The importance of benchmarking habitat structure and composition for understanding the extent of fishing impacts in soft sediment ecosystems

Sean J. Handley *, Trevor J. Willis [1], Russell G. Cole [†], Anna Bradley, Daniel J. Cairney, Stephen N. Brown, Megan E. Carter

National Institute of Water & Atmospheric Research, PO Box 893, Nelson, New Zealand

ABSTRACT

Trawling and dredge fisheries remove vulnerable fauna, homogenise sediments and assemblages, and break down biogenic habitats, but the full extent of these effects can be difficult to quantify in the absence of adequate control sites. Our study utilised rare control sites containing biogenic habitat, the Separation Point exclusion zone, formally protected for 28 years, as the basis for assessing the degree of change experienced by adjacent areas subject to benthic fishing. Sidescan sonar surveys verified that intensive trawling and dredging occurred in areas adjacent to, but not inside, the exclusion area. We compared sediment composition, biogenic cover, macro-faunal assemblages, biomass, and productivity of the benthos, inside and outside the exclusion zone. Disturbed sites were dominated by fine mud, with little or no shell-gravel, reduced number of species, and loss of large bod-ied animals, with concomitant reductions in biomass and productivity. At protected sites, large, rarer molluscs were more abundant and contributed the most to size-based estimates of productivity and biomass. Functional changes in fished assemblages were consistent with previously reported relative increases in scavengers, preda-tors and deposit feeders at the expense of filter feeders and a grazer. We propose that the colonisation of biogenic species in protected sites was contingent on the presence of shell–gravel atop these soft sediments. The process of sediment homogenisation by bottom fishing and elimination of shell-gravels from surficial sediments ap-peared to have occurred over decades – a 'shifting baseline'. Therefore, benchmarking historical sediment struc-ture at control site like the Separation Point exclusion zone is necessary to determine the full extent of physical habitat change wrought by contact gears on sheltered soft sediment habitats to better underpin appropriate con-servation, restoration or fisheries management goals.

1. Introduction

Trawling and dredging cause physical disturbance to the sea floor, homogenise habitats and their benthic assemblages, and reduce biodi-versity (Jennings and Kaiser, 1998; Kaiser et al., 2006; Rice, 2006; Thrush and Dayton, 2002; Tillin et al., 2006). Much of the published lit-erature regarding bottom fishing comprises assessments of the effects on the abundances of organisms, either individually or at the assem-blage level (Gray et al., 2006; Jennings and Kaiser, 1998; Kaiser et al., 2006; Thrush and Dayton, 2002). Investigations have also focussed on the effects of trawl disturbance on other ecological parameters like the importance of size structure of invertebrates and their relative contribu-tion to biomass and productivity (Blanchard et al., 2004; Cartes et al., 2009; Hermsen et al., 2003; Hiddink et al., 2006; Jennings et al., 2002).

As benthic disturbance by fishing gear selects for smaller invertebrates (Duplisea et al., 2002; Tserpes et al., 2006) a shift to the dominance of smaller-sized species could increase productivity per unit biomass at the expense of standing biomass which will decrease (Cartes et al., 2009; Queirós et al., 2006). While bottom fishing gear breaks down and removes diverse biogenic habitats (Tserpes et al., 2006; Watling and Norse, 1998) causing reductions in sediment habitat heterogeneity, species diversity and ecological function (Hewitt et al., 2008), few stud-ies have investigated the effects of fishing on the heterogeneous mollusc shell gravel component of coastal soft sediments. Bivalve shells act as ecosystem engineers in the succession of biogenic habitats as shells provide substratum for the recruitment of plants and animals that bind the shell fragments together (Powell and Klinck, 2007). Shells from dead bivalves can also provide important ecosystem services in-cluding; stabilising sediments (Hewitt et al., 2005), provide refugia from predation, buffer physical or physiological stress, and control transport of solutes and particles in the benthic environment (Gutiérrez et al., 2003; Powell and Klinck, 2007). Biogenic structure, in turn, may provide recruitment habitat and shelter for small fish (Kaiser et al., 2003; Thrush et al., 2002) or invertebrates (Kamenos

