Effects of Otter Trawling on a Benthic Community in Monterey Bay National Marine Sanctuary

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Abstract: *Bottom trawling is one of the most disruptive and widespread human-induced physical disturbances to seabed communities and has become a global environmental concern. We used a comparative approach to test the hypothesis that persistent otter trawling decreases bottom habitat complexity and biodiversity, increases the abundance of opportunistic species, and benefits prey important in the diet of some commercially valuable fish. We compared two similar and adjacent fishing areas at 180 m off central California in Monterey Bay National Marine Sanctuary: one inside the three-mile coastal zone of restricted fishing with light levels of trawling and one beyond the three-mile limit with high levels of trawling. Differences in fishing effort between the two areas were confirmed and quantified by means of data and tow number statistics from Pacific Fishery Management Council (PFMC) Trawl Logbook records. We used still photography, video footage, bottom grab samples, and experimental trawling to compare the physical and biological parameters of the two areas. The area with high levels of trawling had significantly more trawl tracks, exposed sediment, and shell fragments and significantly fewer rocks and mounds and less flocculent material than the lightly trawled area. Most invertebrate epifauna counted were significantly more abundant in the lightly trawled area. The density of the amphinomid polychaete,* Chloeia pinnata, *as well as that of oligochaetes, ophiuroids, and nematodes, were higher every year in the highly trawled area, and there were significantly fewer polychaete species every year in the highly trawled area. Content analysis of fish guts showed that* C. pinnata *was a dominant prey item for some of the commercially important flatfishes in both lightly and heavily trawled areas. Our study provides evidence that high levels of trawling can decrease bottom habitat complexity and biodiversity and enhance the abundance of opportunistic species and certain prey important in the diet of some commercially important fishes. Our work also illustrates how constraints currently imposed on fisheries research by the near universal absence of true unfished control sites severely limit our ability to determine appropriate levels of harvest pressure for maintaining sustainable fisheries and marine biodiversity. Valid research in these areas will require marine reserves in which fishing effort and methods can be manipulated in collaborative studies involving fishers, researchers, and resource agencies.*

Efectos de Artes de Pesca por Arrastre en Comunidades Bentónicas del Santuario Nacional Marino de la Bahía de Monterey

Resumen: *El arrastre de fondo es una de las perturbaciones físicas inducidas por humanos más perjudicial y ampliamente dispersa sobre comunidades del lecho marino, lo cual la ha convertido en una preocupación ambiental. Utilizamos una aproximación comparativa para probar la hipótesis de que los arrastres persistentes disminuyen la complejidad y biodiversidad del fondo, incrementa la abundancia de espicies oportunistas y beneficia a especies-presa importantes en la dieta de algunos peces comercialmente valiosos. Comparamos dos areas de pesca similares y adyacentes 180 m fuera del Santuario Nacional Marino de la Bahía de Monterey, California: uno dentro de la zona costera de las tres millas restringida a la pesca con niveles bajos*

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de arrastre y una mas allá del límite de las tres millas con niveles altos de arrastre. Las diferencias en los niveles de esfuerzo de arrastre entre las dos zonas fueron confirmadas y cuantificadas usando los datos de los libros de registro del Consejo para el Manejo de Pesquerías de Arrastre del Pacífico y estadísticas de datos de arrastres. Utilizamos fotografías, video y muestras de fondo, así como arrastres experimentales para comparar los parámetros físicos y biológicos de las dos áreas. El área con niveles altos de arrastre tuvo significativamente más marcas de arrastre, sedimentos expuestos, fragmentos de conchas y significativamente menos rocas, montículos y material fluculento que el área con pocos arrastres. La mayoría de la epifauna de invertebrados contados fueron significativamente mas abundantes en la zona con poco arrastre. La densidad del poliqueto anfinómido Chloeia pinnata, *así como la de oligoquetos, ofiuroides y nemátodos fue mayor cada año en la zona con mayores arrastres y cada año hubo significativamente menos especies de poliquetos en la zona con menos arrastres. Análisis de contenidos estomacales de peces mostraron que* C. pinnata *fue una presa dominante en algunas de las especies de lenguados comercialmente importantes tanto en las áreas con pocos arrastres, como en aquellas con intensos arrastres. Nuestro estudio provee evidencia de que niveles altos de arrastres pueden disminuir la complejidad y biodiversidad del hábitat de fondo y promueve la abundancia de especies oportunistas y de especies-presa importantes en las dietas de algunas especies de peces de importancia comercial. Nuestro trabajo ilustra también cómo las restricciones actuamente impuestas a la investigación pesquera debidas a la carencia de sitios control completamente libres de pesca limitan nuestra habilidad para determinar niveles apropiados de presión por cosecha para el mantenimiento de pesquerias sustentables y de la biodiversidad marina. Investigaciones válidas en estas áreas requerirán de reservas marinas en las cuales los esfuerzos y métodos pesqueros puedan ser manipulados en estudios de colaboración que involucren pescadores, investigadores y agencias de recursos.*

Introduction

Bottom trawling and dredging are thought to be the most disruptive and widespread anthropogenic physical disturbance to coastal bottom communities (Rumohr & Krost 1991). Otter trawls are the most commonly used bottom trawling gear; they affect the bottom by scraping and digging into the seafloor (deGroot 1984; International Council for Exploration of the Sea [ICES] 1988; Krost et al. 1990; Bergman & Hup 1992; Jones 1992). The net components that disturb the seabed include two otter boards or doors that weigh up to a ton each, rubber bobbins or steel weights (and in some cases roller gear), tickler chains, and the cod end (Watling & Norse, this issue). Although it is incontestable that otter trawling affects the physical and biological seafloor environment, the kind and degree of impact has been difficult to demonstrate (Messieh et al. 1991; Auster et al. 1994).

