GOI – UNDP SEA TURTLE PROJECT

Workshop on
‘Networking and Coordination for TED Manufacture
and Promotion Along the Indian Coast’

10th & 11th December 2002,
Visakhapatnam, Andhra Pradesh

SPONSORED BY
MINISTRY OF ENVIRONMENT & FORESTS, GOVERNMENT OF INDIA
AND
UNITED NATIONS DEVELOPMENT PROGRAMME

MARINE PRODUCT EXPORT DEVELOPMENT AUTHORITY
WILDLIFE INSTITUTE OF INDIA, DEHRADUN

SELECTED READINGS
FINAL REPORT OF WORK DONE BY THE SIFT, KAKINADA UNDER THE GOI UNDP OLIVE RIDLEY SEA TURTLE CONSERVATION PROJECT.

A contract under the GOI-UNDP Olive Ridley Sea Turtle Conservation Project, was entered into by the Wildlife Institute of India, Dehradun (implementing agency) and the State Institute of Fisheries Technology, Kakinada (recipient organization) in August 2001 with the following broad terms of reference:

- To conduct a workshop for the fishing communities, fisheries officials and other stakeholders on the usage of TED along the coast of A.P.
- To set up a demonstration cum information base at the SIFT, Kakinada for a proposed period of one year for the dissemination of information and practical demonstrations of TED, which they may continue operating after project completion.

Tasks to be accomplished:

- To conduct a two day workshop primarily for fishing communities and also for Fisheries officials and other stakeholders on the usage of TED along the coast of A.P. including a practical demonstration and a theoretical workshop.
- To conduct demonstrations for trawler operators at sea on the use of TED for the conservation of sea turtles.
- To educate the fisherfolk on the need to conserve turtles.
- To serve as a state wide information center for dissemination of information on turtle conservation for fishers, students, general public and gear technologists.
- To train and encourage fishers in the use of TED.

The implementing of the project by the SIFT was carried out in a phased and planned manner to achieve the intended results. The tasks put forth were accomplished in the following manner:

1. Awareness programs were conducted in the vulnerable areas during the Turtle Pre-nesting period in the fisherman villages to create an awareness among the fisherfolk about the need to conserve turtles and their habitat for protecting the marine environment.

2. A two day workshop on the "Operation of the TED" was conducted at Kakinada on the 24th and 25th January 2002, wherein about 200 members consisting mostly of fishermen from all over the state participated.

3. A TED demonstration cum information centre was established on 26-1-02 at the SIFT, Kakinada in the second floor of the Administrative Building.

4. Demonstrations of the operation of the TED were conducted at all the Fishing Harbors and jetties in the state to encourage the fishermen in the use of TED.

5. The "Save Turtle Team" comprising the Faculty of the SIFT conducted beach patrols to make a random survey of the incidental mortality in fishing gear, followed by awareness meetings at the fisherman villages.

6. Literature in Telugu consisting of three catchy pamphlets were prepared and distributed during the awareness programs and TED demonstrations to make the mission more effective.

7. A poster in Telugu and English on sea turtle conservation was printed to convey the message to most interior fisherman villages.

8. Audio visual equipment was purchased with the balance of TED workshop funds to exhibit the activities taken up by the Fisheries Department for conservation of sea turtles and implementing the use of the TED, even to the fishermen living in interior villages.

Detailed reports of the work done on these lines is submitted in the following pages.
The recommendations put forth by the participants during the “Workshop on the Operation of the TED” conducted by the Dept. of Fisheries and Wildlife Institute of India at Kakinada on 24th & 25th January 2002 have been categorized under 3 heads as follows:

1. Protection, Enforcement & Regulation
2. Monitoring, research & evaluation
3. Community based conservation

The recommendations put forth by the participants have been summarized as follows:

Recommendations under Protection, Enforcement & Regulation:

1. Interdepartmental co-ordination among concerned state govt. departments i.e. Fisheries and Forest departments in collaboration with Wildlife Institute of India, ICAR Institutes, Fishermen and NGOs is necessary, as the strategies for conservation of turtles will not be successful with isolated efforts.
2. As the status of sea turtles varies from state to state, strategies for conservation should be as per local conditions.
3. National Marine Turtle Conservation Policy is to be formulated.
4. Existing Legislations need to be reviewed.
5. Reclamations of beaches and protection of nesting beaches should be taken up by the Forest dept.
6. Illumination of nesting beaches by hatcheries should be lessened during nesting season.
7. Strict implementation of the use of the TED in shrimp trawling, as prescribed in the A.P. Marine Fishing Regulation Act
8. An attempt to be made on collection of data on incidental mortality of turtles in fishing gear along the Andhra Pradesh coast.
9. Proper regulatory measures for mitigating incidental mortality in gill nets should be formulated by the Fisheries department and the CIFT.
10. The proposal to declare certain areas in A.P. near the Orissa border as turtle sanctuaries needs to be considered.
11. A long term Action Plan for atleast 10 years should be drafted for effective conservation of sea turtles.
12. Identification of nesting beaches along coastline to be confirmed.
13. Feedback from the fisheries department and fishermen must be taken into consideration for future TED designs.
14. The State Institute of Fisheries Technology, Kakinada in coordination with the Jt. Director of Fisheries(coast), NGOs to work out an Action Plan at village level.
15. Eco-tourism to be linked with conservation of turtles.

Recommendation Under Monitoring, Research & Evaluation:

1. a) Monitoring of the use of the TED by the fishing trawlers has to be monitored at sea by means of the patrol boats.
   b) Monitoring of nesting zones along the entire coastline of A.P. to be surveyed for nesting and incidental mortality; landside monitoring to be done by the Forest dept and sea based to be taken by the Fisheries Dept.
   c) Monitoring the regulatory measures should be taken up by the Fisheries Officials of the concerned areas.
2. Apex monitoring team comprising of officials of Save turtle team of S.I.F.T.; other departmental officers of A.P. State Fisheries, Forest Department, CMFRI, Andhra University, NGOs and local fishermen.
3. On-going research on TED technology to be a long term process to suit to the needs of local fishing.
4. Tagging and Telemetric methods to be taken up by NRSA and WII.

5. Collection of data of incidental mortality of turtles all along coast, Computerization of the same-Comparing it with the base line data, Evaluation to be done every year by the apex team and disseminate the same to all concerned.

6. Based on Evaluation - Intermediary meet of all department officials involved to revalidate the effectiveness of the plan.

7. Research on TED designs to be explored by CIFT.

8. Funding by concerned agency throughout the action plan period is necessary.

9. Study tour of SIFT faculty to Gaharimata in the forthcoming month is to be arranged to study different aspects of turtle conservation.

10. TED - information centre of SIFT - to act as Nodal monitoring and information centre.

11. Training to faculty of SIFT on conservation of sea turtles to be given at Orissa coast and on design of TED at CIFT, Cochin.

12. Research on probes for identification of entry of turtles in trawls nets to be done by WII and NRSA.

13. Periodic trial netting with new designs of TED need to be experimented in order to decide its efficiency.

Recommendations for Community based Conservation:

1. SIFT - should play a vital role in bringing about awareness and co-ordination among all the stake holders viz. NGOs, Fisherfolk and Forest department.

2. Awareness programmes should be conducted throughout A.P. Coast line about conservation of turtles.

3. For popularization of TED awareness at all leading fishing harbours of A.P. it is necessary to safeguard the interests of fisherfolk.

4. Regional level work-shop on small scale may be organized in order to bring all concerned for a better understanding about conservation of sea turtles, as fishing activities vary from region to region.

5. Forest department officials should take ample interest to see that volunteers of VSS also cater to the interests of turtle conservation.

6. Awareness among fisherfolk children regarding conservation can be initiated at school level onwards by arranging competitions like debate, painting and poster making etc.

7. Sea Turtle Conservation messages may be disseminated to the coastal communities vide plays, skits, folks songs, dramas and display of placards, by organizing rallies, posters etc.

8. Formation of Turtle clubs at village level may be taken up and the best club may be awarded incentive.
The AusTED

Excluded Species

Description

The AusTED is designed to exclude large animals and fish from prawn trawls (Figure 1). This BRD features a flexible grid of wire encased in plastic secured to the trawl at approximately 70 degrees. Bar spacing is 110mm (4 1/5"). A funnel of netting guides all animals to the bottom of the grid and prevents prawn loss through the escape opening in the top of the codend. Large animals are then guided by the grid through the escape opening while prawns and other small animals pass between the bars and enter the codend (Figure 2). A simple fisheye is located ahead of the grid to reduce fish bycatch. A second funnel behind the grid prevents the catch from being flushed through the escape opening during haulback. The following details describe the construction of an AusTED to fit a 45mm (1 1/4") mesh codend measuring 150 meshes in circumference.

Construction

1. Grid placement

- Construct codend. Note the completed AusTED will be located in the first 50 meshes of the codend with the lifting strops located aft of the grid.
- Construct grid as shown (Figure 3).
- With the codend seam uppermost count 46 meshes back from the leading edge of the codend.
- Make a 21 1/2 mesh cut either side of the seam (43 meshes in total) followed by two converging 40 bar cuts towards the leading edge of the codend. Cut the remaining 2
The **NAFTED**

**Excluded Species**

![Figure 1](image)

**Description**

The NAFTED is primarily designed to exclude large animals from prawn trawls although animals may also be excluded (Figure 1). This BRD features an aluminium grid secured to at 45 degrees, with a bar spacing of 60mm (2 3/4\(\)\). A panel of netting guides all animals to the grid and prevents prawn loss through the escape opening in the top of the codend. Animals are then guided by the grid through the escape opening while prawns and other debris pass between the bars and enter the codend (Figure 2). The bars of the grid prevents sponges and other debris from becoming clogging the grid. A flap of netting is attached to the codend to prevent prawn loss through the escape opening. The grid is attached to a frame of aluminium. This allows rapid replacement of the grid should it become damaged. The following details describe the construction of a NAFTED grid codend measuring 150 meshes in circumference.

**Construction**

1. **Grid placement**
   - Construct codend. Note the completed grid will be located in the first 50 meshes of the codend and the lifting strops located aft of the grid.
   - Construct outer frame and grid as shown (Figure 3). The bar spacing is 60mm. The outer frame is made from 25mm tube (wall thickness 3mm). The inner grid is made of 16mm tube (wall thickness 1.6mm) and
The NAFTED

Excluded Species

Description

The NAFTED is primarily designed to exclude large animals from prawn trawls although smaller animals may also be excluded (Figure 1). This BRD features an aluminium grid secured to the trawl at 45 degrees, with a bar spacing of 60mm (2¼") A panel of netting guides all animals to the bottom of the grid and prevents prawn loss through the escape opening in the top of the codend. Large animals are then guided by the grid through the escape opening while prawns and other small animals pass between the bars and enter the codend (Figure 2). The bars of the grid are bent backwards near the escape opening. This prevents sponges and other debris from becoming fouled on the horizontal bar (at the top of the grid) and clogging the grid. A flap of netting is attached to the codend to prevent prawn loss through the escape opening. The grid is attached to an outer frame of aluminium. This allows rapid replacement of the grid should it become damaged while ensuring grid angle is maintained. The following details describe the construction of a NAFTED to fit a 45mm (1¼") mesh codend measuring 150 meshes in circumference.

Construction

1. Grid placement

- Construct codend. Note the completed grid will be located in the first 50 meshes of the codend and the lifting strops located aft of the grid.
- Construct outer frame and grid as shown (Figure 3). The bar spacing is 60mm. The outer frame is made from 25mm tube (wall thickness 3mm). The inner grid is made of 16mm tube (wall thickness 1.6mm) and 16mm solid bars.
and may result in prawn loss through the escape opening. Careful observation of the grid floats will assist checking for a twisted codend. Meshes unevenly secured to the grid may also cause twisting of the codend.

Clogged guiding funnel: this may be caused by starfish, coral, sponges or large animals fouling the meshes of the funnel. A smaller mesh size or canvas material may prevent clogging. Increasing funnel diameter may allow larger animals to pass more freely through the funnel but may also cause prawn loss through the escape opening.

Clogged grid: A clogged grid may be caused by large animals, sponges and other debris. Reducing grid angle may reduce this problem.

Hauling: When hauling the codend care must be taken to ensure the grid does not foul on the lazy line guides or 'bull horns'.

The above details are taken from an AusTED loaned to the AMC by the Northern Territory Department of Primary Industry and Fisheries. The size and types of materials used have varied in trials on the east coast to those in the NPF. For further information contact QDPI or the NTDPIF.
• Secure the first 5 meshes of the sides of the cover to the codend.
• Secure a 900mm length of lead core rope to the trailing edge of the cover.

Trouble Shooting

Prawn Loss: Prawn loss may be due to incorrect grid angle, grid blockage (see below), stretched funnel netting, a stretched escape cover or a large animal caught in the escape opening.

Twisted codend: This may be due to poor codend deployment (prior to shooting away) and may result in prawn loss through the escape opening. Careful observation of the grid floats will assist checking for a twisted codend. Meshes unevenly secured to the grid may also cause twisting of the codend.

Clogged guiding panel: This may be caused by starfish, coral, sponges or large animals fouling the meshes of the panel. A smaller mesh size or canvas material may prevent clogging. Increasing panel width may allow larger animals to pass more freely through the funnel but may also cause prawn loss through the escape opening.

Clogged grid: A clogged grid may be caused by large animals, sponges and other debris. Reducing grid angle may reduce this problem.

Hauling: When hauling the codend care must be taken to ensure the grid does not foul on the lazy line guides or 'bull horns'.
Sea turtles are an ancient and widely distributed species whose migratory pattern extends over all the oceans of the world. Due to harvesting of sea turtles and their eggs and their accidental mortality associated with shrimp trawling and other fishing operations, turtles have been threatened with extinction in all parts of the world. Accidental catch of marine turtles are reported to occur particularly along the east coast of India. Marine turtles are endangered species, which are protected under Schedule I of the Indian Wildlife Protection Act 1972. They are also protected under the international conventions such as Convention on Migratory Species (CMS) and Convention on International Trade on Endangered Species of Wild Flora and Fauna (CITES), to which India is a signatory. Of the seven species of sea turtles found worldwide, five are reported to occur in India. They are Leatherback (Dermochelys coriacea), Green turtle (Chelonia mydas), Hawksbill (Eretmochelys imbricata), Loggerhead (Caretta caretta) and Olive Ridley (Lepidochelys olivacea), of which Olive Ridley is the most common species.

Researchers have developed special equipment known as Turtle Excluder Device (TED) that greatly reduces incidental death of sea turtles in shrimp nets. TEDs were introduced in US shrimp trawling operations in 1980s. A TED is a frame consisting of a grid of bars installed before the codend of the trawl net at an angle leading upward and downward to an escape slit. Small animals such as shrimp, slip through the bars and are retained in the codend, while large animals, such as turtles, large fishes and large elasmobranchs are stopped by the grid bars and can escape through the opening. Experience has shown that the use of TEDs when combined with other elements of an integrated turtle conservation, can stop the decline in sea turtle population and will, over a period of time, lead to their recovery. Expert Scientific Panel (March, 2000) in their Report Study on the Distribution of Sea Turtles, their Incidental Mortalities in Fishing Nets and Use of Turtle Excluder Device in Fishing Trawlers, submitted to the Ministry of Agriculture, Government of India, has recommended the mandatory use of TEDs by all mechanized trawlers operating in areas where higher incidental mortalities have been recorded, in Indian waters.

Shrimp is the major foreign exchange earner contributing to over 70% of the marine products export earnings. Section 609 of Public Law 101-162 of the US restricts imports of shrimp harvested with fishing equipment such as trawl nets which are not equipped with TEDs that result in incidental mortality of sea turtles. The law ensures that US market demand for imported shrimp does not involve the Endangered Species Act. In October 1996, India, Malaysia, Thailand and Pakistan requested consultation with the United States under WTO dispute settlement procedures regarding US import restrictions, claiming that it is inappropriate for the US to prescribe their national conservation policies. In April 1998, WTO ruled that the trade restrictions were illegal. However, arguments are gaining ground that US laws are covered under exceptions to WTO rules for measures relating to conservation of exhaustible natural resource, but only failed in the way in which the law was administered.

The Code of Conduct for Responsible Fisheries (FAO 1995), which gives guidelines for sustainable development of fisheries, prescribes the need for protecting endangered species like sea turtles. As a signatory, India is duty-bound to conduct research, develop appropriate devices and practices, and implement regulatory measures for the protection of endangered turtles.

Shrimp trawling is currently the most valuable fishing system in India, in terms of the export earnings and domestic supply for fish. Concerns expressed by trawler fishermen over the lessening quantity of shrimp and fish by-catch owing to the installation of TEDs has to be taken into consideration. Standardization of TED for regional bottom trawling operations has to take place before regulations in terms of its mandatory use,
can be brought into operation. Trade barriers by the environmentally conscious importing nations of Indian shrimp are still a perceived threat, unless regulatory measures are taken up.

