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Inferring fishing intensity from contemporary and archaeological size-frequency data

Michael J. Plank [a, c, *], Melinda S. Allen [b, c], Reno Nims [b, c], Thegn N. Ladefoged [b, c]

[a] School of Mathematics and Statistics, University of Canterbury, Christchurch 8140, New Zealand
[b] Anthropology, School of Social Sciences, University of Auckland, Auckland 1010, New Zealand
[c] Te Pūnaha Matatini, a New Zealand Centre of Research Excellence, New Zealand

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Establishing whether pre-industrial societies caused significant harvesting impacts on fish stocks is often hindered by the paucity of historic evidence. Some archaeological assemblages contain information on the sizes and/or species of individuals in the catch, but this does not provide any direct evidence on the absolute size of the catch or comparative metrics. We develop a method for using size-frequency data to infer the intensity of fishing and the size-selectivity of the fishing gear in use. The model allows quantitative estimates to be made for the depletion of snapper populations relative to the unexploited pre-human biomass. We evaluate this method using six modern and five archaeological datasets from northern New Zealand for a key commercial and artisanal species, Australasian snapper or silver seabream (*Pagrus auratus*). Our method uses two models for the size selectivity of fishing: one S-shaped, representing mobile fishing gear such as trawls or seines, and one dome-shaped, representing static fishing gear, such as hooks, longlines, or gillnets. The results show that the estimated fishing intensity is lower, and the size of fish being caught is larger, in the archaeological datasets than in the modern datasets, as might be expected. Nevertheless, some of the archaeological datasets show evidence that is consistent with substantial resource depression and depletion of the largest fish in the population, while others suggest only light exploitation. The method allows the five archaeological cases to be rank ordered in terms of exploitation pressures and the relative orderings are further assessed using independent information on site chronology, stratigraphy, and recovery procedures (i.e., screen size). Other factors that can affect size-frequency data are briefly considered, but require additional environmental and taphonomic data that are not currently available. The results provided by our new method support the hypothesis that the depletion of large fish and capture of progressively smaller ones occurred in the pre-European era, albeit in spatially localized areas and at a much less severe level than in modern times. The model results also help identify potential biases in the archaeological assemblages and directions for further research.

1. Introduction

The effects of human activity on nearshore marine fisheries today is uncontroversial. The impact of humans, particularly small-scale societies, in the past, however, is sometimes debated, was possibly variable, and is generally challenging to assess (e.g., Allen, 2002; Broughton, 1999; Butler, 2000; Field et al., 2016; Giovas et al., 2016; Grayson, 2001; Ono and Clark, 2010; Reitz, 2004). Nonetheless, there is increasing interest in archaeological evidence, not only for understanding local historical sequences, but also for the deep-time perspectives it might bring to contemporary resource management and conservation (e.g., Braje et al., 2017; Erlandson and Rick, 2010; Etnier, 2007; McKechnie et al., 2014). By its nature, archaeological evidence is often coarse-grained, incompletely sampled over time and space, and influenced by a range of factors that cannot always be controlled for. Analysts have thus occasionally turned to modelling as a complementary approach to aid understanding of zooarchaeological patterns and the underlying causes (e.g., Morrison and Addison, 2008; Morrison and Allen, 2015). In this paper, we present a mathematical method

* Corresponding author. School of Mathematics and Statistics, University of Canterbury, Christchurch 8140, New Zealand.
E-mail address: michael.plank@canterbury.ac.nz (M.J. Plank).

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for assessing the intensity of human impacts on fisheries and the size-selectivity of associated fishing gear. We then evaluate the results using geographically proximate contemporary and archaeological datasets from northern New Zealand.

In the New Zealand context, there have been arguments both for and against human harvesting effects in pre-European times. Some studies have advanced evidence that suggests certain species were depleted by pre-European inhabitants, while others have argued that any harvesting impacts or resource depression (*sensu* Charnov et al., 1976) would have been subtle in comparison to those of post-European fishing (Leach and Davidson, 2000, 2001). The question is difficult to address directly because archaeological assemblages can only provide information about the relative composition of sizes and/or species in the catch, and do not provide direct evidence of the total numbers of fish that were caught in any given period of time.

Size-frequency datasets are a rich source of information, but it can be difficult to disentangle the contribution of different causal factors to the observed data. For example, if the data indicate a mean length of 30 cm, does this mean that fish significantly larger than 30 cm had previously been removed from the population? Or does it indicate that fishers were using a technology (e.g., gillnets or hooks) that specifically targeted fish of around 30 cm in length? If the data have a high standard deviation, does this mean that different types of fishing gear were used, allowing a wide range of sizes to be captured? Or does it mean that fishing pressure was low, and hence the full range of fish sizes was available to catch? We present a method for using size-frequency data, derived from body size estimates of archaeological fish remains, to infer both the intensity and the size-selectivity of fishing. The method provides a quantitative estimate for the level of resource depletion, relative to the unexploited pre-human biomass, and the fraction of biological production being harvested. The resulting quantitative outputs can be used to rank order archaeological sites in terms of potential fishing pressure and facilitate comparisons of modern and prehistoric fishing impacts. The approach also allows inferences about the fishing gear and practices behind zooarchaeological assemblages by providing information about variability in the sizes of captured fish. Importantly, the method does not require or assume any information about the total size of the catch (i.e., how many fish were caught per year), as this information is typically not available from archaeological assemblages. Instead, the method relies on changes in the size structure of the catch (i.e., the proportions of different sized fish) to make inferences about variability in past fishing practices. As variability in fish body size can arise from causes other than fishing pressure, it is important to evaluate inferences about harvesting pressures using independent stratigraphic, taphonomic, and environmental data.