Previous studies suggest that trawling reduces the biomass and abundance of benthic (bottom-dwelling) organisms and leads to long-term shifts in benthic species composition (Reise 1982; Reise & Schubert 1987; Thrush et al. 1991; Thompson 1993). Trawling has also been implicated in an increase in the abundance of fast-growing species such as polychaetes at the expense of slow-growing, late-reproducing species such as molluscs and crustaceans (Reise 1982; Riesen & Reise 1982; deGroot 1984; Pearson et al. 1985; ICES 1988). Cause and effect, however, have yet to be demonstrated because trawl-impact studies such as these have been constrained by a lack of control, non-fished areas for comparison. Recommendations (ICES 1988) for future research include recording and evaluating the immediate and short-term environmental effects that directly relate to trawling; assessing the long-term effects of commercial activity on important, well-established fishing grounds by direct comparison with non-trawled areas; and considering the long-term impact of trawling on the geographical distribution, abundance, and diversity of noncommercial components of benthic communities in relation to marine conservation policy. We set out to address some of these questions.

Although many trawl-impact studies have been performed along continental shelves around the world, our study is one of the first off the West Coast of the United States. Trawl fishing began in California in 1876. Since the mid 1940s, otter trawls have been the dominant means of bottom trawling applied by the commercial Pacific Coast groundfish industry. Trawl fishing increased greatly in the late 1970s after the passage of the Fisheries Conservation and Management Act of 1976 (FCMA or Magnuson Act), when the U.S. government began providing fishermen with financial and technical assistance to expand and upgrade their fishing operations (Starr et al. 1998). In spite of a modernized trawling fleet, California groundfish landings have declined steadily from a peak in 1982 of 52,000 metric tons to 28,000 metric tons in 1996 (California Cooperative Oceanic Fisheries Investigations [CalCOFI] 1993, 1997).

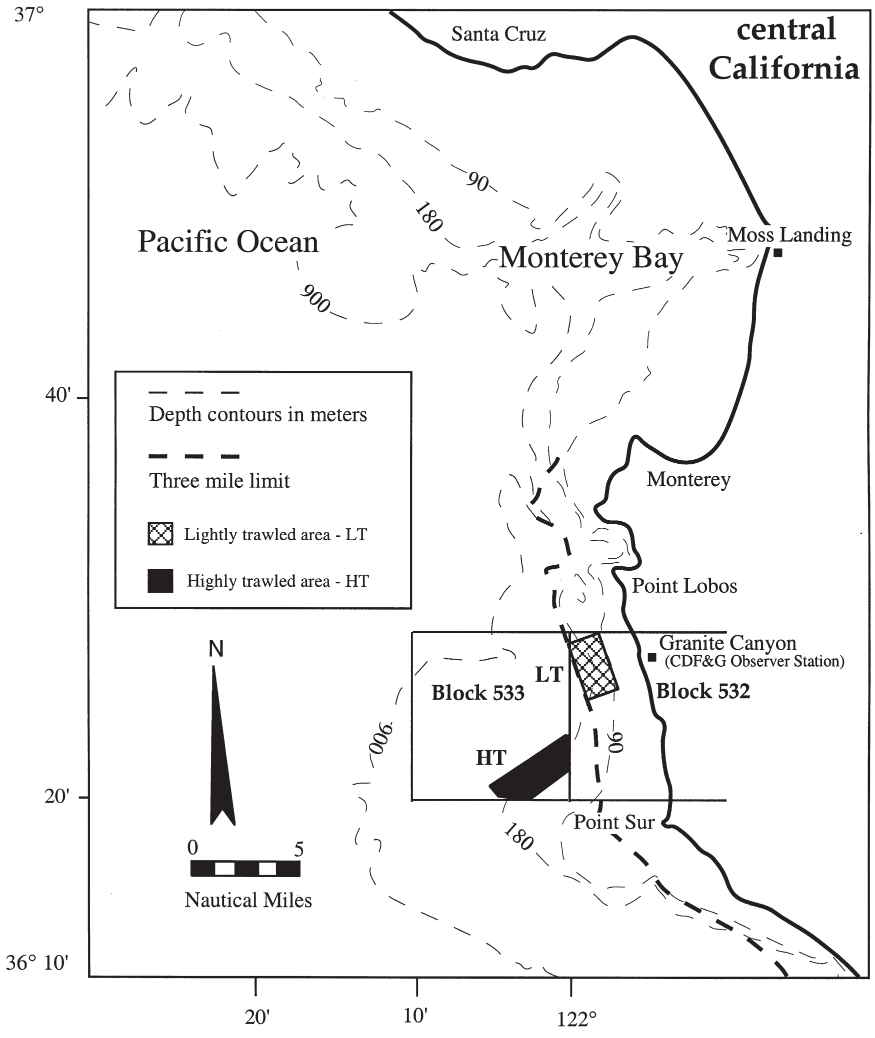

Figure 1. Map of study region in Monterey Bay National Marine Sanctuary showing the lightly trawled area (LT) in block 532 and the highly trawled area (HT) in block 533. All sampling was performed along the 180-m contour within the boundary displayed by the boxes around the respective study areas.

Our study was performed off central California in Monterey Bay National Marine Sanctuary waters from 1994 to 1996 (Fig. 1). We concentrated our study at 180 m, the depth zone targeted most heavily by fishermen (B. Leos, California Department of Fish and Game, personal communication). We examined biological and physical differences along a fishing pressure gradient, comparing a highly trawled (HT) area and a lightly trawled (LT) area. The highly trawled area was in the historic Italian fishing grounds, a popular and productive fishing ground that has been fished for nearly a century (center point: 36°21.5′N, 122°01′W). The lightly trawled area was in an adjacent site, inside three nautical miles of the coast (center point: 36°27′N, 121°59′W). Our goal was to use this fishing gradient as a limited control to determine if bottom trawling (1) reduces habitat heterogeneity, (2) reduces biodiversity, (3) increases the abundance of opportunistic species, and (4) increases the abundance of prey important in the diet of commercially harvested fish.