Construction and Installation of CIFT-TED

**Construction of the Frame:** An oval frame measuring 1000x800 mm is constructed of 10 mm diameter stainless steel rod. Five vertical grid bars of 8 mm diameter stainless steel rod are welded to the inside of the frame. The spacing between deflector bars is 142 mm and the maximum spacing between the frame and the adjacent deflector bar is 86 mm (Fig.1).

**Construction of TED extension:** The TED extension is constructed of single piece of polyethylene netting of 40 mm stretched mesh size and 1.5 mm diameter twine of size 150 x 60 meshes. The 60 mesh sides of the netting piece are sewn together to construct a cylinder (Fig.2).

**Construction of hoop:** A single hoop having a diameter of 900 mm is constructed of 8 mm stainless steel rod, for attachment to the leading edge of the TED extension (Fig.3).

**Fixing the grid at the correct angle:** The hoop may be laced to the TED extension leaving 5 meshes from the leading edge. For ease of installation, another hoop could be attached to the other end of the extension. The TED frame may be slid into the extension. Using the hoops, the extension tube may be stretched so that it is taut. The TED extension may be so positioned that the extension seam is at the bottom. Starting from the rear edge of the extension, 36 meshes may be counted forward along the seam and the bottom centre of the TED frame may be attached to the netting. 18 meshes forward from the rear edge of extension along the seam may be counted followed by counting of 75 meshes perpendicular to the seam to arrive at the top centre attachment point. Later the TED frame may be attached to the extension netting (Fig.3 & 4). The sides of the secured TED frame may then be sewn to the extension netting. Grid angle should be between 40 to 55° from the horizontal, for proper operation.

**Cutting the exit hole:** The 1/2 mesh cut may be begun in front of the top centre of the TED frame and continued to cut along the frame maintaining 1/2 mesh distance from the frame, to either side until 1st and 5th grid bars are reached. The distance between 1st and 5th grid bars is 620 mm. 19 meshes may be turned and cut forward on either side. They may be turned again and cut to obtain a rectangular opening of 40 x 19 meshes in the extension.

**Construction and attachment of exit hole cover (flap):** The exit hole cover is made of a single piece of depth stretched and heat set polyethylene netting of 96x50 meshes, with 25 mm stretched mesh size and 1.0 mm diameter twine size.

The centre mesh of 96 mesh edge of the flap may be attached to the centre mesh of forward edge of the exit hole opening and this may be continued to 45 meshes of the flap to 20 meshes of the opening on either side of the attachment point. Remaining meshes of the flap may be sewn to the extension meshes to provide strength and shape to the flap. Along the sides may be attached 30 meshes of the flap to 19 meshes of the extension ahead of the TED frame. Six meshes of the flap may be attached to 4 meshes of the extension ahead of the TED frame. The remaining 14 meshes of the flap are to be left unattached.

**Construction and installation of accelerator funnel:** Two trapezoidal pieces of depth stretched and heat set polyethylene netting (25 mm stretched mesh size and 1.0 mm diameter twine size) with 75 meshes each in the leading edge may be cut; 30 and 42 meshes each in depth with a cutting rate of IN1B resulting in 55 and 47 meshes, respectively, in the rear edge (Fig.5). The two pieces are sewn together along the tapered edges, beginning from the leading edges, to form the funnel. The funnel may be installed inside the extension, forward of TED frame with the longer half of the funnel positioned opposite to the exit hole. The funnel is sewn.
to the TED extension, immediately after the hoop, which is attached to the leading edge. Attach 150 meshes of the funnel may be attached, mesh to mesh to the 150 meshes of the extension. The longer half of the funnel, may be secured at appropriate intervals, to the grid bars, a few centimetres from the bottom.

**Attachment of floats:** Two 150 mm hard plastic floats are to be attached to the outside of TED on the upper side, to the frame at the junction of outer grid bars, and another float is to be attached to the top of the hoop as shown in Fig.4, for weight compensation and stability, during operation.

**Installation of TED in trawl:** The completed TED is installed between codend and hind belly/extension of the trawl, with the exit hole facing upwards, by joining the edge meshes.

**Operation and Maintenance**

Before shooting the gear, the net should be inspected to ensure that the netting ahead of the TED is not twisted. The speed of vessel should increased before deploying the otter boards, so that the TED extension will ride high in water and twists, if any, could be easily detected. If twists are present, they should be removed before deployment of the gear.

While hauling the gear, it is better to keep the vessel against the current or maintain a low speed, in order to prevent the catch from being washed forward, to the exit hole. Once the otter boards are hauled up, the vessel should maintain speed and direction for a few minutes so that all catches are washed past the TED, into the codend. After each haul, the accumulated trash and debris that may clog the grid may be removed. Also, any gilled fish in the netting around the TED may be removed in order to permit good filtration.

It is important to check the grid angle on a regular basis, and make sure that it is between 40 to 55°, from the horizontal. This can be done as follows:

- An even row of meshes around the trawl body located approximately 1 m forward of the TED frame, may be gathered and tied tightly with a whip line;
- Using the whip line, the TED frame may be suspended freely, about 1 m off the deck, ensuring that there are no twists;
- The angle of the grid bar to the horizontal may be meshed by using a carpenter’s protractor, inserted through the exit hole.

Feeding rates, light control and alarms can be set and monitored with the keypad and display on the main controller. The simple sequential menu system allows easy alternation of parameters. IBM PC control through an RS232 link enables alteration and monitoring of all parameters in a user friendly Windows 95/98 environment. Parameters can be stored and reports generated on a PC remote from the main unit.

**Culture tanks**

Biopromasz Hipron Trading of Poland has a wide range of square, circular, conical or raceway tanks for use in fish culture. The tanks are made of high quality durable fibreglass reinforced with polyester. Each tank is equipped with bottom drainage of stainless steel or aluminium, PVC or stainless steel outlet pipes, overflow outlets, flanged collar tops and legs made of hot-dip zinc coating steel or impregnated wood. Tanks are designed in such a way as to limit "dead" or unproductive space. Various colours are available.

**Shrimp waste to pharmaceuticals**

Indonesia’s Marine and Fisheries Ministry together with PT Philip Seafood and a German company plan to build a factory to process shrimp and squid waste into preparations widely used in the pharmaceutical industry.

In the first phase, investment is estimated to be Rp800 million to provide a facility with a processing capacity of 10,000 tons a year.
Bycatch reduction devices can benefit prawn fishers

Scientific trials have shown that bycatch reduction devices can greatly benefit fishing practices in Australia's Northern Prawn Fishery. David Brewer, Nick Rawlinson, Steve Eayrs and John Salini describe how several devices reduce significant amounts of bycatch without losing catches of valuable prawns.

Fishers in the Northern Prawn Fishery (NPF) will soon be in a position to address many of the concerns relating to trawl impacts on bycatch. Recent research has shown that bycatch reduction devices (BRDs) allow fishers to exclude turtles from prawn trawls while maintaining or even increasing prawn catches. Other BRDs also significantly reduce the amount of unwanted fish bycatch as well as excluding under-commercial-sized prawns from their catch.

Australia’s Fisheries Research and Development Corporation (FRDC) funded research that has greatly advanced fishers’ ability to counter claims that their harvesting method is indiscriminate, and not compatible with the Commonwealth Government policy of encouraging ecologically sustainable practices. This research has been carried out by biologists and fisheries technologists from the Australian Maritime College, CSIRO, Northern Territory Department of Primary Industry and Fisheries, NSW Fisheries Research Institute, Queensland Department of Primary Industries, and in conjunction with members of the fishing industry.

Turtle catches eliminated

The recent scientific trials have shown that turtles and most other large animals, such as large sharks and stingrays, can be eliminated from prawn trawl catches by using inclined grids such as the Super Shooter, the Nardmore grid or the AusTRED (Figure 2). Each of these BRDs physically blocks large objects from entering the codend by guiding them out of the net. There is also evidence that the Super Shooter and the Nardmore grid can exclude other large objects such as sponges, that can damage prawns and be a nuisance in the catch. The angle of the grid (about 45°) allows most objects to “roll” out, either through a bottom opening grid (Super Shooter) or a top opening grid (Nardmore grid), without blocking the grid and therefore allowing prawns to pass freely into the codend.

In addition to greatly reducing catches of large animals, the Super Shooter (Figure 2a) has also been shown to consistently maintain prawn catches during scientific trials in the NPF. Preliminary results from trials on board the NPF trawler, ‘Petannë’ (Figure 1) appear to support this finding. The Nardmore grid — shown here combined with a square-mesh window to increase fish exclusion (Figure 2b) — required some modifications to decrease prawn losses recorded during scientific surveys, and these were made before the trial on board ‘Petannë’. Different versions of the AusTRED have been extensively trialed in different locations with varying levels of prawn retention (Figure 2c). In one set of trials north of Groote Eylandt, the AusTRED eliminated turtle catches, and decreased unwanted fish bycatch with no loss of prawns.

These devices will greatly assist fishers to reduce catches of turtles and other bycatch without losing valuable prawns. Fishers are already voluntarily beginning to test these devices. This will greatly increase our understanding of which devices work the best in different fishing grounds and under different conditions. Fishers will also improve the performance of these BRDs as their experience with them increases.

Value adding through bycatch reduction

The importance of maximising the catch of high quality undamaged prawns is now greater than ever. This is because most operators in the NPF maximise their returns by finger packing tiger prawns for export and these prawns must be in near perfect condition. Large animals will crush or break prawns in the codend and on the sorting tray.

Recent research has shown that approximately five to 10% more tiger prawns are damaged compared to catches without large animals. These prawns are known as “broken” and are of a lower market grade and fetch much lower prices. Even a small increase in the quality of undamaged prawns would translate into a significant increase in annual profit.

By using BRDs to reduce catches of large animals, fishers can increase the value of the catch by increasing the proportion of near perfect prawns. These devices are now “ready to go” and given the expected financial benefits to fishers, BRDs could be widespread throughout the NPF within a few years.

Avoiding catches of under-commercial-sized prawns

Most Florida Flyer trawls currently used throughout the NPF are rigged with 45 mm diamond mesh netting throughout the codend. This mesh size and type allows only the smallest of prawns to escape through the narrow mesh openings.

Trials of 45 mm square-mesh codends have shown that not only are catches of commercial sized tiger prawns (“under 30s”) maintained (only a 3% loss), but 28% of the bycatch is excluded (Figure 3). Equally important is the fact that in the NPF, most under-commercial-sized tiger prawns (between 58 and 98%) (“over 30s”) can escape, avoiding probable death on the sorting tray. This will mean that large numbers of small tiger prawns can be left to enhance future stocks and be re-caught when they are far more valuable.

BRDs may increase prawn catches

There is growing evidence that effective BRDs can increase catches of prawns. NSW Fisheries Research Institute scientists have developed the composite square-mesh panel which reduces the amount of unwanted bycatch by up to 41% and increases catches of prawns by four to 14% in their offshore prawn fishery (“PF” July 1996 p24). This panel has already been widely adopted in New South Wales and there is also some voluntary use by several fishers in the NPF.

There is also some circumstantial evidence of unusually high prawn catches from the NPF.

Figure 1: NPF prawn fishers are under increasing pressures to use more environmentally friendly trawl gears. 'Petannë' was recently used to conduct BRD trials in the NPF

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research when large amounts of bycatch were excluded using fisheye BRDs ("Australian Fisheries" May 1995 pp24-26). Although more evidence is needed to confirm this result, it adds weight to the argument that use of some bycatch reduction devices can increase prawn catches.

Increased prawn catches by using BRDs could be explained as follows. The exclusion of bycatch by using a BRD decreases the overall weight of catch in the codend, which reduces drag and promotes the maintenance of a wider wingend spread compared to a standard trawl. So a trawl fitted with an effective BRD can have a wider swept area over the duration of the tow than a standard trawl, resulting in higher prawn catches. Improvements in prawn catches will become more widespread as fishers adopt effective BRDs and make their own performance enhancing adjustments.

Ongoing gear improvements

Although recent BRD research has made significant steps towards providing prawn trawl fisheries with devices that are ready to use, there is plenty of scope for improvement in BRD technology. Even the most effective BRDs will be improved by fishers' experience and ingenuity once they are used more extensively on commercial trawlers. As BRD technology improves and new devices are developed, a greater range of options will be available to fishers that will allow them to select the device most suited to their needs and fishing conditions.

Commercial trials

In October, 1996, a selection of BRDs was tested on board the NPF trawler, 'Petann'. These trials form part of the ongoing campaign to provide a choice of the most effective BRDs for use by Australian prawn trawl fishers. The results will be presented at a fishing industry bycatch workshop in Cairns being planned for February 1997.

Further testing of BRDs will occur almost exclusively on commercial trawlers. An FRDC funded project began in July this year to provide Queensland, NPF and Torres Strait fishers with opportunities to use BRDs over the next three years, as well as providing an ongoing platform for continual improvement of the most promising devices.

Voluntary adoption of BRDs

By offering NPF fishers a range of different devices that have been shown to exclude bycatch and still catch prawns, we will see an expansion of the voluntary adoption of BRDs that has already begun in this fishery. It has been shown that voluntary adoption is undoubtedly the best way to incorporate new fishing technology such as BRDs into the industry (e.g. the Nordmøre grid into the NSW estuarine trawl fishery — "PF" June 1996 p28). Forced adoption (as seen in the USA) caused long and costly litigation battles and promotes extremely poor relations between the fishing industry and management bodies.

Further details of the new "loan-a-BRD" project can be obtained by contacting Julie Robins at Queensland Department of Primary Industries, Deception Bay (PH: +61 7 3817 9500), Steve Eayrs at the Australian Maritime College, Tasmania (PH: +61 3 63 354 404), or Brian Taylor at CSIRO, Cleveland (+61 7 3826 7226).

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Turtle Excluder Devices: Good for Sea Turtles, Good for People, and Good for Business

Peter A. Fugazzotto

Abstract

*Turtle Excluder Devices in shrimp nets protect more than just sea turtles. Not only do TEDs prevent the needless drowning of turtles, but they also protect overall marine biodiversity by allowing other species to escape from trawl nets. TEDs benefit commercial fisheries and coastal communities through reduction in bycatch. The economies of local communities are especially impacted by declining local catches as a result of mechanized trawling and the export-oriented economy that depletes locally consumed resources. In the US, the Sea Turtle Restoration Project has created a cooperative program between family shrimpers, environmentalists, retailers, and consumers, which creates incentives for shrimpers to properly use TEDs by increasing their access to the growing natural food industry in the US. The burgeoning US consumer market for environmentally- and socially-responsible products (such as tree-free paper, Dolphin-Safe tuna, and cruelty-free products) provides an opportunity for those using the best-available standards and technologies to benefit. TEDs are an important part of an overall sea turtle protection strategy, which also must include issues such as the creation of marine protected areas, limiting fishing effort, and finding solutions for other impactful fishery techniques, such as longlining and gillnetting.*

Discussion

Imagine a world where there are no more sea turtles. No females crawling up the beaches, no hatchlings scrambling to the sea, no turtles swimming among the coral. Imagine a world where there are no more fish in the sea. Where fishing nets are pulled up empty. Imagine a world where people no longer have fish to eat. Coastal people who has survived off the bounty of the sea for generations can no longer feed their children. Coastal communities are decimated as jobs are gone.
This chapter introduces Turtle Excluder Devices (TEDs), and how we must view them not only in terms of protecting sea turtles, but also in terms of how they help people and strengthen local economies. Ecological sustainability is not only about protecting one species or one place, it is also about promoting a framework for enhancing the livelihoods and quality of life of people, ensuring local control of resources for local benefit, and protecting the life support systems of the earth for future generations. As shown by the case of TEDs, it is possible to make simple, technological changes that help us move towards achieving all these goals.

**Why do we need TEDs?**

**For the sea turtles** — All seven species of sea turtles have been listed as endangered, threatened or vulnerable. The US National Academy of Sciences has concluded that shrimp trawling kills more sea turtles than all of other humans means combined in US waters, and it is believed that shrimp trawling has the same impact on sea turtle populations throughout the world. It is estimated that 150,000 sea turtles get caught in shrimp nets every year.

**For protecting fisheries and marine biodiversity** — The UN FAO estimates that 27 million metric tons of bycatch are discarded every year, equivalent to about one third of the total annual catch that is brought to port. Shrimp trawling accounts for 35% of the total global bycatch. Scientists have identified trawling as the most important source of human-caused physical disturbance on the ocean's floor, churning sediments on the seabed, crushing or burying marine life, and reducing the structural complexity of the seabed.

**For helping coastal fishing communities** — Throughout the world, we are seeing declining catches of fish. This means less food for people. For example, the FAO has reported that demersal fish stocks in the Gulf of Thailand are $1/10^6$ of what they were 30 years ago. Coastal communities are suffering through competition with mechanized fishing vessels because trawling occurs in the same inshore waters used by traditional small scale fishers. In some instances, once self-sufficient artisanal fishers have turned to collecting bycatch from shrimp trawlers, such as in Cameroon and Mozambique. Subsidies to large-scale industrial fisheries place local fishers at an economic disadvantage. This competition often leads to conflict. In South America, much of the fish caught is not for human consumption but rather
as an ingredient in animal feed in North America. It is estimated that one third of production is for fishmeal or secondary products. An FAO report indicates that 90% of fish caught is discarded in India, Malaysia, and the United States, meaning less food for people.