In this analysis, our target species is Australasian snapper or silver seabream (*Pagrus auratus*), which is important today in commercial and artisanal fisheries, and was a dominant component of indigenous northern Māori subsistence economies for ca. 600–700 years prior to European arrival. Australasian snapper (henceforth snapper) inhabit a range of marine environments, including rocky reefs, estuaries, bays, and other shallow and sheltered marine environments (Paulin, 1990). Snapper reach maturity at 3–4 years of age and around 30 cm in length (Froese and Pauly, 2017). Contemporary estimates of the maximum (asymptotic) length are around 70 cm, though fish in the range 25–50 cm are more common (Walsh et al., 2017). Snapper are mainly bottom-dwelling and inhabit coastal waters 15–60 m deep (Ministry for Primary Industries, 2012). However, juveniles (<30 cm length) are often found in inshore areas, and mature adults also school in shallow waters during the spring-summer spawning season. Older individuals tend to be more solitary (Russell, 1983). Snapper are serial spawners, producing multiple batches of eggs during the spawning season once the water temperature reaches 18 °C (Froese and Pauly, 2017).

Snapper can be taken using a variety of fishing methods, including hooks and nets. Based on oral traditions, early ethnohistoric accounts, and ethnographic observations, pre-European Māori in northern New Zealand are thought to have caught snapper using both shore-based and offshore fishing methods (Best, 1977; Leach, 2006; Waitangi Tribunal, 1988). In addition, both juveniles and mature adults spend some portion of their life cycle in shallow, inshore waters and knowledge of these movements would enable mass capture techniques (Leach and Davidson, 2000). It is therefore likely that pre-European Māori would have had access to a wide range of snapper ages and sizes. While our analysis relates most directly to exploitation resource depression, behavioral and microhabitat resource depression (*sensu* Charnov et al., 1976) might also be outcomes of intensive human harvesting. Snapper are relatively sedentary but also capable of substantial migrations (Froese and Pauly, 2017), so it is possible that traditional fishing practices caused multiple types of localized resource depression. Below, we generically refer to “resource depression” and do not attempt to differentiate between these possibilities.

2. Assemblage details

We apply our newly developed method to previously published size-frequency data from Leach and Davidson (2000). This consists of data on lengths of snapper (*P. auratus*), a monotypic genus in New Zealand, from six modern trawls and from five archaeological assemblages dating from pre-European times, all from northern New Zealand (see Fig. 1 for a map of field sites). The archaeological assemblages come from Twilight Beach (number of individual specimens or NISP = 1914), Kokohuia (NISP = 721), Houhora (NISP = 8847), Galatea Bay (NISP = 212) and Cross Creek (NISP = 997). Leach and colleagues identified both whole and fragmentary archaeological bones as snapper on the basis of five diagnostic cranial bones (the dentary, articular, quadrate, premaxilla and maxilla), using a large zooarchaeological reference collection housed at Te Papa Tongarewa (Museum of New Zealand). Archaeological body size reconstructions were derived using regression formulae developed from multiple measurements on easily recognized element landmarks found on the aforementioned

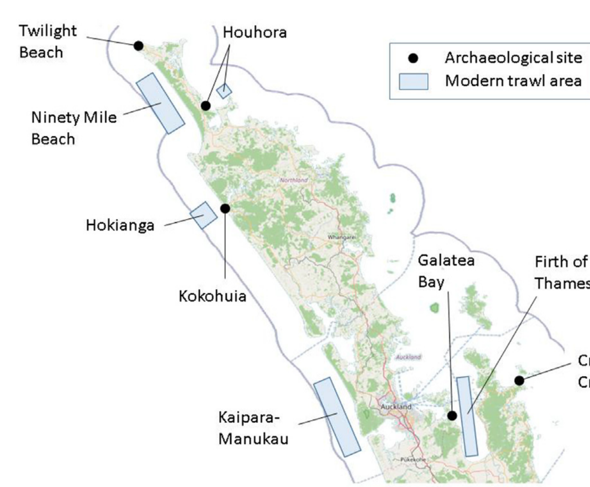

Fig. 1. Map of northern New Zealand showing the locations of the five archaeological sites and five modern trawl areas. Map is from OpenStreetMap ©, available under the Open Database Licence.