Study Design

Our original design took advantage of the restriction of commercial trawling to areas beyond three nautical miles off the West Coast of the continental United States. For a treatment-control pairing, we located an area suitable to trawling where the 180-m contour dips inside three nautical miles and is adjacent and physically similar to a highly fished area. On our first sampling trip we observed trawl tracks in our non-fished "control" and learned that fishermen had petitioned and won permission in 1970 to use this area as a refuge region to fish during bad weather (California State Code, section 8836.5). With this finding, our work was immediately relegated to the same constraint as so many others (Dayton et al. 1995)—a study without a true control—but we were able to use the fishing pressure gradient (light trawling and high trawling) between our study areas as a basis of comparison. We used Pacific Fishery Management Council Trawl Logbook records managed by the

California Department of Fish and Game (CDFG) to document differential fishing pressure, which was possible because our study areas are located in separate blocks. The coastal ocean is divided into blocks 10 miles square (18.5 km^2) with assigned reference numbers, and fishermen are required to report a number of parameters including total harvest and hours spent fishing on a per-block basis (Pacific Fishery Management Council 1993).

Methods

Fishing pressure differences were established by comparing total harvest, number of hours trawled, and catch per unit effort (CPUE) data between block 532 (LT area) and block 533 (HT area) from 1987 to 1992. Student's *t* tests were performed on total yearly harvest, hours trawled, and CPUE values from blocks 532 and 533. We also used tow number statistics, compiled by Bob Leos of the CDFG, who has assembled 2 years (1989 and 1996) of data on number of tows per block, to document differences in fishing pressure. We calculated the number of times a square meter in each block might be fished per year based on area of target fishing grounds, average yearly trawling hours, average tow speed (3 knots), and average net width (20 m) (Messieh et al. 1991). Towing speed and net width averages are conservative estimates. The area of target fishing ground (90–270 m) in block 533 (location of HT area) was 22,008 km^2 and 60,801 km^2 in block 532 (location of LT area). Average trawl hours per year (1987–1992) were 816 in block 533 and 220 in block 532.

Our study entailed looking at the physical and biological differences between our study areas. To examine physical differences, we quantified the density of trawl scours, rocks, pits, and mounds and the percent cover of flocculent matter, exposed sediment, and shell debris in each area. To assess biological differences, we quantified the density of invertebrate epifauna (surface dwelling) and infauna (subsurface dwelling) between areas and used gut content analysis to estimate the diets of commercially important fish species.

We used Delta Oceanographic's submarine (DELTA) to collect still and video photography in October 1994. Five dives at randomly chosen stations along the 180-m contour were made in each study area. A 35-mm camera fitted with an intervelometer and mounted on the right side of the submarine was programmed to take photographs every 30 seconds. Fifteen slides from each of four dives in the lightly trawled and four dives in the highly trawled study areas were randomly selected. We analyzed the slides with a randomly generated, 50-point grid for percent cover of exposed sediment, flocculent material, shell fragments, rocks, and "other" (rocks and the amphinomid polychaete, *C. pinnata*). Percent cover results were compared by Student's *t* tests.

Two or three 15-minute video transects were run on each dive and later analyzed for physical (trawl tracks, rocks, mounds, and pits) and biological (epifaunal invertebrates) surface features ($n = 5$, LT area; $n = 4$, HT area). The video camera was mounted on the right side of the DELTA where the passenger porthole is located. Laser dots, separated by a constant 20 cm and superimposed on the video, were used to measure transect width on the screen. Mean transect width was measured by randomly pausing the video 20 times during each transect, measuring the distance between laser dots, and averaging the individual frame-width values. We determined the distance covered during each 15-minute video transect with PISCES software (latitude, longitude, and compass heading, as well as temperature, depth, and distance of submarine off the bottom). The PISCES data allowed us to chart each transect track and obtain the exact distance covered for each transect. This value, along with transect width, was used to determine the area covered on each transect. Density values from video transect images were generated from counts of individual physical and biological features per area of each transect and standardized to 500 m^2. Student's *t* tests were performed on the physical and biological video results.

Three years of bottom grab samples were collected with a 0.1-m^2 Smith McIntyre grab in each study area at randomly determined stations along the 180-m contour for infaunal density, biomass, and community structure analysis ($n = 4$, October 1994, LT and HT area; $n = 6$, December 1995, LT and HT area; $n = 6$, September 1996, LT and HT area). All samples were swirled and sieved with a 1-mm mesh sieve. Infauna were sorted, counted, and grouped as follows: amphinomid polychaete, *Chloeia pinnata*, other polychaetes, oligochaetes, crustaceans, ophiuroids, molluscs, nematodes, nemerteans, and "other" invertebrates (including echinoderms, sipunculids, echiurans, urochordates). Polychaetes and crustaceans were further sorted to species level. We performed two-way analysis of variance for uneven but proportional replication, followed by Tukey post hoc tests, on infaunal category data and polychaete and crustacean species data (Zar 1984).

Subsamples for sediment grain size analysis were taken in October 1994 ($n = 4$, LT and HT area). Grain-size analysis was performed following a modification of the techniques of Folk (1974) (Engel 1998). A Student's *t* test was run on grain-size results.