For supporting economic development – There is a growing economic disparity between hemispheres. There has been an increase in fishing effort in order to service debt, i.e., harvested as an export, even at the price of local food sources. There is the pressing need for alternative, local sources of income. The increasing catch of undersized fish by trawlers impacts local fishers. Undersized fish cannot grow to larger size, they are harvested before having the chance to reproduce, and are less economically valuable.

What are the benefits of TEDs?

To protect endangered sea turtles – TEDs are a simple, low technology solution that prevents the needless drowning of sea turtles. TEDs allow more than 97% of sea turtles caught in shrimp nets to escape, thus reducing the impact of trawling on sea turtles. TEDs prevent the needless killing of adult and juvenile sea turtles, which are critical to the continued propagation and survival of the species.

To conserve fishery resources – TEDs reduce the bycatch of other species of fish and marine life, in some cases up to 60%. The minimization of bycatch also helps make trawling more efficient, as less bycatch equals less fuel used, and less time sorting catch. TEDs also protect fishery stocks allowing adults to propagate the species.

To benefit traditional fisherpeople – TEDs help offset the amount of fish taken by trawlers. TEDs enable fishers to benefit from strong fishery stocks in terms of a local food source and a consistent source of income.

To create economic benefits through a healthy sea turtle population – A healthy sea turtle population can contribute to ecotourism development. Waheed (n.d.) determined the value of viewing marine wildlife was US$19 million per year (with turtles accounting for $4 million in the Maldives. Recent information has shown that ecotourism is the fastest growing segment of the tourism economy. A healthy sea turtle population can support limited, managed egg harvesting programs for local communities. In Costa Rica, the
community of Ostional has been legally harvesting sea turtle eggs in exchange for protecting the beach from poachers. Without a healthy population this harvesting cannot be justified.

**How can fishers use TEDs to their economic advantage?**
The Sea Turtle Restoration Project (STRP) believes that fishers can use increased environmental protection to their economic advantage. As public awareness grows about the state of the environment, increasing numbers of people are willing to buy, and pay higher prices, for products that help protect the environment. People are recognizing that cheaper is not always better, especially when thinking about health, the environment, and future generations.

Increasingly in the US, there is consumer interest in environmentally-friendly products. The natural foods industry, which is based on organic foods used without the use of pesticides, has been the strongest segment of the retail food industry. And this consumer choice ranges widely from cruelty-free shampoos to dolphin-safe tuna to beef produced without the use of steroids and antibiotics. The products are providing consumers with an environmental choice and providing jobs for people.

One example of this type of environment and jobs program is a cooperative program in the US among shrimpers, retailers, consumers, and environmentalists: the Turtle-Safe® Shrimp Certification Program.

In 1995, in response to lax government enforcement of US TED laws and cases of shrimpers purposefully disabling TEDs, STRP launched a cooperative program with shrimpers in order to provide an economic incentive for using TEDs properly. STRP designed a program to independently certify shrimp from trawlers that sign legally binding agreements with STRP requiring the use of TEDs and permitting us to conduct unannounced spot inspections of their vessels to ensure that they are properly using TEDs.

STRP has played a major role in educating the public and retailers about the availability of Turtle-Safe shrimp. We have placed advertisements; we have secured news coverage; we have designed fact sheets and brochures; we have talked to workers at restaurants and foodstores. What began as a good idea has turned into a positive program for the shrimpers and for the sea turtles, that also allow retailers and consumers to participate.

To date, we certify on average 1.5 million kg of shrimp every year. Turtle-Safe shrimp is now offered in several important consumer markets in
the US, including the San Francisco Bay Area, Georgia, the Pacific Northwest, and Colorado. Currently, the nation's second and third largest natural food store chains are offering Turtle-Safe shrimp to their customers.

**How do TEDs fit into the larger sea turtle protection picture?**

**TEDs as One Step in the Right Direction** – Many people have complained that TEDs are not the end all solution to the ongoing crisis that sea turtles face. We agree, but we think that TEDs are an integral and necessary part of a complex plan to protect sea turtles: Protecting nesting beaches from development does not prevent sea turtles from drowning in shrimp nets. Finding other means of livelihood for egg poachers does not prevent sea turtles from drowning in shrimp nets. But TEDs do, and therefore must be included in comprehensive sea turtle protection programs.

Even with all their benefits, TEDs are only a technical fix that help mitigate some of the impacts of fishing activities, and there is much else that we need to do to protect sea turtles: we need to close sensitive areas to fishing (in the US, the effort to create marine protected areas dedicated to sea turtles); reduce in fishing efforts; examine the impacts of trawling on tropical sea bottoms, and; examine of other fishery impacts beyond shrimp trawl vessels (longlines and gillnets).

STRP continues to stand strong in our call for the global use of TEDs and will continue to ensure that steps are taken to make this dream a reality, from the courts of the US to the docks of Costa Rica to the beaches of India. And we invite you all to join us in this effort to protect the endangered sea turtles.

**Acknowledgements**

I would like to thank the ASEAN Sea Turtle Symposium for the opportunity to present a paper and participate in discussions to increase sea turtle protection efforts worldwide. I would also like to thank the LaFetra South-North Exchange Program for providing financial assistance that has enabled STRP to participate in this symposium.

**References**

The Impacts of Mobile Fishing Gear on Seafloor Habitats in the Gulf of Maine (Northwest Atlantic): Implications for Conservation of Fish Populations

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ABSTRACT: Fishing gear alters seafloor habitats, but the extent of these alterations, and their effects, have not been quantified extensively in the northwest Atlantic. Understanding the extent of these impacts, and their effects on populations of living marine resources, is needed to properly manage current and future levels of fishing effort and fishing power. For example, the entire U.S. side of the Gulf of Maine was impacted annually by mobile fishing gear between 1984 and 1990, based on calculations of area swept by trawl and dredge gear. Georges Bank was impacted three to nearly four times annually during the same period.

Studies at three sites in the Gulf of Maine (off Swans Island, Jefferys Bank, and Stellwagen Bank) showed that mobile fishing gear altered the physical structure (complexity) of benthic habitats. Complexity was reduced by direct removal of biogenic (e.g., sponges, hydrozoans, bryozoans, amphipod tubes, holothurians, shell aggregates) and sedimentary (e.g., sand waves, depressions) structures. Also, removal of organisms that create structures (e.g., crabs, scallops) indirectly reduced complexity. Reductions in habitat complexity may lead to increased predation on juveniles of harvested species and ultimately recruitment to the harvestable stock. Because of a lack of reference sites, where use of mobile fishing is prohibited, no empirical studies have yet been conducted on a scale that could demonstrate population level effects of habitat-management options. If marine fisheries management is to evolve toward an ecosystem or habitat management approach, experiments are required on the effects of habitat change, both anthropogenic and natural.

KEY WORDS: ROV, occupied submersible, sidescan sonar, habitat distribution.
that the great and long iron of the wondyrchoun runs so heavily and hardly
over the ground when fishing that it destroys the flowers of the land below water
there . . .

Commons petition to the
King of England, 1376
(cited in Graham 1955)

Habitat alteration by the fishing activities themselves is perhaps the least
understood of the important environmental effects of fishing.

Committee on Fisheries, Ocean Studies
Board, National Research Council (1994)

I. INTRODUCTION

While the scientific community is sure that fishing gear alters the bottom, controversy
has continued from the fourteenth century to this day regarding the implications of
those impacts (Graham, 1955; deGroot, 1984; Messieh et al., 1991; ICES, 1992; Jones,
1992; National Research Council, 1994; Dayton et al., 1995). The overall impacts of
mobile fishing gear are unknown despite research efforts in the U.S. spanning nearly
80 years (beginning with Alexander et al., 1914). Understanding the extent and role
of mobile gear impacts is particularly important because of large increases in fishing
effort over the last 2 decades (NOAA 1955, Appendix 1). Studies of the impacts of
mobile gear can be divided into two major categories: (1) those that focus on specific
species; and (2) those that focus on habitat or a portion of the benthic community.

Studies concerning the effects of fishing on target species are the most common
and usually deal with valuable fisheries such as lobster (Homarus americanus) or
sea scallops (Placopecten magellanicus). Trawl impact studies on lobster populations
found that damage and mortality to lobsters during trawling varied seasonally
with molt state and air temperature (during handling on deck; Ganz, 1980; Smith
and Howell, 1987). Caddy (1973) and Shepard and Auster (1991) found dredge-associated
mortality of nonlanded sea scallops increased with increased bottom hardness.
Mortality was lowest on sand bottoms and greatest on pebble-cobble bottoms. Other
studies pertaining to the effects of scallop dragging on lobsters (Jamieson
and Campbell, 1985), and the effects of raking for Irish moss on lobsters and scallops
(Scarratt, 1973; Pringle and Jones, 1980) demonstrated the gear conflict issues that
persist in geographically overlapping fisheries. Although those studies provide
estimates of target species mortality during harvest, they do not consider the effects
of fishing on habitat degradation.

Studies that examined the effects of fishing gear at the habitat and community
level are less common. Early studies often drew conclusions based on little factual
evidence. Alexander et al. (1914) reported that the effect of trawling on the bottom
was negligible and stated that “otter trawls do not seriously disturb the bottom over
which they are fished nor materially denude it of organisms which directly or
indirectly serve as food for commercial fishes.” Their conclusion was based on data
from trawl catches, and shifts in species composition and abundance were attributed
only to harvesting by the fishery with no connection made to changes in habitat or the benthic community. This conclusion is not surprising given the state of ecological knowledge at the time (Auster, 1988). More recent studies found that fishing changed associations and species composition of nonharvested taxa, but the effects of those changes on the dynamics of harvested populations are not yet known (Holme, 1983; Langton and Robinson, 1990).

Many of the cited studies were conducted over previously fished grounds, and it is difficult to demonstrate trawling-induced habitat changes if specific habitat types have already been altered (Margetts and Bridger, 1971; Caddy, 1973; Gibbs et al., 1980). Recognizing this problem, more recent studies were conducted in areas that contained both trawled and reference sites (Van Dolah et al., 1987; Riemann and Hoffmann, 1991), or have sequentially surveyed an untrawled area before and after initial fishing activities (Sainsbury, 1987; Peterson et al., 1987).

Herrington (1947) was the first to make a connection between habitat composition and production of exploited stocks. He suggested the removal of benthic fauna such as sponges, and overturning and burial of rocks, would reduce spatial complexity of bottom habitats and affect the production of prey for harvested species. Peterson et al. (1987), using a manipulative field experiment, linked seagrass destruction by mechanical clam harvesting to reduced bay scallop production. The complex habitat formed by dense seagrass was directly linked to settlement density of scallops.

Sainsbury (1987, 1988) was the first to demonstrate a direct link between habitat change and subsequent changes in catch. On the northwest Australian shelf, he found that golden thread (Saurida spp.) and lizardfish (Nemipterus spp.) occurred predominately on open sand/"sparse" emergent benthos bottoms, while porgies (Lebrius spp.) and snappers (Lutjanus spp.) occurred in areas of "dense" emergent benthos (e.g., sponges, gorgonians, alcyonarians). Trawl data showed the bycatch of sponges and associated corals fell during the course of the developing trawl fishery, eliminating "dense" habitat types. Concurrently, fauna associated with sand/"sparse" emergent habitats increased in the catch, while the fauna associated with "dense" emergent habitats decreased.

Recent levels of fishing effort on the continental shelf of the northeast U.S. by trawl and dredge gear may have had profound impacts on the early life history in general, and survivorship in particular, of a variety of species due to small-scale (=microhabitat) alterations. We posit that mobile fishing gear has measurable effects on microhabitat availability. Herein we summarize studies conducted at three different locations in the Gulf of Maine (Figure 1) that show measurable impacts of mobile fishing gear on habitat complexity and discuss the implications of fishing gear impacts on the sustainability of harvested species.

II. CASE STUDIES

A. SWANS ISLAND

The area off Swans Island (44° 08.0' N 68° 23.0' W; 30 to 40 m) consists of coarse-grained material where cobble-shell and sand-shell bottoms predominate. The
Swans Island Conservation Area was closed to mobile fishing gear in 1983. Comparisons of habitat complexity, measured from video transects on cobble-shell and sand-shell bottoms, were made between reference (inside) and impacted (outside) sites using a remotely operated vehicle (ROV) during July 1993. Transects were approximately 50 m in length and conducted with the video camera set at a fixed angle. Each video frame covered an area of 0.35 m².

Video transects were treated as a series of nonoverlapping adjacent video quadrats (sensu Auster et al., 1989). The video records were time coded (i.e., hour, minute, second, video frame number) to identify and facilitate multiple viewing of individual video frames. Habitat types for the cobble-shell bottom were (a) cobble-shell pavement, (b) cobble-shell with emergent epifauna, and (c) cobble-shell with
sea cucumbers (Cucumaria frondosa). Habitat types on the sand-shell bottom were (a) flat sand-shell, (b) sand-shell with biogenic depression, and (c) sand-shell with sea cucumbers. (Sea cucumbers were considered as a habitat feature independent of attached epifauna because they are mobile.) A cover index (CI) for each habitat type was determined using random dot techniques. The CI was used rather than percent cover as the video images were trapezoidal (due to the oblique angle of the camera) and had pitch and roll bias within transects. In order to reduce the effects of this bias, each video frame was divided into two sections to assess cover. The nearfield half of each quadrat, on the video monitor, was overlaid by 20 computer-generated random dots on acetate. After the forward portion of the frame was enumerated, the farfield portion of the quadrat was “rolled” forward using the shuttle search feature of the video player. Different random dot patterns were used for each frame within a transect. The CI was expressed as a percentage of the dots (n = 40) covering each habitat type within each frame. The CI was arcsine transformed and comparisons of habitat cover within and outside the conservation area were made using two sample t-tests.

Emergent epifauna (i.e., hydroids, bryozoans, sponges, serpulid worms) and sea cucumbers were the dominant habitat features on cobble-shell bottoms (Figure 2a,b). The cover provided by emergent epifauna was significantly lower outside the conservation area (Table 1). We attribute this pattern to direct removal of epifauna by mobile fishing gear. Observations at the border of the conservation area showed cleared swaths in the epifaunal cover caused by scallop dredges and trawl doors.

Habitat complexity on the sand-shell bottom consisted primarily of biogenic depressions created by mobile fauna (Figure 2c) and sea cucumbers attached to shell and other biogenic debris. The cover provided by both types of structures was significantly lower outside the conservation area (Table 1). Reductions in the cover provided by biogenic depressions is attributed to harvest of those species that produce such structures (e.g., sea scallop, lobster, crab, white hake). Sea cucumbers may have been removed as bycatch or targeted for a directed fishery.

B. JEFFREYS BANK

Jeffreys Bank is a large mud-draped gravel bank (43° 22.5' N, 68° 44.5' W) with large boulders resting on the gravel bed. Until recently, parts of the bank have been inaccessible to mobile fishing gear because of boulders exceeding 2 m diameter. As part of a wide-ranging study of the gravel bank fauna in the Gulf of Maine, a submersible dive was conducted near the top of Jeffreys Bank during July 1987 at 94 m depth. The location was chosen specifically to sample an area that had not experienced reductions in the fauna due to gear impacts. Large communities of erect sponges were observed on a bottom of gravel and boulders covered with a thin veneer of mud. A 10-min video transect was conducted to document the extent of that community. The camera was kept at a constant angle and distance from the bottom. The rock surfaces were covered with an assortment of invertebrates, including long-legged pycnogonids, bryozoans, hydroids, anemones, sponges, crinoids, and tunicates. Also abundant were smaller mobile fauna, including several species of crustaceans, snails, and scallops.
FIGURE 2. (A) Emergent epifauna (i.e., sponge, bryozoans) attached to cobble, shell, and living Modiolus modiolus. (B) A sea cucumber used as shelter by an American lobster. (C) Depressions were formed by harvested species such as the sea scallop. (D) The ascidian, Mogula arenata, was distributed on coarse unconsolidated sand.
TABLE 1
Analysis of Cover Index (CI) for Each Bottom Type and Habitat Feature. Note That CI Is an Index of Cover and Not a Direct Measure of Percent Cover. (I = Inside Conservation Area; F = Fished Site Outside Conservation Area)

<table>
<thead>
<tr>
<th>Bottom type</th>
<th>Number transects</th>
<th>Mean CI</th>
<th>SD</th>
<th>T-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cobble-shell</td>
<td>I 13</td>
<td>60.25</td>
<td>2.47</td>
<td>$t = 5.51$</td>
</tr>
<tr>
<td>(emergent epifauna)</td>
<td>F 12</td>
<td>48.89</td>
<td>7.13</td>
<td>$p &lt; 0.001$</td>
</tr>
<tr>
<td>Cobble-shell</td>
<td>I 13</td>
<td>9.64</td>
<td>2.36</td>
<td>$t = 3.76$</td>
</tr>
<tr>
<td>(holothurians)</td>
<td>F 12</td>
<td>6.19</td>
<td>2.21</td>
<td>$p = 0.001$</td>
</tr>
<tr>
<td>Sand-shell</td>
<td>I 18</td>
<td>16.47</td>
<td>1.90</td>
<td>$t = 6.10$</td>
</tr>
<tr>
<td>(biogenic depressions)</td>
<td>F 17</td>
<td>11.82</td>
<td>2.54</td>
<td>$p &lt; 0.001$</td>
</tr>
<tr>
<td>Sand-shell</td>
<td>I 18</td>
<td>3.53</td>
<td>3.21</td>
<td>$t = 3.09$</td>
</tr>
<tr>
<td>(holothurians)</td>
<td>F 17</td>
<td>0.95</td>
<td>1.47</td>
<td>$p = 0.005$</td>
</tr>
</tbody>
</table>

This site was resurveyed 6 years later in August 1993. The camera was set closer to the bottom and at a different angle than in 1987 so video transects were not directly comparable. Even so, it was evident that much of the thin mud veneer was missing, exposing more of the gravel base, most of the epifaunal species were not present, and the extensive sponge community was reduced to the occasional small colony attached to the large boulders. Analysis of the approximately 2 hours of videotape indicated boulders had been moved and the area had been disturbed by fishing gear, probably resulting from trawling that was occurring during our study.

