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Broad-scale abundance changes are more prevalent than acute fishing impacts in an experimental study of scallop dredging intensity

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ABSTRACT

There is limited understanding of the relationship between mobile gear fishing intensity and the magnitude of the resulting perturbation in marine benthic communities. Theory predicts that instantaneous fishing-induced mortality should generally scale directly with fishing intensity. This study used a before–after-impact experimental design with 16 fishing intensity levels to assess the impact of scallop dredging on benthic communities at two experimental sites. Few instances of statistically significant effects of fishing intensity were detected for individual taxa, although there was some evidence of impacts on community structure at one site. In contrast, short-term natural abundance fluctuations were much more prevalent and were of a magnitude similar to that estimated to be produced by fairly intense fishing, as would occur in only very limited geographic areas in the commercial fishery. Post-hoc simulations used to estimate the statistical power of the study suggest that true effects of elevated fishing mortalities could reasonably be detected, but that power was low for small instantaneous fishing mortalities. This situation is comparable to other well-designed mobile gear impact studies that reported power. The simulations also revealed comparable levels of statistical power for correctly detecting abundance changes due to fishing and due to natural fluctuations. The results of this study taken in the context of the commercial fishery suggest that impacts of scallop dredging on the local benthic communities are small with respect to natural variation in the ecosystem. This study highlights the need to account for natural spatio-temporal variation in the designs of studies of mobile fishing gear impacts. Failure to do so increases the risk of drawing incorrect conclusions.

1. Introduction

Mobile bottom fishing gears such as scallop dredges are known to cause numerous direct physical and biological impacts on benthic ecosystems, such as reduced seabed habitat complexity and heterogeneity (Caddy, 1968, 1973; Currie and Parry, 1996; Watling and Norse, 1998) and death and injury of biota related to collision with the fishing gear or capture (Caddy, 1973; Gislason, 1994; Prena et al., 1999; Bergman and van Santbrink, 2000; Jenkins et al., 2001). These direct effects can in turn lead to modification of the benthic community structure, such as increase in small opportunistic species, scavengers and predators (for reviews see Dayton et al., 1995; Jennings and Kaiser, 1998; Lindeboom and de Groot, 1998; Kaiser and de Groot, 2000; Kaiser et al., 2002; Thrush and Dayton, 2002). The short and long term consequences of mobile-gear bottom fishing effects depend on their magnitude relative to natural disturbance and to the resilience of the local benthic assemblages, which is itself related to the frequency and magnitude of natural disturbances (Jennings and Kaiser, 1998; Collie et al., 2000; Kaiser et al., 2002, 2006).

Understanding the magnitude of disturbance and how it scales with local fishing intensity (i.e., effort) is an important element in marine spatial planning, such as determining the location, size and anticipated results of closed or protected areas (Jennings et al., 2001a,b; Queirós et al., 2006; Hinz et al., 2009). While there have been numerous studies of bottom-gear impacts (see reviews in Collie et al., 2000; Kaiser et al., 2002, 2006), only a limited number of studies have considered the issue of fishing intensity specifically. Most of these studies adopted a comparative approach, evaluating differences in benthic communities between geographic areas that had experienced different intensities of commercial mobile gear fishing effort (Jennings et al., 2001a,b; Hiddink et al., 2006; Hinz et al., 2009; Queirós et al., 2006; Reiss et al., 2009). The comparative approach has the advantage that it considers potential

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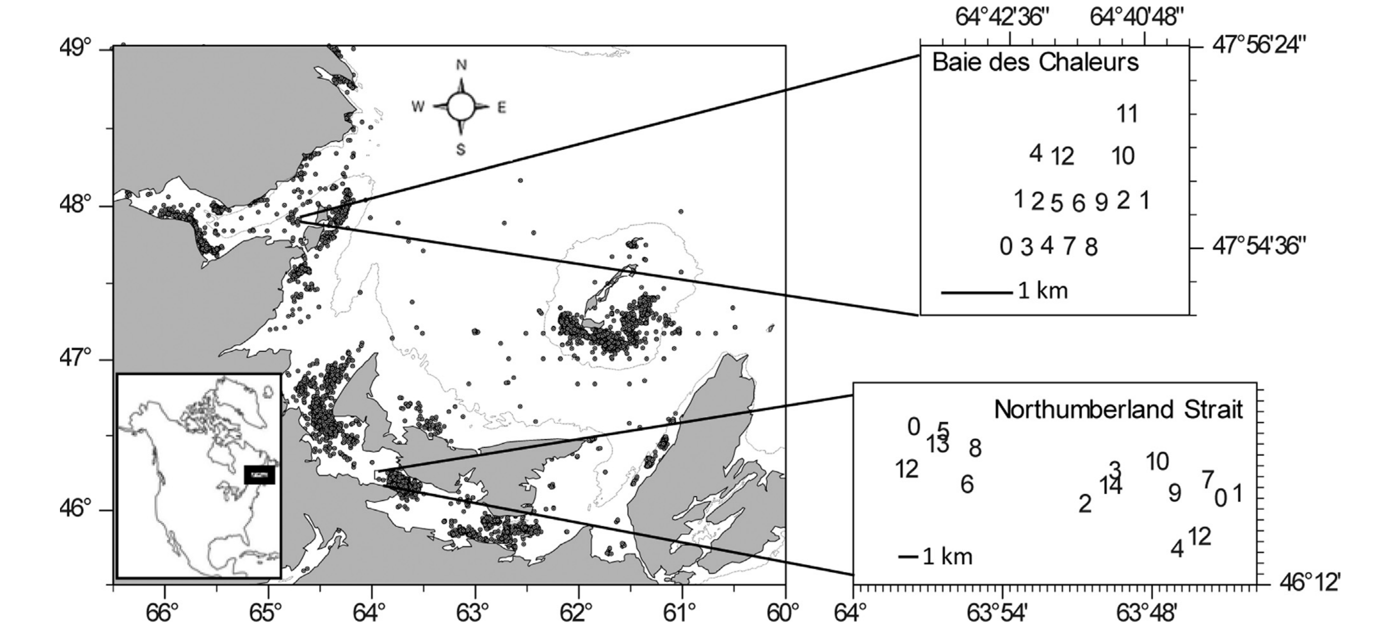