Experimental trawls were made in September 1996 to collect fish stomachs for gut composition analysis. Three 10-minute tows were made at stations randomly chosen along the 180-m contour in the lightly and highly trawled areas. Net contents from each haul were sorted (15 fish maximum per species) for commercially important species: Pacific sanddab (*Citharichthys sordidus*), English sole (*Pleuronectes vetulus*), Dover sole (*Micros-*

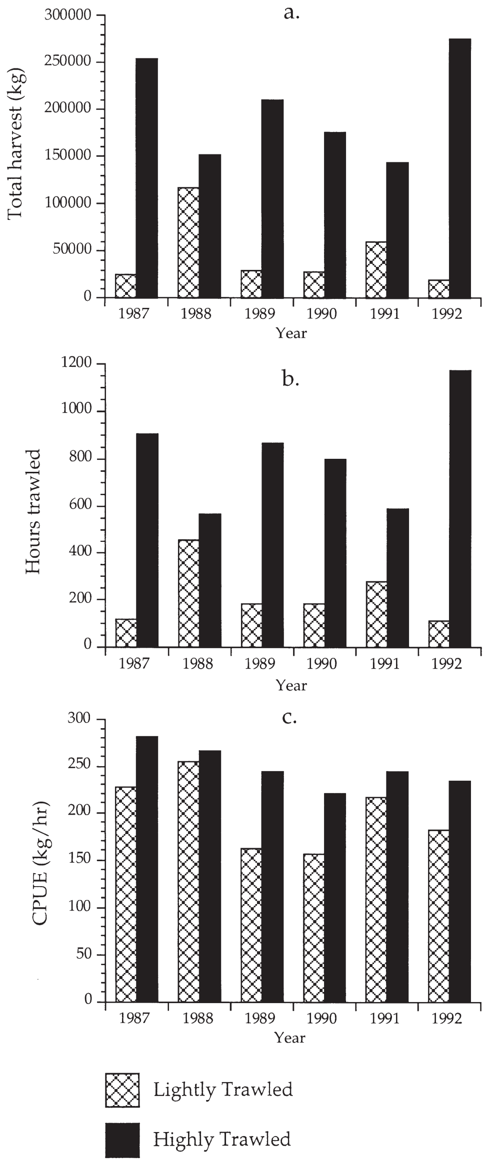

Figure 2. Pacific coast trawl logbook data in lightly trawled area (LT, block 532) and highly trawled area (HT, block 533) for years 1987 through 1992: (a) total harvest (kg) per year, (b) hours trawled per year, and (c) catch per unit effort (CPUE, kilogram/hour) per year.

tomus pacificus), rex sole (*Errex zachirus*), petrale sole (*Eopsetta jordani*), curlfin turbot (*Pleuronichthys decurrens*), lingcod (*Ophiodon elongatus*), sablefish (*Anoplopoma fimbria*), chilipepper rockfish (*Sebastes goodei*), and ratfish (*Hydrolagus colliei*). Weight wet of total stomach content and of the most common infaunal invertebrate, *Chloeia pinnata*, were measured after they were blotted on absorbent paper. A gut-content adequacy-of-sampling evaluation indicated that index of relative importance measures (Cailliet et al. 1986) should be performed only on Pacific sanddab, curlfin turbot, English sole, and Dover sole gut contents. Index of relative importance parameters computed for the stomach-content categories of *C. pinnata* and "other" (other polychaetes, molluscs, echinoderms, crustaceans, etc.) were percent total abundance (%N), percent total volume (%V), and percent total frequency of occurrence (%FO). Percent total abundance and percent total volume were calculated for each gut and then pooled to get a mean value for the LT and HT areas.

Results

Trawl logbook and CDFG tow number data showed a difference in fishing pressure between the HT and LT study areas from 1987 to 1992, with high fishing pressure in the HT area and low fishing pressure in the LT area. More kilograms of fish were caught every year in the HT area than in the LT area ($t = -5.932, p < 0.001$; Fig. 2a). More hours were spent fishing every year in the HT area than in the LT area ($t = -5.638, p < 0.001$; Fig. 2b). When harvest and fishing effort (trawling hours) data are considered together, it makes sense that the most fish are caught where the most hours are spent fishing. One might assume that fishing effort is applied where more fish exist and that there are simply more fish in block 533 than 532. There was, however, no significant difference in catch per unit effort (hours/kilogram) data, implying that fish density is similar in the two areas (Fig. 2c).

An average of 30 trawl tows were made in the LT area and 250 in the HT area in 1989. In 1996 an average of 31.5 tows were made in the LT area and 63 in the HT area. (Fewer tows were recorded in the HT area in 1996 because in the last few years draggers have been moving into deeper water [B. Leos, personal communication]). We calculated that any square meter of the highly trawled site might be trawled four times per year, whereas any square meter of the lightly trawled area might be trawled once every 3 years.

Sediment-grain size characteristics were similar in the two areas, with no significant difference found for any category (gravel, coarse sand, medium-fine sand, and silt-clay), indicating that the bottom type was the same in the LT and HT areas. Percent cover of shell fragments and exposed sediment was significantly higher in the HT area ($t = 4.968, p = 0.003$ and $t = 5.215, p = 0.002$, respectively), whereas percent cover of flocculent matter was significantly higher in the LT area ($t = -11.85, p < 0.001$). Trawl tracks were significantly more abundant in the HT area ($t = 3.685, p = 0.008$), whereas rocks larger than 5 cm in diameter and mounds were significantly more abundant in the LT area ($t = -2.481, p = 0.042$, and $t = -2.484, p = 0.042$, respectively).

All densities of invertebrate epifaunal species counted were higher in the LT area than the HT area. Those species that were significantly more dense were sea pens (*Ptilosarcus* sp., $t = -2.351, p = 0.051$), sea stars (*Me-*

diaster sp., $t = -2.99$, $p = 0.02$), sea anemones (*Urticina* sp., $t = -2.59$, $p = 0.036$), and sea slugs (*Pleurobranchaea californica*, $t = -4.316$, $p = 0.003$) (Fig. 3).