Percent cover of sponges was calculated for all nonoverlapping video frames (n = 150) in the video record from 1987. Each field of view covered an area of 1 m$^2$. The same number of video frames (starting at a randomly selected point) from the 1993 transect were enumerated, although the field of view was 0.5 m$^2$. Percent cover was estimated for each video frame using a perspective grid drawn on acetate that was divided into 100 equal area units and mounted on the video monitor. The number of units that contained sponge cover determined the percentage value.

In 1987, 15 frames had at least 10% cover, and a few had more than 25% cover (Figure 3a,b). No video frame had more than 7% sponge cover from the 1993 transect. Analysis of the 1987 transect ended in a region where the sponge cover was the greatest (Figure 3a), and the camera angle was changed to cover more area, dubbed the "sponge garden". In the entire 2 h of videotape taken in 1993, the "sponge garden" was never relocated and sponge cover was never greater than 7%.

C. STELLWAGEN BANK

Side-scan sonar mapping of the crest and upper flanks of Stellwagen Bank (42° 11.5' N, 70° 20.0' W, 20 to 55 m) during 1993 has shown it is not a homogeneous sand sheet, as suggested by previous generalized maps of the region (Schlee et al., 1973). It is covered by large expanses of sand, gravelly sand, shell deposits, and gravel. The
FIGURE 3.  (A) Percent cover of sponges per sequential field of view from 1987 and 1993 transects.  (B) Frequency of percent cover categories from 1987 and 1993 transects.
Sedimentary environments are created and altered by large storm waves from the Gulf of Maine to the northeast (Valentine and Schmuck, 1995). Although strong storms from the northeast are the primary cause of bottom disturbance, they do not occur every year. By contrast, mobile fishing gear is deployed on the bank on a nearly daily basis. Storm sand ripples of coarse sand that measure 30 to 60 cm between crests and 10 to 20 cm in height are disturbed by scallop dredging (Figure 4a). In addition to sand ripples, storms deposit large sheets of fine sand whose surface is sculpted into low sand waves that measure 15 to 35 m between crests. The troughs of these sand waves are filled with shell debris (primarily the ocean quahog Arctica islandica) that make up 10 to 20% of the bottom in these areas. The shell deposits form a complex habitat that is dispersed by mobile gear (Figure 4b).

FIGURE 4. (A) Side-scan sonar image of Stellwagen Bank seafloor showing storm sand ripples disturbed by scallop dredge gear (depth 40 m). (B) Side-scan sonar image of Stellwagen Bank seafloor showing storm dunes of fine sand with shell debris packed in the troughs (light linear areas). Scallop dredging has smoothed the bedforms and dispersed the shell (depth 38 m).
Observations on the crest of the bank in July 1993 (32 to 43 m) showed that epibenthic organisms that anchor in the coarse sand are removed by mobile fishing gear, changing the densities and associations of mobile species. Corymorpha pendula is a hydrozoan that attaches to the bottom during its annual benthic phase. Densities of Corymorpha and shrimp (primarily Dichelopandalus leptoceros and Crangon septemspinosa) were measured in 10 video quadrats (0.42 m² each) from each of three 50 m ROV transects (n = 30). There was a positive association between the density of shrimp and increasing cover provided by Corymorpha ($r^2 = 0.852$, ANOVA $p < 0.001$). Wide linear paths in benthic microalgal cover indicated recent passage of trawls and scallop gear through the area. In areas where microalgae were removed, aggregations of Corymorpha were absent. The density of shrimp was reduced from a mean of 13.3 m⁻² outside drag paths to zero in a scallop dredge path covering 199.1 m². Observations in July 1994 showed that the ascidian, Mogula arenata, was widely distributed over the bottom and the hydrozoan was absent (Figure 2d). Tracks from trawls were evident as the ascidians were removed in linear patterns consistent with that type of gear.

III. DISCUSSION

We have shown that mobile fishing gear alters seafloor habitats and reduces habitat complexity. Both sedimentary structures and emergent epifauna are impacted. Mobile species, including commercially important finfish and crustaceans, have associations with specific sedimentary and biogenic habitat features (Able et al., 1982; Grimes et al., 1986; Shepard et al., 1987; Cooper et al., 1988; Langton and Robinson, 1990; Auster et al., 1991, 1994, 1995; Malatesta et al., 1992, 1994; Auster and Malatesta, 1995; Felley and Vecchione, 1995; Langton et al., 1995). Various taxa (primarily groundfish and crustacean species) associate with structures such as biogenic depressions, shell, burrows, sand wave crests, sponges, amphipod tubes, cerianthid anemones, and holothurians. For example, the density of postlarval silver hake (Merluccius bilinearis) increased as cover provided by amphipod tubes increased (Auster et al., 1994). Similarly, redfish (Sebastes fasciatus) density increased in patches of cerianthid tubes (Shepard et al., 1987). Also, there are groups of species that produce habitat features such as depressions (e.g., Raja spp.) and those that utilize the depressions produced by others (e.g., squid, Loligo pealei; sculp, Stenotomus chrysops; Auster et al., 1991, 1995). These associations imply that use of complex habitats increase survival.

Reductions in habitat complexity may lead to increased predation on juveniles of living marine resources with subsequent decreases in recruitment (e.g., Walters and Juanes, 1993). Field studies off Nova Scotia have shown that juvenile Atlantic cod (Gadus morhua) settled in all habitats (i.e., sand, seagrass, cobble, and rock reef) but survivorship and density were higher in more complex habitats (Tupper and Boullier, 1995a). Reduced predation in complex habitats was attributed to higher shelter value and reduced predator efficiency. Laboratory studies have demonstrated that the use of various microhabitat features can play a functional role in enhancing juvenile survivorship. For example, in the presence of a predator, juvenile cod survivorship was enhanced by a shift in their substrate preference from sand or gravel-pebble to cobble (Goteitas and Brown, 1993). Individuals used the
interstices of the cobble substrate to seek refuge from predation. This work illustrated that use of habitats with even subtle changes in complexity can have an effect on survivorship. Young-of-the-year Atlantic cod established territories around shelter sites in a bay off eastern Newfoundland (Tupper and Boutilier, 1995b). Territory size increased with size of fish, and fish in larger territories grew faster. It follows that if settlement density is sufficient to saturate available habitats, cohort strength may be determined by competition for high-quality shelter sites. Individuals occupying low-quality sites would be subject to more intense predation. Population responses to changes in habitat complexity have yet to be quantified in the field.

Reduction in habitat complexity may also cause sublethal effects such as reduced growth rates. For example, Pickering et al. (1987) showed that lack of cover in experimental aquaria caused chronic stress responses in Atlantic salmon (Salmo salar) and caused significant reductions in growth rates. Proximity to cover therefore may be needed to optimize foraging.

The abiotic and biotic features of habitat are dynamic at a variety of spatial and temporal scales (Langton et al., 1995). The abiotic features of the Gulf of Maine seafloor are the product of glacial processes, tidal currents, storm currents and surge, and depositional processes (Belknap et al., 1988). Tidal currents affect the seafloor at scales of minutes to months, while storm events occur at scales of days to centuries. Both processes produce erosional and depositional features depending on water depth and sediment type. Biotic features are, in contrast, the result of the interaction between an animal's life history and abiotic habitat features. Recruitment of benthic species varies, for example, over wide spatial and temporal scales (Scheltema, 1986) as a result of larval transport, predation, competition, and available substrate for settlement. Biotic and abiotic responses to fishing gear disturbances also vary on a variety of spatial and temporal scales depending on physical oceanographic processes, life history characteristics of epibenthic species, and the level and timing of fishing effort in an area. Physical structures such as sand waves can, if altered by fishing gear, reform rapidly due to tidal currents or reform more episodically due to aperiodic storm events. Similarly, animal life histories are unique and the time for reestablishment of the benthic community following a perturbation by fishing gear can vary significantly. For example, the impact on taxa such as hydroids, which typically have life spans of approximately 1 year, would be short-term, whereas sponges are long lived and growth of newly settled colonies is slow, often taking many years. The timing and intensity of mobile fishing gear impacts, interacting with substrate and fauna, may therefore profoundly alter benthic community structure. For example, 41 to 53% of rocks (>5 cm maximum dimension) were dislodged and rotated by a single pass of a scallop dredge during an experimental gear impact study (unpublished data). Fishing gear disturbance could continuously reduce survivorship of epifauna that settle on the exposed surfaces of rocks. Long-term effects, due to changes in community structure, unfortunately cannot be predicted yet (Witman and Sebens, 1992).

Habitat-based management should consider mobile fishing gear impacts. Fish assemblages on the northeast U.S. are part of a system where predation mortality on postlarval and juvenile fishes has a major effect on year-class strength (e.g., Sissenwine, 1984; Sissenwine et al., 1984). Much work has been directed at understanding the role of egg and larval mortality as a factor establishing year-class strength, although post-settlement mortality is of comparable magnitude (Sissenwine,
1984). If use of specific seafloor habitats significantly reduces predator-induced mortality (e.g., Lough et al., 1989; Wahle and Steneck, 1992), then maintaining complexity should be part of the management regime (Langton et al., 1996).

Impacts of fishing gear have to be understood not simply in terms of removal of the targeted species but also in terms of their impact on ecosystem productivity. Productivity has a strict biological definition but, in a broader ecosystem-based management sense (Slocombe 1993), it includes human values and a vision of what the fishery should produce and what degree of biodiversity should be maintained in the system. In this article we have presented data on the impacts of fishing gear at three locations on a variety of bottom types, together with a calculation on the extent of trawling region wide (Appendix 1). These impacts may have long-term deleterious effects on harvested populations. Clearly, mobile gear provide efficient ways to harvest living marine resources in the short-term, but economic efficiency may have an ecological price that requires restriction of the activity in select areas. Our current understanding of the impacts of mobile fishing gear is often more correlative than causal, particularly in the Gulf of Maine. Directed programs are needed to provide information on the extent and magnitude of these impacts.

Gear impacts need to be evaluated and balanced against the need for resource harvesting. Developing an understanding of these impacts in the Gulf of Maine is difficult because no sufficiently large areas exist that can act as true nonimpacted reference sites. One approach to this problem is the designation of marine reserves (Dugan and Davis, 1993; Auster and Malatesta, 1995; Shackell and Lien, 1995; Auster and Shackell, in press) that would provide reference sites in selected biogeographic regions. Experiments on the intensity and magnitude of fishing effort with specific gear types could be conducted at sites adjacent to such protected areas. These experiments should be long-term in order to understand natural vs. gear-induced changes in habitat. As information becomes available it could be incorporated into an adaptive-management scheme that attempts to balance resource harvesting with maintaining habitat integrity to produce sustainable harvestable populations.

ACKNOWLEDGMENTS

The authors thank the support vessels and crews of the submersibles Delta, Clelia, and the NURPI ROV. The comments of two anonymous reviewers greatly improved the manuscript. The submersible and ROV projects were funded by NOAA's National Undersea Research Center at The University of Connecticut (NOAA grants NA87AA-D-UR039, NA56RU0066-01, and NA46RU0146). Sidescan sonar studies were funded by the U.S. Geological Survey. Sampling at Stellwagen Bank National Marine Sanctuary was done under permits to PJA and PCV. The views expressed herein are those of the authors and do not necessarily reflect the views of NOAA, USGS, or any of their subagencies.

REFERENCES


only to harvesting by the fishery with no connection made to changes in habitat or the benthic community. This conclusion is not surprising given the state of ecological knowledge at the time (Auster, 1988). More recent studies found that fishing changed associations and species composition of nonharvested taxa, but the effects of those changes on the dynamics of harvested populations are not yet known (Holme, 1983; Langton and Robinson, 1990).

Many of the cited studies were conducted over previously fished grounds, and it is difficult to demonstrate trawling-induced habitat changes if specific habitat types have already been altered (Margarites and Bridger, 1971; Caddy, 1973; Gibbs et al., 1980). Recognizing this problem, more recent studies were conducted in areas that contained both trawled and reference sites (Van Dolah et al., 1987; Riemann and Hoffmann, 1991), or have sequentially surveyed an untrawled area before and after initial fishing activities (Sainsbury, 1987; Peterson et al., 1987).

Herrington (1947) was the first to make a connection between habitat composition and production of exploited stocks. He suggested the removal of benthic fauna such as sponges, and overturning and burial of rocks, would reduce spatial complexity of bottom habitats and affect the production of prey for harvested species. Peterson et al. (1987), using a manipulative field experiment, linked seagrass destruction by mechanical clam harvesting to reduced bay scallop production. The complex habitat formed by dense seagrass was directly linked to settlement density of scallops.

Sainsbury (1987, 1988) was the first to demonstrate a direct link between habitat change and subsequent changes in catch. On the northwest Australian shelf, he found that golden thread (Saurida spp.) and lizardfish (Nemipterus spp.) occurred predominately on open sand/“sparse” emergent benthos bottoms, while porgies (Lethrinus spp.) and snappers (Lutjanus spp.) occurred in areas of “dense” emergent benthos (e.g., sponges, gorgonians, alcyonarians). Trawl data showed the bycatch of sponges and associated corals fell during the course of the developing trawl fishery, eliminating “dense” habitat types. Concurrently, fauna associated with sand/“sparse” emergent habitats increased in the catch, while the fauna associated with “dense” emergent habitats decreased.

Recent levels of fishing effort on the continental shelf of the northeast U.S. by trawl and dredge gear may have had profound impacts on the early life history in general, and survivorship in particular, of a variety of species due to small-scale (=microhabitat) alterations. We posit that mobile fishing gear has measurable effects on microhabitat availability. Herein we summarize studies conducted at three different locations in the Gulf of Maine (Figure 1) that show measurable impacts of mobile fishing gear on habitat complexity and discuss the implications of fishing gear impacts on the sustainability of harvested species.

II. CASE STUDIES

A. SWANS ISLAND

The area off Swans Island (44° 08.0' N 68° 23.0' W; 30 to 40 m) consists of coarse-grained material where cobble-shell and sand-shell bottoms predominate. The


Sainsbury, K. J. Assessment and management of the demersal fishery on the continental shelf of northwestern Australia. pp. 465–503. In: Tropical Snappers and Groupers: Biology and


APPENDIX

Trawling activities occur over large parts of the northeastern continental shelf of North America. Using fishing effort data compiled by NMFS, it was possible to estimate the area impacted by mobile fishing gear on the U.S. side of the Gulf of Maine and on Georges Bank (Figure A1). Fishermen report catch and effort data when they unload fish at the dock after each trip and are required to report data on days fished. Days fished is an index of fishing effort based on the time that fishing gear is in the water. These data were summarized for trawl and scallop fisheries within each region. In this analysis, the area altered by trawlers was estimated by using an average distance of 40 m between the doors for all size classes of trawler. For scallop dredge gear, 2, 4, and 6 m were used as gear widths for class 2, 3, and 4 vessels, respectively. Vessel speed was assumed to be 5.5 km/h in both fisheries. Total area fished was then calculated by multiplying days fished (in hours) by gear width and vessel speed (Figure A2). We believe these to be conservative estimates. The U.S. side of the Gulf of Maine is approximately 65,000 km² and Georges Bank is approximately 41,000 km². Therefore, approximately all of the U.S. side of the Gulf of Maine, on a percentage basis, was impacted annually by mobile fishing gear since 1982. Between 200 and nearly 400% of the U.S. side of Georges Bank, on a percentage basis, was impacted since 1976 (the time frame of our available data). Of course, some areas were not impacted at all and others are impacted even more frequently. Currently, greatly reduced populations of groundfish, changing regulations, vessel buyouts, and large area closures in three major fishing zones will cause shifts in the level and distribution of effort (NEFMC, 1994, 1995).