Figure 1. Map of the southern Gulf of St Lawrence indicating the location of the two experimental sites, Baie des Chaleurs and Northumberland Strait, the location of scallop fishing sets based on harvester logbooks for 1991–2012 (grey dots) and the 50 m isobaths (dashed line). The inset panel shows the location of the southern Gulf with respect to the North American continent. The panels on the right show the distribution of experimental plots at each site, with the mapped numbers indicating the fishing intensity in each plot. Note that the scale differs between the two panels.

impacts at a geographic scale and an intensity that are pertinent to the fishery, but confounding effects of natural or background spatial and temporal variation can be difficult to isolate (Underwood, 1992, 1994; Lindegarth et al., 2000; Sciberras et al., 2013). An alternative approach which has commonly been used in mobile gear impact studies in general, though not in studying fishing intensity effects specifically, is experimental manipulation using planned fishing (e.g., Eleftheriou and Robertson, 1992; Pranovi et al., 1998; Moran and Stephenson, 2000). This approach can control for external factors affecting community change, thereby strengthening inferences. However, many past experiments lacked the replication or the proper experimental controls to fully realize this benefit (reviewed in Pitcher et al., 2009). Furthermore, logistical constraints on the amount of fishing that can be done during an experiment typically limit the geographic scale of the study and the fishing intensity to levels that are inferior to those of the fishery. Care is therefore required in interpreting the experimental results in the context of what may be occurring in the fishery.

There are two general ways disturbance is expected to scale with mobile bottom-fishing intensity. First, fisheries theory predicts that the instantaneous rate of fishing mortality should be proportional to fishing intensity (Hilborn and Walters, 1992). This result has been borne out in a number of comparative studies of mobile bottom-fishing intensity (Jennings et al., 2001a,b; Hinz et al., 2009). Second, the disturbance may have a saturating or knife-edged relationship with intensity, such that most or all of the bottom-fishing related change at a site is associated with the first pass of the gear (Hall-Spencer and Moore, 2000). Such a relationship is predicted to occur when the gear intercepts unproductive sensitive emergent biota (e.g., coral reefs), but does not appear relevant for benthic communities typically found on traditional mobile-gear fishing grounds (Moran and Stephenson, 2000; Jennings et al., 2001a,b; Hinz et al., 2009). Clearly, management decisions with respect to the locations and times that mobile bottom-gear use is permitted depend on how disturbance scales with intensity.

In the present study, before–after type experiments (e.g., Underwood, 1992, 1994) were conducted at two sites to experimentally evaluate the short-term impact and one-year post-disturbance recovery of benthic communities in response to different intensities of fishing using a scallop dredge. Our manipulative approach allowed us to separate the effects of fishing intensity from responses due to unrelated environmental changes and meso-scale spatial variation. Although the experiments were designed to consider effects of fishing that are proportional to fishing intensity, evidence for a knife-edged relationship was also evaluated. Post-hoc simulations were used to evaluate the statistical power of the experimental and statistical approaches employed. Finally, the relevance of the experiment is evaluated with respect to the commercial scallop (*Placopecten magellanicus*) fishery in terms of areal expanse and intensity of disturbance.

2. Methods

2.1. Study areas

The study was undertaken in two areas of the southern Gulf of St. Lawrence (NW Atlantic, Canada), the Northumberland Strait (NS) and the Baie des Chaleurs (BdC) (Fig. 1). Both study locations were known scallop habitat that had been closed to scallop harvesting as a scallop conservation measure for a minimum of two years, and only lightly fished in at least the five years that preceded closure. The NS location was characterized by sand–gravel sediments over bedrock and a depth range of 20.6–26.5 m, while the BdC location was characterized by gravel–cobble sediments and a depth range of 7.8–10.6 m. Although the habitat of the two sites differed, inferences about fishing effects with respect to the habitat type were precluded by confounding with differences between the studies in experiment timing and methods of sampling the biological community (details below).

2.2. Experimental design

Impact studies such as the present one often use before–after-control-impact (BACI) experimental designs, which consist of control and treatment plots sampled both before and after the application of an experimental treatment (Underwood, 1992,