* Corresponding author. Tel.: +64 3 548 1715; fax: +64 3 548 1716.
E-mail address: sean.handley@niwa.co.nz (S.J. Handley).
[1] *Present address*: Institute of Marine Sciences, School of Biological Sciences, University of Portsmouth, Ferry Road, Eastney, Portsmouth PO4 9LY, United Kingdom.
[†] Deceased.

et al., 2004). Of importance to fisheries managers, habitats that are less damaged are suggested to contribute more recruits to fisheries (Auster et al., 1996; Carbines et al., 2004), and to contain greater diversity than disturbed habitats (Auster and Langton, 1999; Thrush et al., 1998).

Without adequate benchmarking, it is difficult to predict how much fishing (in terms of the intensity or frequency of activity), and over what time scales, such changes are brought about. Because of the ubiquitous nature of bottom fishing (Cryer et al., 2002) and the potential for shifting baselines (Pauly, 1995), it is unlikely that public and institutional knowledge can be used to benchmark the pre-impact potential of affected assemblages and habitats. Without attempts to benchmark lost assemblage structure, in the absence of adequate control sites, we cannot determine the past environmental conditions, the rate, direction and magnitude and cause of change in relation to natural variability (Saunders and Taffs, 2009; Smol, 2008). In the context of fishing effect studies, the magnitude and scale of effects can be estimated by using appropriate control sites if available, by using gradient approaches (e.g. Thrush et al., 1998; Tillin et al., 2006), or by using marine reserves and marine protected areas (MPA's) to measure recovery rates and successional processes following cessation of bottom fishing (e.g. Asch and Collie, 2008). When adequate control sites are not available it is difficult to examine the true range of effect size. This potential disjuncture between the pre- and post-impact compositions of fished habitats has important implications for conservation, ecosystem approaches to fisheries management and restoration goals for depleted fishery species.

Various forms of exclusion zones or temporal closures have been used to evaluate the nature and magnitude of effects of fishing on benthic and demersal composition and production (e.g. Asch and Collie, 2008; Dimech et al., 2008; Duineveld et al., 2007; McConnaughey et al., 2000; Murawski et al., 2000). No studies have examined the effects of fishing on benthic invertebrate productivity in the southern hemisphere in shallow, productive, euphotic waters. Due to the late colonisation of New Zealand (Wilmshurst et al., 2008), there is a relatively short history of human disturbance. With the foresight of early fisheries managers, some areas of soft sediment habitats have been preserved to protect unique biogenic habitats that would otherwise have been modified or removed by bottom fishing gears (Bradstock and Gordon, 1983; Mace, 1981). Such sites offer a unique opportunity to benchmark the effects of fishing on the benthos. Here we utilise the Separation Point exclusion zone, an area that has not been trawled, seined or dredged for at least 28 years to estimate the degree to which trawling may alter the benthic habitat and associated biota. This area contains a relict biogenic bryozoan assemblage atop shell gravel substratum providing rare control sites from which to demonstrate the importance of benchmarking habitat composition in the study of fishing effects. We compare protected areas with neighbouring sites that have been intensively trawled and historically dredged, by measuring sediment characteristics, and invertebrate abundance, size, biomass, productivity, and functional composition.

2. Materials and methods

2.1. Study location and fishing history

Separation Point lies between Golden and Tasman Bays, in the north of the South Island of New Zealand (Fig. 1). The seabeds of the two bays slope gradually to ca.50 m depth. The Golden and Tasman Bay seabeds are intensively fished, by trawling and seining for finfishes including flatfish species (*Rhombosolea plebius*, *R. leporina*, *R. tapirina*), barracouta (*Thyrsites atun*), snapper (*Pagrus auratus*), tarakihi (*Nemadactylus macropterus*) and red cod (*Pseudophycis bachus*) and by dredging for scallops (*Pecten novaezelandiae*) and oysters (*Ostrea chilensis*). Recreational fishers are also permitted to dredge for scallops and oysters.