FIGURE A1. Approximate area (km²) on the U.S. side of the Gulf of Maine and Georges Bank.
FIGURE A2. Area impacted by mobile fishing gear on the U.S. side of the Gulf of Maine (left) and on Georges Bank (right).
ON THE TURTLES' SHARE
IN SHRIMP EXPORTS

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Sea turtles are a group of harmless reptiles which coexisted with the dinosaurs and were most common during the Cretaceous, 30 million years ago. Though the fossil record extends back to 200 million years, all the present day genera and species originated in the period from the early Eocene to the Miocene, between 60 and 10 million years ago. Turtles, aptly termed as living fossils, ot only have a long evolutionary history but also surpass all other vertebrates in longevity (some of them live for more than 150 years).

Their distribution is mostly tropical and subtropical and they depend on land only during the reproductive period. The scientific and common names of the eight species of sea turtles are given in Table 1.

Otherwise almost an economic non-entity, turtles assumed precedence recently by virtue of the verdict of US Court of International Trade that all countries exporting shrimp to U.S.A should install Turtle Excluder Device (TED) in shrimp trawl nets. This stipulation came into effect from May 1, 1996. Though National Fisheries Institute of U.S.A. challenged the verdict, the effort was futile since they could not change the Court's mind. It would be appropriate to discuss why turtle conservation has become such an important issue.

Unlike some animals such as cockroaches, which became well adapted to the changing environment and became the best survivors in the most hostile habitats, turtles did not evolve any mechanism to ensure survival in the changed environment. Of course, many animals failed to cope up with the ingenuity at efficiency of the most versatile hunter and destroyer - the man. Following the age-old message encoded in their genetic material, they still come en masse our after year to lay their eggs. This nesting behaviour as becomes the weakest aspect in the life of turtles. Undue advantage of their vulnerability during breeding period, is taken by man and predatory animals. Adults as well as eggs, are often exploited pushing the turtle populations to the verge of extinction. Added to that, pollution, beach invasion, poaching, entanglement of turtles in set-nets or their capture in trawl fishing are further endangering the turtle populations of the world.

Fortunately, all sea turtles are considered threatened or endangered by the International Union for Conservation of Nature and Natural resources (IUCN). Quoted in the Red Data Book, their commerce is prohibited in those countries that have signed the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).

The five species of turtles available in local waters are placed in Schedule I of Indian Wild life (Protection) Act 1972.

A look at the world turtle trade indicates that all the eight species of sea turtles are exploited for their meat and/or shell and have some commercial value. Their economic importance varies among countries and also locally within countries. In some areas they constitute a valuable protein source and in others they are only used as a delicacy. In certain countries sea turtles have been the object of ancient ritual practices or they are venerated as sacred animals. Fisher communities in certain localities of India attribute medicinal property to turtle blood in curing 'piles'.

Available statistics state that about 3,100 tonnes of adult turtles were caught all over the world during 1987. Subsistence fishery for sea turtles existed in Indian waters, particularly in Gulf of Mannar and along Orissa - West Bengal coast during mid seventies - before the enforcement of Wild life (Protection) Act. But in recent years the magnitude of poaching has very much come down due to the efforts of the conservation agencies. It must be noted that the contribution of Western Indian Ocean (FAO Fishing Area 51) and Eastern Indian Ocean (FAO Fishing Area 57) to world's exploited turtle fishery mentioned above was mere 371 and 501 tonnes respectively.

The option now left for many of the 50 odd countries which export shrimp to U.S.A is something like 'do or die'. For India, the stakes are high since U.S.A. is the second largest buyer of Indian shrimp accounting for nearly 11% of its seafood exports which is now virtually the 'turtles share' and cannot be ignored. We cannot ignore this Turtles share. Bulk of the smaller grade shrimp caught along south-west coast of our country is exported to U.S.A.

Experiments with TED in India have been largely very successful. No turtle was entangled in the experimental trawl net attached with the TED, indicating that all turtles might have found their way out through the escape chute. An often asked question, how do we know whether a turtle has entered the net is irrelevant since that is not the objective of the experiment. So long as nothing contradicting the objective exclusion of turtle has happened, the experiment must be considered as successful. Absence of evidence cannot be taken as evidence of absence!

US authorities made the use of TEDs compulsory for all the vessels for which 1% of the total catch is shrimp (not turtles!). Naturally all our trawlers qualify to have TEDs in their nets. But how often do they get turtles in their catch? Available information says that turtles are encountered by vessels operating off Orissa coast, Gulf of Mannar and off Gujarat coast and are usually caught occasionally during breeding season. A preliminary inquiry with the crew of a random selection of 20 trawlers at Visakhapatnam Fisheries Harbour revealed the following facts:

* An average trawler encounters turtles 2 to 10 times (huals) in a year.
* They occur generally north of Paradip. * They are caught only during September-March period and more frequently during November-January.
* Alive or dead, they are always discarded in the sea (dead ones are rarely encountered in the net).

The crew members are aware that catching of turtles is prohibited by law.

Introduction of TED in India would create additional employment in the fabrication and repairs of TED. Though the TED is reported to
cost $2000 a piece, we can always bank on the Indian fabricators to produce a cheaper 'desi' version. Even at the rate of one TED per vessel, about 30,000 units have to be immediately made available to the fishing industry, leaving the additional replacement demand.

However, implementation of TED programme has some inherent problems. Apart from the inconveniences in handling the gear, installation of TED in trawl nets would cause serious damage to the operational economy of the vessels. Indian shrimp trawlers also land fish in larger quantities than shrimp. The fish catches reach domestic markets. Unfortunately, TED also permits the exit of big sized good quality fish along with the shrimp. Reports say that there was readjustment in fish catch to the extent of 30% in the nets fitted with TED. This will amount to a huge loss for a country like India with shortage of protein food. Since the crew in many parts are entitled for a share of the proceeds from the fish catch, the introduction of TED will be hardship to the crew. The vessel operators, on the other hand, are not very particular whether their shrimp catch is exported to U.S.A. or Japan. The exporters get their material through middlemen from various sources including that from the traditional gears and aquaculture farms. Therefore, they cannot impose any restrictions on the trawlers not owned and operated by them. It would also be difficult to distinguish the final product based on the source of raw material.

Who cares about TED? Marine Products Export Development Authority (MPEDA), being accountable for whatever happens in marine products exports, will be the only Agency concerned with the implementation of TED programme. If it is from MPEDA, an Agency known for liberal subsidy schemes, distribution of TED to the vessels may have to be on 100% subsidy basis. At a modest rate of Rs. 5,000/- per TED, it may require not less than Rs. 15.50 crores for equipping the 30,000 odd trawlers in the country, with one TED each! But how far will it serve to achieve the objective of conservation of turtles? Aren't there other means of achieving the objective of conservation of turtles?

Trade barriers in different forms (now in the form of TED) are not unfamiliar to the Indian shrimp exporters to US market. One may feel that it is naive on the part of US authorities to conclude that conservation of turtles can be achieved by imposing an embargo. Would it help in any significant way when Japan, the world’s largest importer of shrimp, is not bothered about TED at all? Further do we really deserve the imposition of TED?

There are some important points to be brought to the notice of US authorities to effect at least some amendments in the directive, if not a complete exemption from implementation of TED programme. The contribution of India to the total world turtle catches as obvious from the catch data for Indian Ocean mentioned earlier, is very meager. Since the area of abundance of turtles and the seasonality of their occurrence are clearly demarcated, the application of the TED programme uniformly to the trawlers operating all along the coast is not a pragmatic approach especially in the light of the economic loss caused by escapement of fish from the net fitted with TED. The damage caused by traditional gears such as drift will not to the turtle population is equally severe if not more. Therefore, it is not rational to impose turtle conservation measures on trawlers along, especially when usually the trawler crew discard the turtles caught in their net unharmed. We, therefore, have to prevail upon the US authorities that it would be desirable to adopt a selective implementation of TED attachment requirement in trawl nets operated in hot-spot areas and also from those trawlers whose target species is mainly shrimps (Large and mini trawlers). By taking an inventory of the turtle conservation measure as in the country and also by allocating funds for turtle conservation to this purpose, we should be able to impress upon the US authorities that abundant measures to conserve these endangered animals have been taken.

It is rather unfortunate that another country has to tag the conservation of turtles to an embargo on the trade of shrimp and impose it on us, taking advantage of the compulsion of exporting shrimp to that country, although a limited part of Indian total exports. It is time that we ourselves become more concerned about the conservation of turtles and ensure that these oldest inhabitants of the earth are not deprived of their right to survive and flourish. Our society is becoming more and more aware of the social responsibility of business interests and the survival and success of future business enterprise is will solely depend on how best to integrate social aspects in its activity. When the fishing industry is largely responsible for the exploitation and habitat destruction of many endangered species, can it escape the responsibility of ensuring their conservation? The marine fishing industry is composed of small enterprises which cannot afford to have motives other than profit. Therefore, it becomes the responsibility of Development (which cannot be sustained without conservation) Agencies such as MPEDA to make a social/environmental audit of the industry. It could finance a few conservation projects on turtles (it need not cost a fortune as it would be for fully subsidising the TED) and produce tangible results. It can also promote educational and research programmes on conservation of endangered species. Such activities would abundantly explain to the world our concern about conservation of endangered species and certainly would ward of any future embargoes and would even entitle us for a special treatment.

### Table-1 Different species of sea turtles, their common names and their occurrence in Indian waters

<table>
<thead>
<tr>
<th>Scientific name</th>
<th>Common name</th>
<th>Availability in Area 51</th>
<th>Area 57</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caretta caretta</td>
<td>Loggerhead turtle</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Chelonia agassizi</td>
<td>Eastern Pacific green turtle</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Chelonia mydas</td>
<td>Green turtle</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Eretmochelys imbricata</td>
<td>Hawksbill sea</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Lepidochelys kempi</td>
<td>Kemp's ridley turtle</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Lepidochelys olivacea</td>
<td>Olive ridley</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Natator depressus</td>
<td>Flat back</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Dermochelys coriacea</td>
<td>Leatherback turtle</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

*Area 51: Western Indian Ocean; Area 57: Eastern Indian Ocean. Only along the Coast of Australia.*

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August 1996
cultural scientist, one agricultural econom¬
ist, one member of parliament, one mem¬
er of assembly and a few commissioners. He told that this social accountability was in¬
evitable now as the fund allocation for R &
D would increase substantially in the near
future to meet the challenges of economic
reforms and liberalisation policies.

The Union Minister also released two
publications on the occasion of which, one
was entitled "Deemed University of Fisher¬
ies-CIFE" and the other "Education, Re¬
search and Extension Highlights of CIFE
1995-96".

The State Minister for Dairy Develop¬
ment, Animal Husbandry and Fisheries, Mr.
Narayan Rao Rane, in his presidential
address, assured the state government’s fullest
assistance for the betterment of fisheries
education and for the welfare of the fisherfolk.

The Joint Director, CIFE, Mumbai, Dr.
N.K. Thakur while proposing a vote of thanks
expressed his pleasure over the fact that the
auspicious ritual of foundation stone laying
for the new university campus of CIFE was
accomplished by the Union Minister, Mr.
Chaturanand Mishra, who hailed from Mithila
region of North Bihar where fish, "makhana", "singhara" etc. were regarded
as important aquacrops and were looked
upon as commodities of immense economic
significance. This could also be borne out
from the fact, Dr. Thakur said, that there was
not even a single ritual of people in Mithila
which did not include these aquacrops as
offerings to God and Goddesses.

On this historical event of CIFE, Dr.
Thakur also remembered and thanked the
ex-Directors of CIFE, namely Dr. D.V. Bal,
Late Dr. C.V. Kulkarni, Prof. K.H. Alikunhi,
Late Dr. N.K. Velenkar, Dr. S.N. Dwivedi,
Dr. V.R.P. Sinha, Prof. Y. Sreekrishna and
Dr. S.D. Tripathi who steered the Institute to
such a height and helped it achieve this
coveted status of Deemed University.

The end of the ceremony was marked by
the visit of the Union Minister to an Aquac¬
lulture Exhibition organised at the present
premises of CIFE campus. Impressed with its
catchy exhibits, the Minister urged the need
to take these scientific and technological
achievements to villages in order to increase
the productivity and thereby remove poverty.

This historic event of foundation stone
laying ceremony of the new university cam¬
pus of CIFE was witnessed by eminent per¬
sonalities namely, Dr. D.V. Bal, Dr. B.N
Desai, Dr. D.N. Mishra, Dr. Somavanshi,
Mumbai; Dr. Iyer, Dr. M.Y. Kamal, Dr. S.C.
Pathak, Dr. M.D. Zingde, Dr. G.A. Shirgur,
Dr. Anil Agrawal, besides a large number of
scientists of the sub-centres of sister insti¬
tutes such as CMFRI, CIFT, MPEDA, NIO and
also officials of Maharashtra state govern¬
ment.

Capture Shrimp Production, Turtle - Safety is de-
manded by Europe and Japan

Exports of Shrimps to the US have plun¬
eted, consequent to the stipulation by the
US that capture shrimp without the use of
Turtle Exclusion Devices will not be al¬
lowed into US. European countries and
Japan have also fallen in line with the US
project. European and Japanese importers
like those in US now stipulated that Indian
exporters should produce a certificate to
prove that their shrimp shipments are "Sea
Turtle Friendly".

This trend, which has now stabilised has
resulted in various implications that too
have a serious effect on the exports of cap¬
ture shrimps from India. Consequently, the
Government of India is understood to have
prepared a report. Armed with this report,
the Indian Government is expected to take
up the issue with the US authorities.
There is a proposal to mount an official delegation
to visit the US to explain the India’s posi¬
tion.

The stand of the Indian government seems
to be that there has been no decline in the sea
turtle population in the waters off Indian
cost which means that the US regulations
should not be made applicable to exports
from India.

The report prepared by the Government
is stated to contain the following points.

1. Only 20% of Indian fishing fleet
consists of mechanised boats. A large por¬
tion is made up of small boats which do not
affect sea turtles.

2. Over 35 percent of the country’s wild
shrimp output is harvested by small fishing
boats which employ only manual methods.

3. There is no decline in sea turtle
population and the incidental harvest is be¬
tween 1,400 to 1,700 t per year. Congrega¬
tion of sea turtles is confined to upper east
coast and the inference drawn from the num¬
ber of nesting females in the Bhitarkanika-
Gahirmatha area of Orissa coast indicates that
there is no depletion in their numbers. Threat
to sea turtles could at best be perceived as
being off the Orissa coast only.

4. India is already protecting sea turtles.
Mechanised fishing vessels have been pre¬
vented from fishing in areas within 10 km of
the coast.

There are also indications that the Gov¬
ernment of India is keeping the options open
in respect of directing Indian fishing fleet to
use Turtle Excluder Devices.

Harassment of A.P. Fishermen by
Orissa Authorities alleged.

It is alleged by Capt. Jacob Rao at a
meeting of the Forum of Fishery Profes¬
ionals held recently in Visakhapatnam, that
the officials of Government of Orissa have been
harassing A.P. Fishermen fishing along the
Orissa coast. Capt. Jacob Rao, according to
a report, is stated to have said that the
government of Orissa is deliberately not
issuing fishing licenses to the fishing vessels
owned by the A.P. fishermen, only to prevent
them from undertaking fishing along the
coast of Orissa which is the traditional fishing
ground of A.P. fishermen. It was pointed
out by him that even when A.P. fishermen
conducted fishing outside the territorial wa¬
ters, officials of Orissa government sub¬
jected them to harassment. He said the
fishing operators from A.P. should challenge
the allegedly illegal activities of the govern¬
ment of Orissa, in a court of law.

Indian Fishermen Allegedly Ab¬
ducted

According to a report from
Rameshwaran, Eight fishermen belonging
to that place were abducted by the Sri Lankan
Navy on August 5, 1996, along with two
fishing boats in which they were fishing from
Rameswaram Port. The District administra¬
tion is reported to have taken steps for secur¬
ing release of the fishermen.

August 1996
Use of TED in Trawl Fisheries - CIFT Initiatives

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Cochin-682 029

Introduction

Conservation of fisheries resources for sustainable yield assumed significant importance in recent years. There has been an increasing effort by many of the world’s fisheries agencies to modify fishing gears so that they are more selective for the targeted catch. This has occurred primarily because of problems associated with the incidental capture and mortality of non-target species and its negative impacts on aquatic resources and biodiversity. It is well known that growth over fishing often results when too many juveniles and sub adults are captured and this poses a threat to optimum utilization of fishery resources. Increased awareness of these problems will remain one of the most important challenges facing commercial fisheries through out the world. While by-catch from prawn trawling provided or has the potential to provide a bonus resource of protein and income in many countries like India, several negative impacts of by-catch from prawn trawling have become a major cause of concern and conflict. Several gear technologists have attempted to reduce the non target by-catch and experimented with various designs of by-catch reduction devises in prawn trawling (Broadhurst & Kennelly, 1996; Watson & Tailor, 1998; Sternin & Allsopp, 1981; Furnel, 1981; Broadhurst et al., 1998; and Day, 1999).

The term by-catch means the portion of catch other than the target species caught while fishing for particular species. By-catch is unavoidable in any fishing technique but the quantity varies according to the type of gear and operation. Among the different fishing gears, trawling accounts for higher rate of by-catch. By-catch levels are generally highest from tropical ecosystem due to the multi-species nature of the fisheries. In India by-catch is a serious problem accounting for 60-70% of the catch. Trawlers take a substantial amount of non-commercial by-catch including sea turtles. Studies on the by-catch reduction devises, including Turtle Excluder Devise will substantially reduce the unwanted and endangered species being caught and will facilitate judicial exploitation of the fisheries resources.

