.

5.2. Effects on identifying fishing strategies

The relative abundance of fish species recovered from a site is often used to understand prehistoric human procurement strategies. Typically, fish feeding behavior determines the effectiveness of different fishing strategies. Carnivorous fish such as carangids are more likely to be attracted to a baited fishhook than herbivorous fish. Thus, an abundance of carangids in an assemblage might be interpreted as reflecting a fishing strategy focused on angling. However, as discussed above, mouth element size and shape are also related to feeding behavior [12,13]. Carnivorous fish, which are typically taken via angling, tend to have larger and more robust mouth parts used for capturing prey, and as a result are more likely to be retained even in larger mesh sieves. Herbivorous fish, on the other hand, have smaller, more fragile mouth elements used to pick off reef detritus. Since herbivorous fish are less likely to be attracted to baited fishhooks, they are often captured by other methods such as netting or spearing. If large sized mesh is used in recovery, herbivorous fish may be underrepresented, and the importance of angling may be overestimated.

Other studies have also used the range of fish species' size to examine fishing strategies. Angling tends to select for fish large enough to take fishhooks into their mouths. On the other hand, seining or other mass capture techniques capture a broader size range including smaller individuals. Since body size is central to this argument, then differential recovery of faunal samples can affect the ability of zooarchaeologists to address this problem. For example, Leach and Davidson [26] suggest that the decreasing average size and increasing standard deviation in size of New Zealand snapper (*Pagrus auratus*) at the Cross Creek site may represent a possible shift in fishing strategies. While they acknowledge that this change in size could be related to other factors such as predation pressure (see below), an accurate representation of the size range of a species is necessary to even begin to examine this question. The sample of fish remains they use in their study was collected using small mesh sieves. If larger mesh was used to recover their samples, only larger individuals

would be represented and the decline in size over time that they documented would not have been evident.

5.3. Effects on documenting changes predation pressure

Changes in the size range of taxa are often used to understand the effects of predation pressure on those taxa [9,13,43]. The assumption is that size is related to age-structure. As harvest pressure increases, populations become relatively juvenile dominated, that is, skewed toward younger, smaller individuals. Again, documenting body size is important to addressing this issue. However, as this study has shown, samples of fish remains can be biased against small sized individuals when large mesh sieves are used in recovery. In New Zealand, Leach and Davidson [26] compared size of snapper from specimens obtained in modern catches to those found at prehistoric sites. The modern specimens were much smaller in size than the prehistoric specimens. The modern fisheries have been intensively harvested for many decades, thus it appears that the change in size across time may be the result of modern predation pressure. The archaeological samples used in Leach and Davidson's study were collected using mesh 3 mm and smaller. If larger mesh screens had been used, then large-sized individuals would have been differentially recovered. Thus, the full range of size would likely not have been represented in the assemblage and size changes would have been difficult to recognize.

5.4. Effects on identifying fish processing

Fish are often processed for drying and storage such that certain elements might not be represented archaeologically [11,49]. In some parts of the Pacific, fish processing of certain taxa is known to have been a cultural practice at least during early historic times. For example, in New Zealand, barracouta (*Thyristes atun*) were harvested during the summer, and processed, dried, and stored for consumption throughout the year [5,27]. Since skeletal elements are recovered differentially based on their size and shape, fish assemblages collected with larger mesh sieves may not retrieve a representative sample of skeletal elements. Thus, it would be unclear if the differential representation of elements is a result of cultural practices or simply recovery bias. In the Pacific, fish processing has not been studied because identification of fish remains is typically limited to just a few skeletal elements of the mouth. Thus, little information is collected on other body parts that may have been differentially processed. As reference collections improve and analysts expand the range of elements used in analysis, documenting fish processing may eventually become a viable goal in Pacific fish analysis. If so, archaeologists should work to create samples of fish remains that are representative, and can be used to make accurate interpretations about fish processing.

6. Conclusions

While the use of large mesh to collect faunal remains is becoming less common, the fact remains that most older assemblages were collected with 1/4 inch mesh. Researchers often reanalyze these previously collected datasets, using them to ask new and more complex questions. Any of the questions described above requires researchers to pay close attention to how differential recovery affects their assemblages. Thus, determining the effects of recovery bias on an assemblage has become standard practice.

In general, evaluating for differential recovery is done on a case by case basis. Screening experiments are generally not explicitly used in these evaluations for two reasons. First, they are often perceived to have limited use because they can only provide ordinal information about what is more or less likely to be recovered rather than tell us exactly what is missing from assemblages. More importantly, the usefulness of screening experiments is questioned because each assemblage is the product of a unique taphonomic history. Thus, experimental data cannot be applied across the board to all situations to "correct for" biases. Unfortunately, data from screening experiments are not a panacea for recovery bias. However, zooarchaeologists can use the experimental data to evaluate the effects of recovery bias. For this purpose, screening experiments provide ordinal data that can direct researchers to sources of equifinality in their faunal data. It falls to the researcher to develop means for evaluating these alternative explanations for patterns in their data. Screening experiments can also be a valuable tool for evaluating an assemblage's taphonomic history. If recovery is viewed as part of the taphonomic history of a site (see [30]), then as discussed above, screening experiments are similar to other ethnoarchaeological and experimental data that have been used to identify the variables and processes that affect taphonomic histories. Experimental screening data, thus provide an ideal recovery and taphonomic scenario that zooarchaeologists can use to identify not only recovery biases, but other taphonomic factors such as differential fragmentation and preservation.

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