In December 1980 commercial trawling, seining and shellfish dredging were excluded from a 146-km^2 sector from the coastline out to ca.50 m depth offshore of Separation Point (hereafter the "exclusion zone", Fig. 1) to protect an area of bryozoans, mainly *Celleporaria agglutinans* and *Hippomenella vellicata*, which was perceived to be important recruitment habitat for fishes (Bradstock and Gordon, 1983; Mace, 1981). Due to the robust nature of the Separation Point bryozoan 'corals', fishers avoided these grounds until pair trawling began between 1972 and 1974 allowing nets to be "flown" above the seabed to avoid nets filling with bryozoa that caused damage to catch and longer catch sorting times (Grange et al., 2003). Thus, although the area cannot be considered "completely pristine", the robustness of the bryozoan beds provided innate protection from fishers who adapted their fishing methods to avoid bottom contact. Declines in numbers of juvenile snapper and tarakihi (Saxton, 1980) subsequently led to protection of the bryozoan beds. A post-protection survey using sidescan sonar and remotely operated vehicle in 2003 reported that bryozoans covered ca. 38% of the protected area (Grange et al., 2003). Recreational fishing is permitted in the exclusion zone, so densities of angling species, potential benthic feeders, are likely to be similar inside and outside the exclusion zone, especially given the small size of the exclusion area in relation to demersal fish movement. Recreational dredging for scallops is likely to be unproductive due to the biogenic nature of the sediments.

Bottom trawling was recorded as occurring both west and south of the exclusion zone in the 2 years preceding our sampling since records began in 2007. Over twice as many trawls occurred south of the exclusion zone in 2007, but trawling was relatively consistent either side of the zone during 2008 (Handley, unpub. data). The majority of trawls targeted demersal flat fish species including sand flounder (Tuck et al., 2011). Commercial scallop dredging occurred west and south of the exclusion zone since at least 1989, with little dredging south of the exclusion zone since 2002–03 and moderate dredging pressure west of the exclusion zone in 2007 in Golden Bay (Williams and Michael, 2011).

Field sampling was carried out in May 2008. Data for a number of additional explanatory variables were collected or modelled as below.

2.2. Infaunal and sediment sampling

We sampled benthic organisms from sediments by using a Van Veen grab (bite area 0.069 m^2). We collected groups of samples at either side of the borders of the protection zone between 20 and 30 m depth, with 12 samples from the fished area on the western side of the zone, and 12 samples nearby but within the protection zone (Fig. 1). An identical distribution of sampling effort (another 24 samples) was allocated at the southern side. Fished and control samples were thus separated by 0.95 to 3.8 km, whereas the two sampling zones (west and south) were separated by 5.4 to 8.3 km. Grab stations were assigned randomly by use of the random point tool in ArcMap 9.1.3 (ESRI Inc. 1999–2009). For grain size analysis, a 5 × 5 cm tube corer was used to vertically subsample sediments from each grab. An additional 5 ml scoop of surficial sediment was removed from each grab sample for analysis of chlorophyll a. These subsamples were frozen for later analysis, whereas the remaining grabs were preserved in 70% ethanol. Preserved fauna were sieved over a log-series of mesh sieves down to 0.5 mm, and analysed for abundance. Biomass, and productivity of infauna were estimated by using the size based conversion factors and methodology of Edgar (1990) and Taylor (1998). Size classes are presented as equivalent organism weights (ash-free dry mass: AFDM) on the log$_2$ scale (Queirós et al., 2006). Data were not normalised. Sediments were wet sieved through 2 and 1 mm sieves and the filtrate collected on a 63 μm sieve. The 1 and 2 mm fractions were then re-dried to constant weight and re-weighed to derive percent mud, sand and shell gravel. Chlorophyll α content of sediment scoops was analysed by using fluorescence spectrophotometry (Cary Eclipse) by freezing (0 °C), sonicating in acetone to extract pigments at 4 °C for 4 h (Untrasonics, Inc, Cell Disruptor, W-225, 20HZ), and centrifuging at 3000 rpm for 15 min (expressed both as a raw value and as a percentage).