Experiments off Paradeep

Devises developed to eliminate the endangered species like turtles, in this case, the Olive Ridley turtles, and reduce the non-target species in trawling are collectively known as by-catch reduction device (BRD). While the BRD is a broad term used to describe any devise used to eliminate or reduce the by-catch, the turtle excluder devise (TED) is a specialized form of BRD designed to eliminate the turtle. To suit the Indian conditions, CIFT has developed a CIFT-TED, which is a simple design with a top opening single grid, hard TED. It is an oval frame measuring 1000x800 mm and is constructed with 12 mm dia stainless steel rod. Five vertical grid bars of 8 mm dia stainless steel rod are welded to the inside of the oval frame. The spacing between the deflector bars is 142 mm and the maximum spacing between the frame and the adjacent deflector bar is 90 mm. The frame was fixed in the extension at 45° angle. CIFT-TED was fixed in a 32 m trawl. Fishing done from a Sonar boat belonging to Orissa State Fisheries Department, off Agarnasi, north of Paradeep at a depth range of 10 to 12 m. Two hauls of 1 hour duration were made. To collect the turtles that escape through the TED opening, a mesh cover was attached.
Results:

Both the hauls landed a total of 120kg of fish and prawns constituted 10kg in the first haul and 12kg in the second haul. In the second haul two fully-grown turtles, a male and a female, weighing nearly 50kg each were trapped in the outer cover. These turtles had escaped through the upper TED opening and got collected in the cover. In the above experiments, the ground was devoid of bottom debris and the catch was 62 kg. Total fish loss and prawn loss were estimated to be 1.2% and 0.62%, respectively. Gary et al. (1999) observed that top exiting TEDs are well suited to clean areas as they are able to exclude all large animals whilst maintaining a higher percentage of prawn catch than a bottom shooting TED. In the cleaner fishing grounds of the Gulf of Carpentaria a top shooting TED lost fewer prawns than a bottom shooting TED (Gary et al., 1999). However if a vessel is working in areas where bottom debris or large animals were abundant bottom shooters will be able to exclude them which would tend to clog a top shooting TED. Therefore, the choice will depend on the grounds fished and the debris likely to be encountered.

Bar spacing is critical for the effectiveness of the grid and determines the size of the animals that can pass through the grid. Should the bar spacing be too narrow, larger prawns and some by-products may be excluded by the grid. The spacing between the bars in CIFT-TED is 142 mm, which allows both fish and prawns to pass through and enter the cod end. An extremely important aspect of TED design is the grid angle. In CIFT-TED the grid was fixed at 45° angle. Garry et al (1999) observed that if the grid angle is too shallow prawn loss will occur. Clogging will be a problem if the grid angle is too steep.

Conclusion:

Unwanted fish by-catch is a feature of almost every trawl undertaken in tropical prawn fisheries. The use of TED and BRD in commercial trawling has become popular in many countries all over the world in order to eliminate the incidental catch of turtles and other larger species. CIFT-TED with top exit is found to be a suitable device for eliminating turtles. Considering the advantages, the TED most suitable for Indian conditions will have to be adopted to save the endangered turtles.

Acknowledgement:

The author wish to thank the Director, Central Institute of Fisheries Technology, Cochin, for his permission to publish this a paper. Also wishes to thank Shri. M.R. Boopendranath., Sr. Scientist and Shri. P.N. Sudhakaran, for their scientific and technical assistance.

References:


IMPLEMENTATION OF TURTLE EXCLUDER DEVICE [TED] IN ANDHRA PRADESH

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PRINCIPAL
STATE INSTITUTE OF FISHERIES TECHNOLOGY
KAKINADA

Andhra Pradesh is one of the longest maritime states in India that has a coastline of 974 Kms and a continental shelf area of 33,227 sq.kms. There are about 508 fishermen villages and several lakhs of fishermen actively engaged in fishing. Marine fishing operations in Andhra Pradesh are generally distributed all over the year except during the closed season i.e., April-May. Apart from the marine resource, the State is blessed with an excellent riverine systems that confluence into sea through many number of tributaries. Mechanized fishing with trawl nets has been supposed to be one of the major fishing activities targeting shrimp catch in Andhra Pradesh. Apart from the targeted catch, By-catch, i.e., the catch other than the target species, is a serious problem accounting for 60-70% of the catch. Trawlers operating at different depths in the sea take a large amount of non-commercial by-catch including low cost fish, juveniles and some other jelly-fishes etc. One of the by-catch problem species in some months is the marine turtle, an endangered species, which is protected under schedule I of the Indian Wildlife (protection) Act, 1972 and its amendment 1991. Use of By-catch Reduction Device [BRD], including Turtle Excluder Device [TED] will substantially reduce the unwanted and endangered species being caught and will facilitate in the judicious exploitation of the fisheries resources. Conservancy measures that were being taken to regulate the over exploitation of fishery resources for sustainable yield will also help in reducing the by-catch as well as eliminating the endangered species.

Sea turtles, supposed to be the 'sea innocents', are widely distributed species whose migratory pattern extends through out the oceans of the world. Due to reasons that harvesting of Turtles and their eggs, accidental mortality associated with shrimp trawling and other fishing operations etc. Sea Turtles have been on the verge of extinction. This accidental mortality of marine turtles is reported to occur particularly along the East Coast of India.

The Sea Turtles are caught either from traditional fishing or from mechanized fishing. Turtles are killed as incidental catch in the traditional fishing gear like Gill nets and seines. They were also trapped in the in trawl nets operated from mechanized fishing craft. Other threats to sea turtles along A.P. coast are poaching by villagers. The traditional fishermen exploit the eggs, carapace and the meat to a lesser extent. Developmental activities close to the beach, plantation, industries near the coast, Aquaculture practices and other factors also contribute to the decline in turtle populations.

Olive Ridley turtles (*Lepidochelys olivacea*) are commonly found in the State of A.P. The nesting intensity of sea turtles is comparatively moderate in this state. Sea turtles in small numbers visit the beaches in most of the coastal villages, particularly those abutting Orissa state, and the nearing the Godavari, Krishna river mouths, but their number is very low as per the survey and the information gathered from coastal fisher folk. It was observed that the nesting season in the state is from November to February with a peak in January. It is rather a precarious situation that the nesting season of sea turtles coincidences with that of the fishing season and as a result more the incidental mortality of sea turtles in the fishing gear along the coast.

Against this backdrop, there is an urgent need for a holistic approach to safeguard the sea turtles and necessary realistic measures have to be adopted as part of conservancy. State Institute of Fisheries Technology [SIFT], Kakinada has been involved in organizing multifarious training programmes and awareness camps for the fisher folk and farmers in various aspects of fisheries and aquaculture as well as health, literacy and conservancy measures. It is taking a proactive role in all fishery related activities there by providing the end users a promising scope for achieving their goals and objectives. It is the apex training institution under the Department of Fisheries, Government of Andhra Pradesh and has been playing a pivotal role as coordinating agency with other like-minded organizations to conserve the sea turtles along the coast of A.P.
The Wildlife Institute of India, Dehradun have taken up a project save turtle and as part of the conservancy and management of Sea Turtles, the Department of Fisheries, Andhra Pradesh was entrusted with the propagation of Turtle Excluder Device [TED] among fisher folk to reduce the chances of incidental mortality of Sea Turtles. Turtle Excluder Devise (TED) is equipment, which facilitate turtles to escape safely without losing the target catch, with frame consisting of grid of bars installed before the cod end of the trawl net at an angle of 45° leading upward or downward to an escape slit. This was designed by the Central Institute of Fisheries Technology [CIFT], Kochi.

Fishermen are, as previous experience, reluctant to use TEDs in their trawl nets, as they felt that they lose valuable target species. To erase their wrong beliefs, awareness camps were organized by the State Institute of Fisheries Technology, Kakinada on turtle conservation through the use of TED at all fishing harbors all along the coastline of A.P. Several demonstrations were conducted taking fisher men on the boats and showing them that the percentage of escape by the use of TED is negligible. The fishermen are now convinced and are willing to use TED in their trawl and are now gradually realizing the importance of endangered species like sea turtles. At this juncture the State Institute of Fisheries Technology (SIFT) Kakinada has taken the initiative and played a locomotive role in the conservation of Sea turtles and propagation of the Turtle Excluder Device [TED].

The moment State Institute of Fisheries Technology, Kakinada has taken up the challenging task of Sea Turtle Conservation through the use of TED, a survey was conducted in the month of December 2001 in East Godavari District to observe the incidental mortalities of turtles. The details of the survey are shown in the following table:

<table>
<thead>
<tr>
<th>Name of the villages</th>
<th>No of carapaces observed</th>
<th>Probable cause of death</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kakinada Harbour</td>
<td>4</td>
<td>Stranding in trawl gear</td>
</tr>
<tr>
<td>Subbampeta</td>
<td>7</td>
<td>Stranding in trawl gear</td>
</tr>
<tr>
<td>Mayapatnam</td>
<td>5</td>
<td>Stranding in trawl gear</td>
</tr>
<tr>
<td>Christupurm</td>
<td>2</td>
<td>Stranding in trawl gear</td>
</tr>
<tr>
<td>Konapapapeta</td>
<td>3</td>
<td>Stranding in trawl gear</td>
</tr>
<tr>
<td>Chodipallipeta</td>
<td>2</td>
<td>Stranding in trawl gear</td>
</tr>
<tr>
<td>Addaripeta</td>
<td>4</td>
<td>Stranding in trawl gear</td>
</tr>
<tr>
<td>Hope island</td>
<td>17</td>
<td>Stranding in trawl gear &amp; Seed nets.</td>
</tr>
</tbody>
</table>

The above table reveals the need to protect the Sea Turtles since they migrate to their nesting grounds in the same season i.e., November-February.

A pre-nesting awareness camp is held during October & November 2001 in order to inculcate the basic motive of conserving the sea turtle in the coastal districts. The details of the awareness camps conducted in each district and the fishers attended were depicted in the following table:

<table>
<thead>
<tr>
<th>District</th>
<th>No of villages</th>
<th>No attended</th>
</tr>
</thead>
<tbody>
<tr>
<td>Srikakulam</td>
<td>7</td>
<td>525</td>
</tr>
<tr>
<td>Vizianagaram</td>
<td>3</td>
<td>340</td>
</tr>
<tr>
<td>Visakhapatnam</td>
<td>5</td>
<td>615</td>
</tr>
<tr>
<td>East Godavari</td>
<td>7</td>
<td>720</td>
</tr>
</tbody>
</table>

In the awareness camps conducted, the faculty of State Institute of Fisheries Technology, Kakinada convinced the fishermen on the necessity of use of TED, explained the need to compulsorily use of TED, informed about the penalties if it is not used, fabrication, functioning and assembling of TED.

TED has been made compulsory in shrimp trawling and necessary amendment was made in the A.P.M.F.R.Act to this effect by imposing a fine of Rs.2,500/- besides confiscation of entire catch. TEDs were supplied to fishermen by MPEDA, on free of cost in Vizag and Kakinada and several demonstrations were organized to fishermen in
various places to convince the fishermen that there will not be any reduction in catch when they are using the TED.

A two-day workshop on operation of TED was conducted by the Department of Fisheries at Kakinada on 24th & 25th January 2002. On the first day of the workshop, a demonstration was organized on the use of TED in trawl nets. After the workshop also, several demonstrations have been conducted in all important fishing harbours on the operation and efficiency of TED. The results of these demonstrations are furnished in the following table:

### TED Demonstration Results

<table>
<thead>
<tr>
<th>Boat No</th>
<th>FKKD1234</th>
<th>FKKD1219</th>
<th>FKKD1021</th>
<th>FKKD1039</th>
<th>NZM2343</th>
<th>NZM2342</th>
<th>KKD1021</th>
<th>KKD1039</th>
<th>EVSP506</th>
<th>EVSP536</th>
<th>FRMPS520</th>
<th>VDRNEW</th>
<th>KKD1019</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth of operation (mtrs)</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>25</td>
<td>25</td>
<td>30</td>
<td>30</td>
<td>40</td>
<td>40</td>
<td>20</td>
<td>25</td>
<td>21</td>
</tr>
<tr>
<td>Towing Speed (knots)</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Towing Period (Hrs)</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1.5</td>
<td>1.5</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>No of hauls</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Catch in Cod end Kg</td>
<td>35</td>
<td>30</td>
<td>15</td>
<td>25</td>
<td>20</td>
<td>15</td>
<td>18</td>
<td>10</td>
<td>6</td>
<td>7</td>
<td>15</td>
<td>10</td>
<td>60</td>
</tr>
<tr>
<td>Catch in Cover net Kg</td>
<td>0.5</td>
<td>0.3</td>
<td>0.2</td>
<td>0.4</td>
<td>0.1</td>
<td>0.15</td>
<td>0.3</td>
<td>0.1</td>
<td>0.05</td>
<td>0.15</td>
<td>0.5</td>
<td>0.2</td>
<td>2</td>
</tr>
<tr>
<td>% Escapement</td>
<td>1.43</td>
<td>1</td>
<td>1.33</td>
<td>1.15</td>
<td>0.5</td>
<td>1</td>
<td>1.66</td>
<td>1</td>
<td>0.83</td>
<td>2.14</td>
<td>3.33</td>
<td>2</td>
<td>3.33</td>
</tr>
<tr>
<td>% Retention of target catch</td>
<td>98.57</td>
<td>99</td>
<td>98.67</td>
<td>98.4</td>
<td>99.5</td>
<td>99</td>
<td>98.34</td>
<td>99</td>
<td>99.17</td>
<td>97.86</td>
<td>96.67</td>
<td>98</td>
<td>96.67</td>
</tr>
</tbody>
</table>

The following are the diagrammatic representations of the results of the demonstrations:

### 24-1-02 KAKINADA

![Graph of 24-1-02 Kakinada](image)

### 13-2-02 NIZAMPATNAM

![Graph of 13-2-02 Nizampatnam](image)
From the foregoing demonstrations, it is observed that the percentage of escape of fish/shrimp range from 0.5% to 3.3%. In one or two occasions, the escaping rate is slightly higher [3.3%] and it is due to large quantity of jellyfish that entered in the net.

These demonstrations helped erase the doubts and dilemmas of the fisher folk that TED is no longer a bane to them and instead it is the boon to the sea turtle conservancy.

Some of the fishermen have expressed that there should be some sort of refinement in the TED. The comments from fishermen in different areas are:

- Mesh size of the TED to be reduced to last belly of the trawl net.
- The space between spokes may be increased in oval grid.
- Weight of the TED may be reduced

The State Institute of Fisheries Technology, Kakinada has been in touch with the concerned organizations to attend to these issues.
The recommendations put forth by the participants during the “Workshop on the Operation of the TED” conducted by the Dept. of Fisheries at Kakinada on 24th & 25th January 2002 have been categorized under 3 heads as follows:

1. Protection, Enforcement & Regulation
2. Monitoring, Research & Evaluation
3. Community Based Conservation

The recommendations put forth by the participants have been summarized as follows:

Recommendations under Protection, Enforcement & Regulation:

1. Interdepartmental co-ordination among concerned state govt. departments i.e. Fisheries and Forest Departments in collaboration with Wildlife Institute of India, ICAR Institutes, fishermen and NGOs is necessary, as the strategies for conservation of turtles will not be successful with isolated efforts.
2. As the status of sea turtles varies from state to state, strategies for conservation should be as per local conditions.
3. National Marine Turtle Conservation Policy is to be formulated.
4. Existing legislations need to be reviewed.
5. Reclamation of beaches and protection of nesting beaches should be taken up by the Forest Department.
6. Illumination of nesting beaches by hatcheries should be lessened during nesting season.
7. Strict implementation of the use of the TED in shrimp trawling, as prescribed in the A.P. Marine Fishing Regulation Act.
8. An attempt to be made on collection of data on incidental mortality of turtles in fishing gear along the Andhra Pradesh coast.
9. The Fisheries Department and the CIFT should formulate proper regulatory measures for mitigating incidental mortality in gill nets.
10. The proposal to declare certain areas in A.P. near the Orissa border as turtle sanctuaries needs to be considered.
11. A long term Action Plan for at least 10 years should be drafted for effective conservation of sea turtles.
12. Identification of nesting beaches along the coastline to be confirmed.
13. Feedback from the fisheries department and fishermen must be taken into consideration for future TED designs.
14. The State Institute of Fisheries Technology, Kakinada in coordination with the Joint Director of Fisheries (Coast), NGOs to work out an Action Plan at village level.
15. Eco-tourism to be linked with conservation of turtles.