There were significantly more polychaete species in the LT area in 1994 and 1996 ($f = 6.829$, $p = 0.02$, $n = 32$, and $f = 6.829$, $p = 0.01$, $n = 32$, respectively), but there was no significant difference in the number of crustacean species between the two areas any year. Oligochaetes and nematodes were denser every year in the HT area and were significantly more dense in the HT area in 1994 ($f = 13.49$, $p = 0.014$, $n = 32$, and $f = 8.65$, $p = 0.007$, $n = 32$, respectively) (Figs. 4 & 5). Ophiuroids were more dense in the HT area every year,

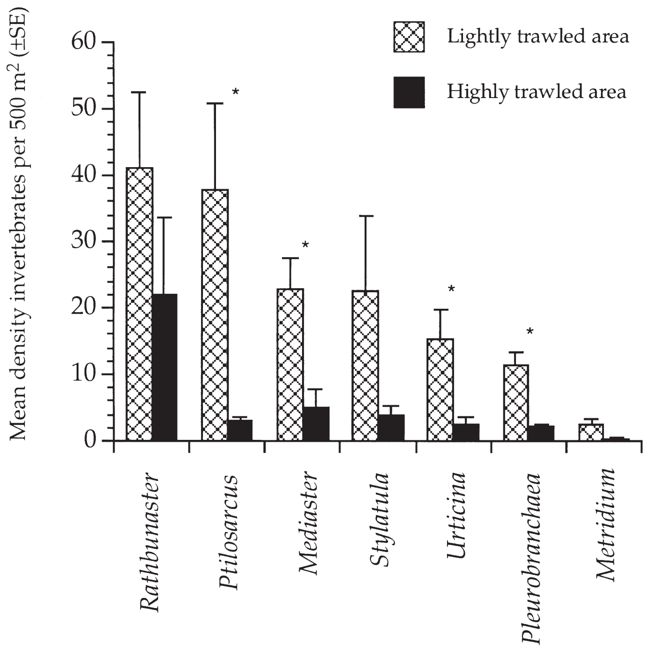

Figure 3. Mean density (± SE) of epifaunal invertebrates (>5 cm) per 500 m^2 in the lightly trawled (LT, n *= 5) and highly trawled (HT,* n *= 4) areas from video transects. The asterisk indicates significant density differences between study areas.*

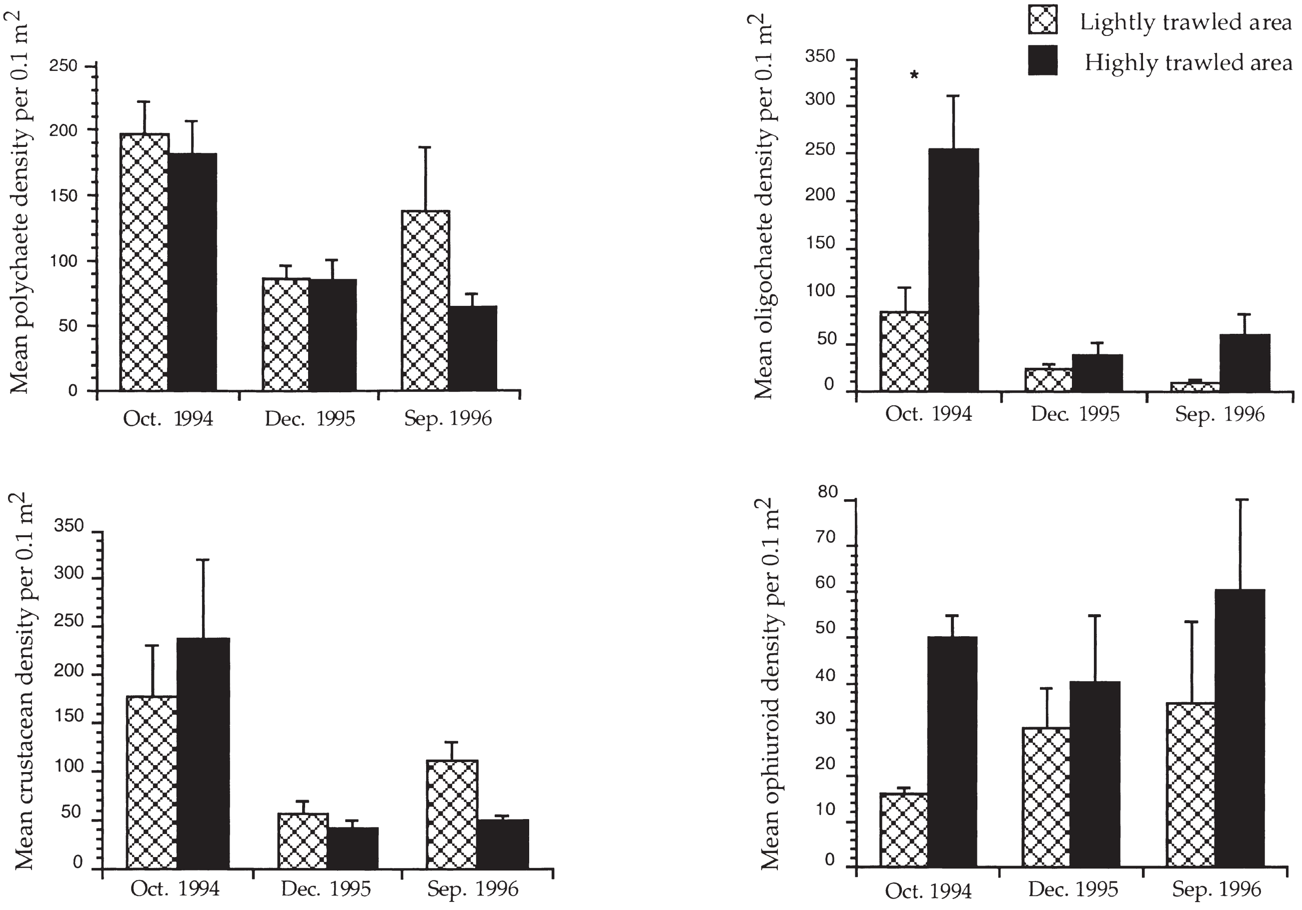

Figure 4. Mean density (± SE) of other polychaetes, oligochaetes, crustaceans, and ophiuroids over time in the lightly trawled (LT: n *= 4, October 1994;* n *= 6, December 1995;* n *= 6, September 1996) and heavily trawled (HT:* n *= 4, October 1994;* n *= 6, December 1995;* n *= 6, September 1996) areas from Smith McIntyre (0.1-m^2) grab samples. The asterisk indicates significant density differences between study areas.*