Recommendations under Monitoring, Research & Evaluation:

1. a) Monitoring of the use of the TED by the fishing trawlers has to be monitored at sea by means of the patrol boats.
b) Monitoring of nesting zones along the entire coastline of A.P. to be surveyed for nesting and incidental mortality; landside monitoring to be done by the Forest dept and sea based to be taken by the Fisheries Dept.
c) Monitoring the regulators; measures should be taken by the Fisheries Officials of the concerned areas.
2. Apex monitoring team comprising of officials of Save turtle team of S.I.F.T; other departmental officers of A.P. State Fisheries, Forest Department, CMFRI, Andhra University, NGOs and local fishermen.
3. Ongoing research on TED technology to be a long run process to suit to the needs of local fishing.
4. Tagging and Telemetric methods to be taken up by NRSA and WII
5. Collection of data of incidental mortality of turtles all along coast, Computerization of the same-Comparing it with the base line data, Evaluation to be done every year by the apex team and disseminate the same to all concerned.
6. Based on Evaluation-Intermediary meet of all department officials involved to revalidate the effectiveness of the plan.
7. Research on TED designs to be explored by CIFT.
8. Funding by concerned agency throughout the action plan period is necessary.
9. Study tour of SIFT faculty to Gaharimata in the forthcoming month is to be arranged to study different aspects of turtle conservation.
10. TED information centre of SIFT to act as Nodal monitoring and information center.
11. Training to faculty of SIFT on conservation of sea turtles to be given at Orissa coast and on design of TED at CIFT, Cochin.
12. Research on probes for identification of entry of turtles in trawl nets to be done by WIU and NRSA.
13. Periodic trial netting with new designs of TED needs to be experimented in order to decide its efficiency.

Recommendations for Community Based Conservation:

1. SIFT should play a vital role in bringing about awareness and co-ordination among all the stakeholders viz. NGOs, Fisher folk and Forest Department.
2. Awareness programmes should be conducted throughout the A.P. Coast line about conservation of turtles.
3. For popularization of TED awareness at all leading fishing harbors of A.P it is necessary to safeguard the interests of fisher folk.
4. Regional level workshops on small scale may be organized in order to bring all concerned for a better understanding about conservation of sea turtles, as fishing activities from region to region.
5. Forest department officials should take ample interest to see that volunteers of VSS also cater to the interests of turtle conservation.
6. Awareness among fisher folk children regarding conservation can be initiated at school level onwards by arranging competitions like debate, painting and poster making etc.
7. Formation of Turtle clubs at village level may be taken and the best club may be awarded incentive.

These recommendations are highly valuable and go a long way in the conservancy and management of marine turtles. The policy makers and planners and scientists should focus attention on how best these recommendations can be implemented to protect the sea turtles from extinction.

A TED Demonstration cum Information Center was established in State Institute of Fisheries Technology, Kakinada where the fisher folk, public and officers of various allied departments will be constantly motivated on the need to protect the Marine Turtles. Hand-outs were prepared and distributed in various occasions like Awareness Programmes, JanmaBhoomi Programmes, Grama Sabhas in Coastal villages. Posters highlighting the urgency to save turtles were affixed in the villages at important places, Fishing Harbours and made available to all and sundry. The fishermen boys undergoing one year training in this institution were also educated and trained on the use of TED during their fishing trips.

It is planned to conduct awareness camps during pre-nesting periods in all coastal villages with audio-visuals aids and results of last year data. Further more, demos at all important mechanized landing centers to create awareness on the use of TED are also planned. Apart from this, it is proposed to conduct refresher course training programme at SIFT to all coastal fisheries staff. Thus the Department of Fisheries is taking all conservancy measures to safeguard the marine turtles, working hand in hand with the Wildlife Institute of India and looking forward for further collaboration in this aspect.

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helping with collection of specimens. P.C.H. Pritchard, A.G.J. Rhodin, and J. Davenport critically read the earlier draft of the manuscript and made many useful suggestions. M. Amano and T. Hikida gave useful advice on statistical analyses.

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Received: 16 January 1996
Reviewed: 23 July 1996
Revised and Accepted: 28 October 1996

Incidental Capture of Sea Turtles in Shrimp Trawls With and Without TEDs in U.S. Atlantic and Gulf Waters

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Five species of endangered or threatened sea turtles inhabit the Gulf of Mexico and Atlantic Ocean. These are the loggerhead (Caretta caretta), green (Chelonia mydas), Kemp's ridley (Lepidochelys kempii), hawksbill (Eretmochelys imbricata), and leatherback (Dermochelys coriacea). The olive ridley (L. olivacea) occasionally occurs in the Atlantic. All are legally protected by the United States Endangered Species Act of 1973. Sea turtles are caught incidentally in shrimp trawls, and these captures have been identified as the major source of sea turtle mortality in the Gulf of Mexico and along the U.S. Atlantic coast (Magnuson et al., 1990). In these areas, Hemwood and Stunz (1987) estimated turtle capture and mortality rates for loggerheads, Kemp's ridleys, and green turtles from a variety of shrimp trawl data collected between 1973 and 1984. Turtle mortality was estimated at 9874 per year for loggerheads, 767 per year for Kemp's ridleys, and 229 per year for greens. Overall capture rates per year for these species were approximately four times higher than their mortality rate. Magnuson et al. (1990) considered the mortality of turtles in shrimp trawls to range from 5000 to 50,000 per year for loggerheads and 500 to 5000 per year for Kemp's ridleys. Information on actual observed captures and catch rates of sea turtles remains relatively scarce, especially regarding incidental catches in trawls equipped with a TED (Trawling Efficiency Device or Turtle Excluder Device) or BRD (Bycatch Reduction Device). The intent of this note is to estimate catch rates of turtles in shrimp trawls, excluding try nets, with and without TEDs in U.S. waters.

Methods. — The National Marine Fisheries Service (NMFS) has conducted two shrimp trawling studies since 1988 in which sea turtles were captured incidentally. The first study (TED study), from March 1988 through September 1990, compared the effects of TEDs on shrimp catch by commercial shrimp trawlers in the southern North Atlantic and Gulf of Mexico (Renaud et al., 1993). Typically, vessels pulled 2 or 4 standard nets (TED-less nets) for 2–6 hrs and intermittently sampled with a smaller try net. Try nets were not equipped with TEDs. Observers recorded shrimp catch during trawling operations. Gear specialists modified the standard nets so that shrimp catch among the nets was nearly equivalent. Then TEDs were installed into half of the standard nets and adjusted to have the least impact, if any, on
shrimp catch of the net. Renaud et al. (1990, 1991) detail the methodology for this work. The second study (bycatch study), still in progress, was implemented in April 1992 when TED regulations were in effect for offshore waters (areas seaward of U.S. Coast Guard defined COREG lines). TEDs were present in all nets except during a brief suspension of TED regulations off the Louisiana coast from 4 September to 5 October 1992. Bycatch in the U.S. shrimp fishery in the Gulf of Mexico and along the U.S. Atlantic coast was characterized by TED-type during commercial operations. Catch of turtles (number/hr/100 ft of trawl headrope), by TED-type and overall, was determined independently for each study and separately for the Atlantic and Gulf of Mexico. Since the time a try net was in the water was not typically recorded, catch rates for try nets could not be calculated during this analysis.

Results and Discussion.—Loggerhead, Kemp’s ridley, green, hawksbill, and leatherback turtles were caught during normal fishing operations in these studies (Table 1). Seventy-two turtles were taken in 6478 hours of trawling during the TED study. Sixty-three turtles were caught in standard shrimp trawls, 6 in try nets, and 3 in TED-equipped nets. Three loggerheads, one Kemp’s ridley, and one hawksbill were landed freshly dead. Two loggerheads, in an advanced state of decomposition, were excluded from the catch per unit effort analyses.

Total catch rate (turtles/hour/100 ft of trawl head rope), excluding try nets, was 0.00075 in the Gulf of Mexico and 0.00718 in the Atlantic (Table 2). Out of the 6 TEDs tested, turtles were only observed captured in the Super Shooter TED. These catch rates were 0.00022 turtles/hr in the Gulf of Mexico and 0.00185 in the Atlantic (Table 2).

Forty-five turtles were taken in 18,631 hours of trawling during the bycatch study from April 1992 through October 1995 (Table 3). J. Nance and L. Scott-Denton, unpubl. data). Twenty-four turtles were captured in TED-equipped nets and 19 in try nets. Two turtles were captured in nets without TEDs. One loggerhead and 2 Kemp’s ridleys were landed freshly dead. Three decomposed turtles (1 loggerhead, 1 Kemp’s ridley, and 1 unidentified) were excluded from the catch per unit effort analysis. Total catch rates for trawls

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1 Six turtles (5 alive and 1 decomposed) captured in try nets and one decomposed turtle captured in a standard net were excluded from these analyses.

2 Standard nets do not have TEDs.

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<th>Area</th>
<th>TED-type</th>
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<th>Number of Turtles</th>
<th>Hours</th>
<th>CPUE</th>
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<th>Hours</th>
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(turtles/hour/100 ft of trawl head rope), excluding try nets. were 0.00016 in the Gulf of Mexico and 0.00047 in the Atlantic. Turtles were captured in 8 of 13 known TED-types used by shrimpers (Table 4). Captures by TED-type ranged from 0.00099 turtles/hr with Georgina Jumper and Morrison Soft TEDs in the Gulf of Mexico (Table 4) to 0.01685 turtles/hr with Anthony Weedless TEDs in the Atlantic. Five TED-types captured no turtles during the study.

Incidentally captured turtles ranged in size from a 23 cm straight carapace length (SCL) hawksbill to a 163 cm SCL leatherback. Excluding 4 decomposed and 4 unidentified turtles, the most commonly captured species was the loggerhead (n = 75; 69%), followed by the Kemp’s ridley (n = 23; 21%), leatherback (n = 6; 5%), green (n = 3; 3%), and hawksbill (n = 2; 2%). Four turtles were not identified to species. Turtle conditions included alive and conscious, alive and unconscious, freshly dead, and dead and decomposed (Tables 1 and 3). Seventy-seven turtles were captured off the coasts of North Carolina, Georgia, and eastern

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Table 4. Turtle catch per unit of effort (number of turtles/1000 ft of headrope of trawl/hour) (CPUE) for various TED-types in the Atlantic and Gulf of Mexico during the bycatch study.

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<th>Area</th>
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1 Nineteen turtles captured in try nets and three decomposed turtles were excluded from these analyses.
2 Standard nets do not have TEDs.

Florida, 25 off the west coast of Florida, and 15 elsewhere in the Gulf of Mexico.

Single or multiple captures of a sea turtle in a shrimp trawl or trawls may result in the turtle's injury or death and its subsequent stranding on the beach. Callofiet al. (1991) found highly significant correlations between strandings of shrimp turtles and shrimping effort in the nearshore waters of Texas and southwestern Louisiana. Manzella et al. (1988) documented the capture of 2 Kemp's ridley's in shrimp trawls, their release, and recapture by other vessels. One of these turtles subsequently stranded alive in poor condition. This provides some confirmation of the theory that turtle strandings may be a result of turtles incidentally captured and released alive by the shrimp fishery.

The activities of man have had severe impacts on sea turtles over the past five decades. The most notable has been on the Kemp's ridley sea turtle. During the 1940s, as many as 40,000 turtles nested in a day at Rancho Nuevo, Mexico (Hildebrand, 1963). Now, less than 1000 nest in an entire season (R. Byles, pers. comm.). This reduction in the number of nesters has been attributed to long-term egg collecting in Mexico and to trawlers in USA and Mexico (Byles et al., in press). Present day activities of man that harm sea turtles include commercial shrimp trawling, gill netting and longlining, recreational fishing with hook and line, injuries caused by encounters with boat hulls and propellers, dredging of navigable waterways, explosive removal of offshore oil and gas structures, and entanglement in marine debris (Magnusson et al., 1990). With respect to sea turtle mortality, Magnusson et al. (1990) concluded that the U.S. shrimp fishery was responsible for ten times more turtle deaths than the next closest cause (all other fisheries combined: finfish trawls, seines, gill nets, traps, and longlines). This ongoing problem must be continually addressed to prevent local extirpation of these marine reptiles.

Acknowledgments. — We would like to acknowledge the observers who spent literally thousands of hours collecting the data on shrimp vessels, the captains and owners of shrimp vessels for allowing us to collect fishery information on their vessels, and Dennis Kosi (NMFS, Galveston) for assistance in the analysis of catch data.

Literature Cited


Received: 16 January 1996
Reviewed: 14 July 1996
Revised and Accepted: 13 August 1996
Disturbance of the Seabed by Mobile Fishing Gear: A Comparison to Forest Clearcutting

LES WATLING* AND ELLIOTT A. NORSE†

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†Marine Conservation Biology Institute, 15806 NE 47th Court, Redmond, WA 98052-5208, U.S.A., email enorse@u.washington.edu

Abstract: Bottom trawling and use of other mobile fishing gear have effects on the seabed that resemble forest clearcutting, a terrestrial disturbance recognized as a major threat to biological diversity and economic sustainability. Structures in marine benthic communities are generally much smaller than those in forests, but structural complexity is no less important to their biodiversity. Use of mobile fishing gear crushes, buries, and exposes marine animals and structures on and in the substratum, sharply reducing structural diversity. Its severity is roughly comparable to other natural and anthropogenic marine disturbances. It also alters biogeochemical cycles, perhaps even globally. Recovery after disturbance is often slow because recruitment is patchy and growth to maturity takes years, decades, or more for some structure-forming species. Trawling and dredging are especially problematic where the return interval—the time from one dredging or trawling event to the next—is shorter than the time it takes for the ecosystem to recover; extensive areas can be trawled 100-700% per year or more. The effects of mobile fishing gear on biodiversity are most severe where natural disturbance is least prevalent, particularly on the outer continental shelf and slope, where storm-wave damage is negligible and biological processes, including growth, tend to be slow. Recent advances in fishing technology (e.g., rockbopper gear, global positioning systems, fish finders) have all but eliminated what were de facto refuges from trawling. The frequency of trawling (in percentage of the continental shelf trawled per year) is orders of magnitude higher than other severe seabed disturbances, annually covering an area equivalent to perhaps half of the world’s continental shelf, or 150 times the land area that is clearcut yearly. Mobile fishing gear can have large and long-lasting effects on benthic communities, including young stages of commercially important fishes, although some species benefit when structural complexity is reduced. These findings are crucial for implementation of “Essential Fish Habitat” provisions of the U.S. Magnuson-Stevens Fishery Conservation and Management Act which aim to protect nursery and feeding habitat for commercial fishes. Using a precautionary approach to management, modifying fishing methods, and creating refuges free of mobile fishing gear are ways to reduce effects on biological diversity and commercial fish habitat.

Perturbaciones del Lecho Marino por Artes de Pesca Móviles: Una Comparación con la Tala Forestal

Resumen: Los arrastres de fondo y el uso de otras artes de pesca móviles tienen efectos en el lecho marino que se asemejan a la tala total de bosques, que es a su vez una perturbación terrestre reconocida como una de las mayores amenazas a la diversidad biológica y la sustentabilidad económica. Las estructuras en comunidades marinas bentónicas son generalmente mucho más pequeñas que aquellas en los bosques, pero la complejidad estructural no es menos importante que la biodiversidad. El uso de artes de pesca móviles quiebra, sepulta y expone animales marinos y estructuras sobre y en el substrato, reduciendo marcadamente la diversidad estructural. Su severidad es burdamente comparable con otras perturbaciones marinas de orden natural o antropogénico. También altera los ciclos biogeoquímicos, de hecho a nivel mundial. La recuperación después de una perturbación es frecuentemente lenta debido a que el reclutamiento es por parches y el crecimiento para alcanzar la madurez toma años, décadas o aún más para algunas especies que forman estructuras. Los arrastres de fondo y dragados son especialmente problemáticos donde el intervalo de retorno

Paper submitted December 5, 1997; revised manuscript accepted July 1, 1998.

Conservation Biology, Pages 1180-1190
Volume 12, No. 6, December 1998
Figure 1. A comparison of three areas of the seabed known to be affected by mobile fishing gear: (a) and (b) are Cashes Basin, Gulf of Maine, U.S.A., water depth approximately 120 m; (a) an area where no recent dragging had occurred and (b) an area where trawl marks are visible (larger forms, such as cerianthid anemones, are undisturbed, but the fine surface layer of sediment has been removed); (c) and (d) are near Swans Island, Gulf of Maine, water depth about 30 m; (c) before a scallop dredge was used in the experimental area and (d) after one pass of the dredge (most surface-dwelling, small invertebrates and their tubes have been removed); (e) and (f) are Australia, North West Shelf, water depth about 70 m; (e) an area where trawling has been prohibited and (f) an area heavily trawled by pair-trawlers (catch rate of sponges was about 500 kg/hour in the mid-1970s but declined to a few kilograms/hour a decade later). Photos by Les Watling (a and b), Peter Auster (c and d), and Keith Sainsbury (e and f).
(tiempo entre un evento de dragado o arrastre y otro) es más corto que el tiempo que toma a un ecosistema recuperarse; aussi estas son arrastradas entre un 100 y 100%, por año o más. Los efectos de las artes de pesca móviles en la biodiversidad son más severos cuando las perturbaciones naturales son menos prevalentes, particularmente en las afueras de la plataforma continental y la pendiente, donde el alijo del oleaje por tormentas es negligible y los procesos biológicos (incluyendo crecimiento) tienden a ser lentos. Recientes avances en tecnología pesquera (e.g., sistemas de posicionamiento global, detectores de peces) aparentemente tienen toda, pero eliminan lo que de facto fueran refugios contra arrastras. La frecuencia de los arrastras (en porcentaje de la plataforma continental arrastrada por año) es órdenes de magnitud mayor que otras perturbaciones severas al lecho marino, anualmente la cobertura de área es equivalente quizá a la mitad de la plataforma continental marina, o 150 veces el área de tierra que es talada anualmente. Las artes de pesca móviles pueden tener impactos grandes y de larga duración en las comunidades bentónicas, incluyendo estadios fósiles de peces de importancia comercial, aunque algunas especies se benefician cuando la complejidad estructural es reducida. Estos descubrimientos son cruciales para la implementación de el “habitat esencial para peces” del Acta de Conservación y Manejo de Pesquerías Magnuson-Stevens de los Estados Unidos y que pretende establecer hábitats de reproducción y alimentación para peces comerciales. El uso de una aproximación precautoria de manejo, la modificación de métodos de pesca y la creación de refugios libres de artes de pesca móviles son formas para reducir los efectos en la diversidad biológica y el hábitat para peces comerciales.