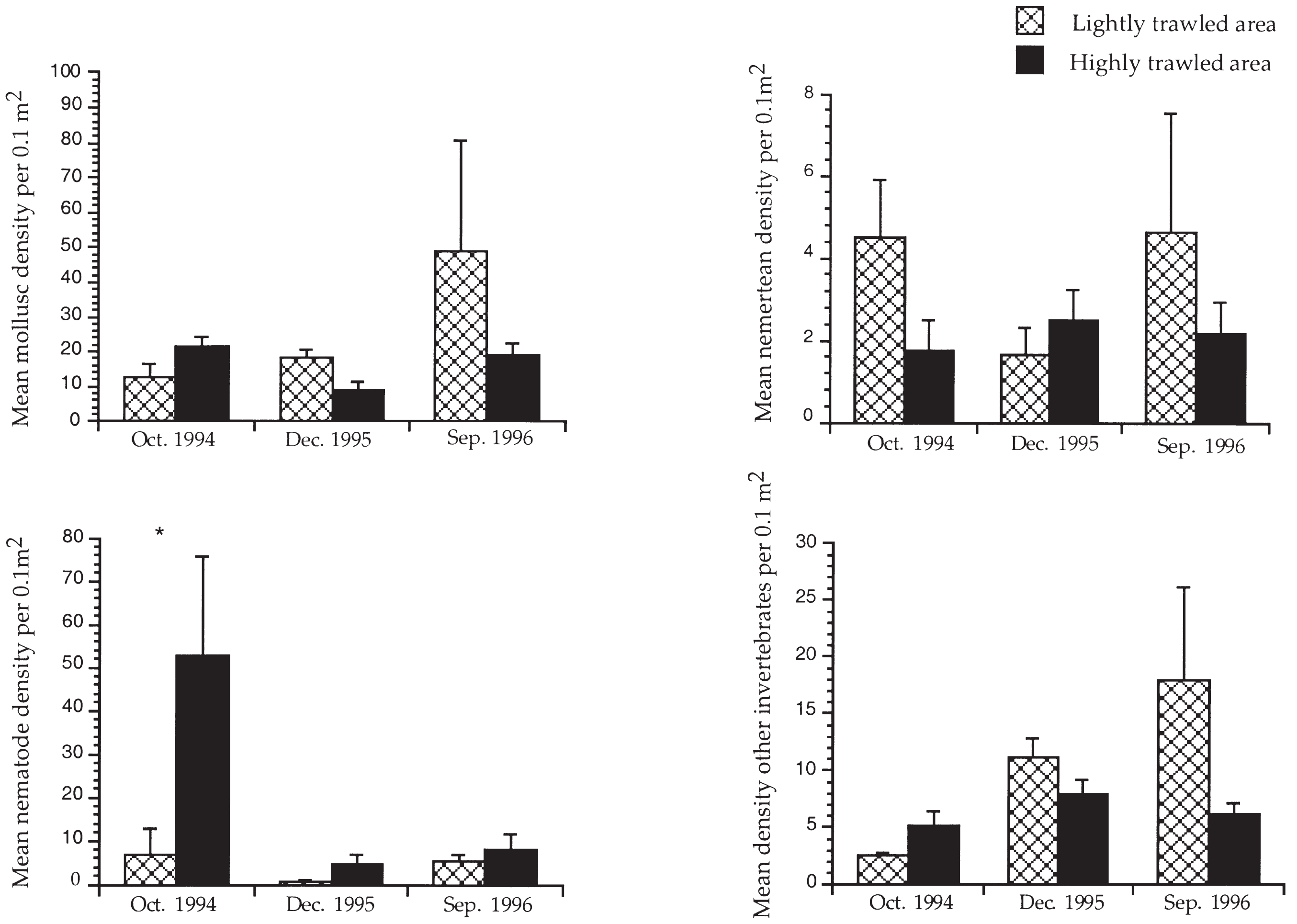

Figure 5. Mean density (± SE) of molluscs, nematodes, nemerteans, and other invertebrates (including echinoderms, sipunculids, echiurans, and urochordates) over time in the lightly trawled (LT: $n = 4$*, October 1994;* $n = 6$*, December 1995;* $n = 6$*, September 1996) and highly trawled (HT:* $n = 4$*, October 1994;* $n = 6$*, December 1995;* $n = 6$*, September 1996) areas from Smith McIntyre (0.1-m^2) grab samples. The asterisk indicates significant density differences between study areas.*

although no significant difference was detected (Fig. 4). There was no significant difference in the density of other polychaetes, crustaceans, molluscs, nematodes, or other invertebrates between study areas any year (Figs. 4 & 5).

The amphinomid polychaete *Chloeia pinnata* was significantly more abundant in the HT area in 1994 and 1996 ($f = 34.24$, $p = 0.002$, $n = 32$, and $f = 34.24$, $p = 0.001$, $n = 32$, respectively) and had significantly higher biomass in the HT area in 1994 and 1996 ($f = 20.94$, $p = 0.007$, $n = 32$, and $f = 20.94$, $p = 0.04$, $n = 32$, respectively) (Fig. 6).

Index of relative importance (IRI) measures (range: 0–20,000) made on Pacific sanddab, English sole, and Dover sole stomach contents showed *Chloeia pinnata* to be the most significant prey item for these fish in both study areas. Curlfin turbot were the only fish examined whose diet was not dominated by this worm. The index of relative importance of *C. pinnata* in Pacific sanddab diets was slightly higher in the HT area (8,424) than the LT area (7,300), whereas the IRI for the category "other" prey items (the catch all for invertebrate prey items other than *C. pinnata*) was slightly higher in the LT area (8,200) than HT area (7,176). The curlfin turbot IRI of other prey items (14,256) was an order of magnitude higher than that for *C. pinnata* (1,900) in the LT area. In the HT area the IRI of other prey items (6,100) was three times higher than that for *C. pinnata* (1,638). English sole were caught in high enough numbers for IRI analysis only in the LT area (IRI: *C. pinnata* = 11,988, other = 4,315), whereas Dover sole were caught in high enough numbers for IRI analysis only in the HT area (IRI: *C. pinnata* = 12,264, other = 4,806).

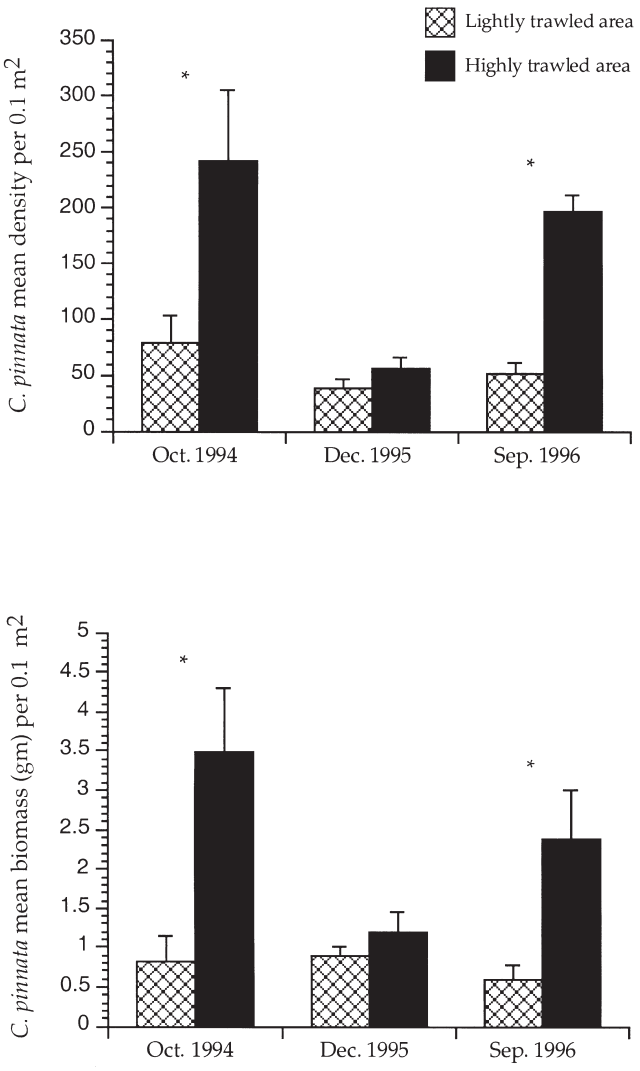

Figure 6. Mean density (± SE; top) and biomass (± SE; bottom) of the amphinomid polychaete Chloeia pinnata, *over time in the lightly trawled (LT:* n = *4, October 1994;* n = *6, December 1995;* n = *6, September 1996) and highly trawled (HT:* n = *4, October 1994;* n = *6, December 1995;* n = *6, September 1996) areas from Smith McIntyre (0.1-m^2) grab samples. The asterisk indicates significant density differences between study areas.*

Discussion

Our physical data indicate that intensive trawling significantly decreased habitat heterogeneity. Rocks and mounds were less common and exposed sediments and shell fragments were more common in the highly trawled area. These differences are consistent with the action of rubber bobbins, steel weights, tickler chains, and heavy otter boards, all of which dig into the substrate to varying degrees, scraping the sediment surface and potentially crushing sessile organisms, including shelled invertebrates (International Council for Exploration of the Sea 1988). Trawl tracks were also more dense in the highly trawled area than in the lightly trawled area. Our method of documentation did not quantify the spatial coverage of trawl tracks because individual tracks were counted once, although they often continued along video transect surveys for a considerable distance.

Video transects showed that both rocks and mounds were more abundant in the LT area, and still photography showed that flocculent matter or detritus was also more abundant in the LT area. Less trawling most likely results in an area with more topographical relief and allows for the accumulation of debris, whereas consistent trawling removes rocks, smooths over mounds, and resuspends and removes debris.

We used species diversity as a proxy for biodiversity. All of the epifaunal invertebrates counted in the video transects were less abundant in the HT area (Fig. 3). Although we found no difference in the number of infaunal crustacean species in the grab samples between study areas, we did find more polychaete species in the LT area than in the HT every year, implying that high levels of trawling can reduce biodiversity.

The greater abundance of oligochaetes and nematodes in the HT than in the LT area every year suggests that high-intensity trawling favors opportunistic species (Figs. 4 & 5). Many oligochaetes are pioneer species, known to be early colonizers in frequently disturbed areas and scavengers that feed on dead organic matter (Brusca & Brusca 1990). Nematodes, one of the most abundant animals on earth, can be found in extremely harsh environments and may be well suited to areas of high trawl disturbance (Brusca & Brusca 1990).

The high numbers of ophiuroids and of the amphinomid polychaete *Chloeia pinnata* found in the HT area were unexpected and intriguing because these species are not identified in the literature as opportunists (Figs. 4 & 6). Bergman and Hup (1992), however, found that the number of the brittle stars (*Ophiura* sp.) living in the upper centimeter of the sediment did not change after heavy trawling, suggesting that these animals escape undamaged through the meshes. Pearson et al. (1985) found an increase in ophiuroids and worms and a decrease in echinoids, with the change most apparent in shallow water. Kaiser and Spencer (1995) reported that few asteroid echinoderms are killed by the passage of trawls and attribute this in part to their regenerative abilities. Brittle stars have been observed in large numbers in trawl tracks in Monterey Bay (M. Yoklavich, personal communication) and in ice scours in the Canadian Arctic (J.A.E., personal observation). Ophiuroids are small, motile suspension feeders that are possibly unaffected by trawl disturbance, perhaps even favored by being small and flexible enough to slip through net mesh unscathed and take advantage of newly exposed nutrients.

Chloeia pinnata is one of the most abundant polychaetes off the coast of California, but its extreme abundance in the HT area was unusual. Jones and Thomson (1987) examined the distribution and abundance of *C. pinnata* in Southern California Continental Borderland waters and found densities ranging from 16 to 1600/m^2, with an average of 200/m^2. Hyland et al. (1991) recorded *C. pinnata* density on the continental shelf between Point Conception and Point San Luis on many sample cruises between 1986 and 1989. At 150 m depth at south and middle stations they recorded an average of 1000 *C. pinnata* per m^2. At the north station, density was below 300 per m^2. We mention these studies because the average density we measured in the HT area in the fall of 1994 and fall of 1996 was over 20 times higher than their values, with an average of 22,500 *C. pinnata* per m^2 and 7000 *C. pinnata* per m^2 in the winter of 1995 in the HT area. Densities in the LT area were also higher, with averages ranging from 4000 to 7000 per m^2. Like ophiuroids, *C. pinnata* are small, motile invertebrates that may be unaffected by trawl disturbance because they pass unharmed through the net mesh and perhaps benefit from organisms (food resource) that the net crushes or kills. According to Fauchald and Jumars (1979), *C. pinnata* is a carrion feeder (carnivorous scavenger) that roams around on the sea bottom. Gut content analyses by Thompson (1982) showed that *C. pinnata* stomachs contained a high proportion of animal remains, with some detrital aggregates and some mineral particles.

Day (1967) writes that the genus *Chloeia* swims well and is occasionally taken in trawl nets and from the stomachs of fishes. We found *C. pinnata* to be the most common invertebrate in the diet of several commercially important flatfish species in both the HT and LT areas. This suggests that certain prey species and commercially important fish may be enhanced by some level of trawling disturbance.

We believe that the differences we observed between our study areas are a result of trawl disturbance effects. Because of small sample sizes, lack of a true nonfished control, and no site replication, however, we cannot rule out the possibility that some of the differences we observed may be attributable in part to physical site differences such as shape, slope, orientation, proximity to shore, substrate chemistry, oceanographic circulation patterns, and hydrographic differences. Because essentially all areas that are suitable for trawl fishing are already fished, it is virtually impossible to locate adequate treatment and control sites for comparison. As a result, we were forced to take the next best alternative—paired sites representing an uncontrolled gradient of trawling pressure.

The results of our study highlight a serious ecological, economic, and social dilemma: high-intensity trawling apparently reduces habitat complexity and biodiversity while simultaneously increasing opportunistic infauna and the prey of some commercial fish. The question of how to maintain the long-term sustainability of fish stocks and benthic communities remains unanswered. Although more prey may be available for adult life stages of economically important fishes, habitat and prey availability for juveniles may be degraded by trawling (Sainsbury 1988; Harris & Poiner 1991). Furthermore, because relationships among trawling intensity, prey enhancement, and community recovery have not been quantified, policies governing the management of trawling grounds are difficult to set. This problem is further exacerbated by the near-universal absence of areas that can be used for true no-harvest controls or sites where fishing effort can be systematically manipulated.

The only way to address these questions adequately is through large-scale, long-term, manipulative studies in marine reserves (National Research Council 1995). For example, the infrastructure for implementing such studies exists in our national marine sanctuaries. Working with all stakeholders—resource agencies, fishery representatives, fishers, elected officials, and research institutions—to determine the size, location, and duration of an experiment and the conditions under which it would be terminated, areas within designated fishery reserves could be identified for research on the impacts of trawl gear. Questions pertaining to biodiversity, habitat heterogeneity, recolonization, and recovery rate following different levels of trawling intensity and frequency could be easily and definitively addressed. This approach has already been applied successfully in the Gulf of Castellammare (NW Sicily), where a total ban on trawling was implemented in 1990, and after 4 years a remarkable increase of the demersal resources (five-fold in the case of red mullet) was recorded (Pipitone et al. 1996). The ban was accepted by drag fishers, who were compensated by the government for their incurred revenue losses. The ultimate goal of such studies should be local management strategies aimed at maintaining global fish stocks and biodiversity.

Auster et al. (1996) write that our understanding of the impacts of fishing gear should include their effect on productivity in a broad, ecosystem-based management sense that includes human values and a vision of what the fishery should produce and what degree of biodiversity should be maintained in the system. Once agreed upon, managers and policy makers will need to know what practices can be applied to achieve their goals. Although our results do show that high levels of trawling can lead to a variety of physical and biological changes, the power of our study was compromised by the lack of a true control site (a similar but untrawled area). Until researchers have the opportunity to manipulate trawl intensity within paired treatment-control sites, we will be forced to make do with unreplicated and poorly controlled experiments. Under these circumstances it will be difficult if not impossible to identify the optimal levels of trawling for preserving fish stocks as well as biodiversity.

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