New opinions are always suspected, and usually opposed, without any other reason but because they are not already common.

—John Locke, An Enquiry Concerning Human Understanding (1690)

Introduction

Disturbances influence patterns of ecosystem diversity by affecting species composition, spatial structure, and biogeochemistry (Grasse & Sanders 1973; Pickett & White 1985; Huston 1994). Disturbance processes span a wide range of spatial and temporal scales, from the burrowing of individual annelid worms to single treefalls to stand-replacement forest fires to plate tectonics; in general, larger-scale disturbances are rarer. Organisms vary markedly in their resistance and resilience to disturbance. As a result, natural ecosystems are mosaics that reflect their disturbance history and organisms’ responses (Huston 1994). Disturbances that humans superimpose on natural disturbance regimes alter community mosaics and form the core of conflicts such that over clearcut logging of the ancient forests of the U.S. Pacific Northwest (Norse 1990). From tropical rainforests to the taiga, clearcutting has become a major issue for conservation biologists, advocates, and policy makers, but there is another comparably severe anthropogenic ecosystem disturbance that is far more prevalent worldwide yet has received little scrutiny: the use of mobile fishing gear—trawls and dredges—to catch bottom-dwelling marine animals (Hutchings 1990; Jones 1992; Dayton et al. 1995). We detail how mobile gear can alter benthic ecosystems, and we compare this disturbance to other marine disturbances and forest clearcutting.

Trawling is a widespread method of catching marine fishes and invertebrates. Individual trawling vessels from 10 m to 130 m long (or, sometimes, pairs of trawlers) fish by pulling large nets through the sea. Midwater or pelagic trawls are used to catch fishes in the water column (e.g., walleye pollock [Theraagela chalcogramma] in the North Pacific and hoki [Macruronus novazelandiae] off New Zealand). Midwater trawling affects biological diversity by removing portions of target populations and others that are caught incidentally (bycatch), but it causes no long-lasting habitat disturbance as long as the trawl does not touch the bottom. Most trawling (and all dredging, when heavy chain-rigged or hydraulic suction devices are used), however, occurs on the seabed, targeting species such as demersal groundfish (e.g., Atlantic cod [Gadus morhua] and plaice [Pleuronectes platessol]) on the continental shelves of the North Atlantic, green sea urchins (Strongylocentrotus droebachiensis) in nearshore waters of New England, shrimp (Peneaus) on the Gulf of Mexico and northern Australian shelves, and scallops (Pectinidae) in the northern and southern hemispheres.

In its first decades, conservation biology has focused mainly on the terrestrial realm (Irish & Norse 1996). So, because human activities in the sea are likely to be less familiar to conservation biologists and because trawling has been likened to clearcutting (McAllister 1995; Levy 1998), we compare these two sources of ecosystem disturbance.

Mobile Fishing Gear

The most widely used towed bottom-fishing gear is the otter trawl (Fig. 1). Its forward motion spreads a pair of otter boards, each weighing tens to thousands of kilograms, that hold the trawl mouth open. The bottom of an otter trawl mouth is a foot rope or ground rope that

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can bear many heavy (tens to hundreds of kilograms) steel weights (bobbins) that keep the trawl on the seabed. A growing fraction of bottom trawls, called roller trawls or rockhoppers, are armed with large (to 40-cm-diameter) rubber discs or steel bobbins that ride over obstructions such as boulders and coral heads that might otherwise snag the net. Some trawls are armed with tickler chains that disturb the seabed to flush shrimp or fish into the water column to be caught by the net. The constricted posterior netting of a trawl is called the cod end. When filled with tens to thousands of kilograms of marine organisms, rocks, and mud, and dragged for kilometers across the bottom, the cod end, like the otter boards, bobbins, rollers, and tickler chains, can disturb the seabed.

Another type of mobile fishing gear, the beam trawl (Fig. 2), is held open by a steel beam (total aperture 4-12 m) instead of otter boards and is typically fitted with chains, with an empty weight up to 13 tons. Beam trawls can be towed at speeds of up to 14.8 km/hour (Polet et al. 1998). Other towed gear, including scallop, oyster, and crab dredges, consist of steel frames and fiber or metal chain-mesh bags that plow over and through the surface layers of the seabed to sift out target species. These dredges can be so effective at collecting objects in sediments that they were used in 1996 to gather buried debris at the crash site of TWA Flight 800 off Long Island, New York. Bivalve mollusks such as ocean quahogs (Arctica islandica) and surf clams (Spisula solidissima) are caught by hydraulic dredges that liquefy and suck up large amounts of seabed (Messieh et al. 1991). Continental shelf, slope- and seamount-dwelling anthozoans used for jewelry, such as precious corals (Corallium spp.) and black corals (Antipathes spp.), are dragged with mobile gear called Italian bars (Risk et al. 1998), tangle nets, and St. Andrew’s crosses.

Trawling has a long history, mainly in estuaries, bays, and continental shelf waters at depths from a few to hundreds of meters, but its use accelerated sharply with the introduction of diesel engines in the 1920s (Lindeboom & de Groot 1998). As more continental shelf fish stocks are overfished, the search for new fisheries has extended bottom trawling onto the continental slope to depths of 1400-1829 m (Gordon & Hunter 1994; Merritt & Haedrich 1997). In the last several decades, bottom trawling has also extended from traditional fishing grounds near the margins of industrialized nations such as the North Sea and Georges Bank to waters off developing nations and even the remotest oceanic seamounts of the Southern Ocean (L.W., personal observation). Until the 1980s or early 1990s, many areas were de facto refuges because their numerous obstacles or steep slopes made trawling risky. Recent deployment of rockhopper trawls, global positioning systems, and fish find-
ers has allowed trawlers to work in previously untouched waters. As a result, trawls or related fishing gear are now used on every kind of bottom type from subpolar to tropical waters.

Unlike clearcutting, most trawling is concealed from view and happens far from traditional study sites, which helps to explain why its effects have been overlooked.

This is not a trivial oversight. As on land, biodiversity in the sea is profoundly threatened (Norse 1993; Butman & Carlton 1995). The estuaries, bays, and continental shelves where most trawling occurs, together constituting approximately 7.4% of the sea’s area (Sharp 1988), are among the most biologically productive (Kohlenstueck-Mishke et al. 1970; Walsh 1988) and heavily altered (Norse 1993) marine ecosystems. Moreover, trawling might have serious economic consequences: many of the world’s fisheries have declined sharply, and trawling has been thought to contribute to diminished fish catches (Messieh et al. 1991), including the commercial extinction of once-bounteous fisheries for haddock (Melanogrammus aeglefinus) and cod on the Grand Banks (Canada). There have been protests in Europe against trawling gear since the fourteenth century because of its presumed effects on benthic organisms (de Groot 1984; Berrill 1997). Most studies of trawling effects have focused on the North Sea (e.g., Lindeboom & de Groot 1998; Kaiser, this issue) and tropical Australia (e.g., Sainsbury et al. 1993; International Council for the Exploration of the Sea 1996). It is difficult to explain why there is virtually no scientific literature on the effects of trawling for shrimp in the Gulf of Mexico, one of the world’s more heavily trawled areas, nor in U.S. Pacific, Latin American, African, or Asian waters.

**Role of Benthic Structures**

Gauging the impact of mobile fishing gear requires an understanding of how natural disturbance affects benthic communities (Hall 1994). The sea’s geographical substratum ranges from massive rocky reefs through boulders, cobbles, pebbles, sands, and muds (silts and clays), reflecting depositional and erosional processes past and ongoing. In general, reefs and coarser clastic substrata are far less common than muds. Reefs and coarse sediments are most prevalent on shallower parts of continental shelves, where storm-generated waves can resuspend and remove finer sediments. Below a few tens of meters depth on the continental shelf and slope, muds are almost universal, except for sand chutes and exposed rocky outcrops in steep-sided submarine canyons or in high-latitude areas where large boulders, cobbles, or pebbles were deposited by icebergs or retreating glaciers and may now occur in deep water. In general, sandy bottoms are the least stable substrata, and their surface is often rippled with waves having periods from a few centimeters up to a meter, reflecting ongoing or episodic resuspension. Pebbles, cobbles, and boulders are more resistant to resuspension by waves or currents and often remain fixed in ecosystems where sands are repeatedly shifted. At the smaller end of the size spectrum, silt and clay particles in muds are so vulnerable to resuspension and removal that they accumulate mainly in areas with a low frequency of resuspension (e.g., the deep sea) or high supply (estuaries).

On both hard and soft substrates, the structural complexity of benthic ecosystems is further increased by living organisms. A wide variety, including foraminifers, coralline algae, corals, brachiopods, bryozoans, worms, and mollusks, form structures of shelly calcium carbonate on rocks down to the size of cobbles or even pebbles. Many other organisms, including algae, seagrasses, mangrove trees, sponges, cerianthid anemones, gorgonians, sea pens, phoronids, polychaete worms, amphipod crustaceans, sea urchins, and crinoids, create solid or tubular structures on the seabed.

Although the largest brown algae, giant kelp (Macrocystis spp.), can exceed 30 m from holdfasts on the seabed to the sea surface, biogenic structures in marine ecosystems are generally orders of magnitude smaller than in terrestrial forests. Some marine structure-formers can reach similar ages, however (Risk et al. 1998), and are no less important because their scarcity often limits the abundance of many benthic species. Far more than on land, structures that reach even a few centimeters into the water column are heavily used by a diversity of taxa, including post-settlement young of commercially important fish species, for at least three reasons. First, because seawater is far denser than air, gravity is less a deterrent to marine than to terrestrial organisms. Many organisms hover close to seabed structures, a behavior that is scarce in terrestrial species. Second, in contrast to land, where there are few suspension-feeders, a large portion of marine species capture small particles from the passing water. The speed of currents increases dramatically in the first few centimeters above the sediment-water interface (Snelgrove & Butman 1994); therefore, organisms in or on benthic structures have access to faster-moving waters, which can carry larger food particles. Third, dissolved oxygen in the millimeters-thick bottom boundary layer results from diffusion of oxygen from overlying waters and respiration in the sediment below. Oxygen in this thin layer can be eliminated by biological activity (Jorgensen & Revsbech 1985). Thus, a sizable number of benthic organisms must either extend some part of their body into the overlying well-oxygenated waters or climb even small seabed structures to avoid sediment-related anoxia.

As on land, there is also abundant biogenic structure within the substratum (Rhoads 1974). Thick mats of seagrass rhizomes maintain sediment stability in some areas (Orth 1977), and annelid and echinuran worms, bivalve
mollusks, amphipod crustaceans, shrimps, crabs, and fishes (together comprising the infauna) construct long-lived (weeks to years) burrows and tubes in soft sediments that pump oxygen into what would otherwise be an anaerobic environment (Aller 1988; Meyers et al. 1988). The perception that the seabed is a featureless biological desert occurs because people's most common experience of the seabed—on sandy intertidal beaches—represents an anomalous situation where nearly incessant wave pressure largely eliminates long-lived structures. In contrast, the vast majority of the seabed is interrupted and honeycombed with biogenic structures, and this heterogeneity is crucial to benthic ecosystems (e.g., Taylor 1978). MacArthur and MacArthur's (1961) observation—that bird species diversity is positively correlated with forest structural diversity—is even more true of biogenic structures and species in marine benthic ecosystems.

Because most of the sea bottom is essentially level, the major sites of increased surface area for habitation by small invertebrates and post-settlement fishes are structures created by larger organisms. In general, areas of the continental shelf seabed with biogenic structures have higher levels of species diversity than those areas lacking such structures. Coral reefs, among the most rugose marine ecosystems, offer a large surface area and myriad interstices for their exceptional diversity of infauna, epibiota, and associated suprabenthic species (Roberts & Ormond 1987; Reaka-Kudla 1997). In the deep sea, where diversity is generally high, mudballs created by polychaete worms provide habitat for a greater diversity of harpacticoid copepods (Thistle & Eckman 1988), and mounds made by sea cucumbers attract suspension-feeding bivalves, amphipods, and polychaetes (Levinton 1995).

Habitat structure provides surfaces for feeding and hiding places from predators and is therefore important in regulating population dynamics and species interactions of fish communities, as has been demonstrated for coral reefs, rock reefs, seagrass beds, and kelp beds (e.g., Heck & Orth 1980; Ebeling & Hixon 1991). Much less work has been done in deeper waters of the outer continental shelf. Juveniles of many fish species and other mobile fauna associate with small-scale habitat features (Grimes et al. 1986; Lough et al. 1989; Auster et al. 1994, 1995; Langton et al. 1995; Tupper & Boutillier 1995) such as cobble, sand ripple crests, biogenic mounds and pits, clam shells, burrows, macroalgae, sponges, and amphipod tubes. The use of these features can be obligatory or facultative to particular life-history stages of a species, but habitat complexity increases the survivorship of individuals by providing cover from predators in species such as Atlantic cod (Gottliebs & Brown 1993; Walters & Juanes 1993) and American lobster (Homarus americanus; Wahlte 1992a, 1992b; Wahlte & Steneck 1992). Lough et al. (1989) found that the pelagic juvenile stage of Atlantic cod occurs over large areas of Georges Bank, but the subsequent benthic phase juveniles were found only on the gravel habitat of the Northeast Peak. Assuming that cod settle over the whole bank, predation pressure might be responsible for this pattern of differential survival. Off Nova Scotia, Tupper and Boutillier (1995) demonstrated that juvenile cod settle in all habitats (i.e., seagrass, sand, cobble, and rock reef), but survivorship and growth are higher in structurally more complex habitats where the cod can avoid predators. Gregory and Anderson (1997) showed that the youngest cod were cryptically colored and hovered above gravel substrates with low relief, whereas older juveniles seemed to spend more time around individual large boulders.

Life Histories of Structure Formers

The effects of disturbance on benthic ecosystems are determined, in part, by species' life histories. As in forest ecosystems, structural dominants in many marine ecosystems are slow-growing and long-lived. Some sponges, for example, are believed to live 50 years or more (Dayton 1979). Northeast Pacific geoduck (Panope generosa) and Atlantic ocean quahog clams are estimated to live up to 146 and 221 years, respectively (Goodwin & Pease 1989; Kraus et al. 1989). A small colony of the gorgonian Primnoa resedae from waters between Georges and Browns Banks, Nova Scotia, Canada, was recently estimated to be about 500 years old; larger ones could reach 1500 years (Risk et al. 1998), more than the maximum longevity for Douglas fir (Pseudotsuga menziesii) trees (Norse 1990). In the sea, no less than in forests, frequency of disturbance relative to recruitment and growth of structure formers determines the severity of human impact, and slow growth rates of key species make recovery from disturbance a long-term process.

Again, as in forests, where widely varying proportions of species can recover from fire or logging by resprouting, some epifaunal and infaunal species can rebuild their structures after disturbance, but others, such as the tube-dwelling polychaete worm Amphitrite johnstoni, cannot (L.W., personal observation). Disturbances that destroy the integrity of burrows or tubes can expose infauna to high risk from predation (Kaiser & Spencer 1994), so recruitment is the only means by which these species can recover after disturbance exposes them. But like many long-lived terrestrial species—such as Douglas fir trees, which generally produce substantial seed crops once every 5–7 years and recruit successfully perhaps once in decades (Norse 1990)—many long-lived marine species do not recruit successfully every year (e.g., Beukema & Essink 1986; Dörjes et al. 1986; Lundälv 1986). The rate of ecosystem recovery after a disturbance that kills structure-forming species can be delayed by slow
recruitment, spatial patchiness of recruitment, and slow post-recruitment growth. As Runkle (1985) noted, a disturbance that is both severe and extensive can result in very long recovery times.

**Recolonization and Spatial Scale**

Ecosystem resilience in the sea, as on land, is affected by the spatial scale of a disturbance (Sousa 1985). Because so many marine organisms have dispersal stages that live in the plankton for hours to months (usually days or weeks), one might assume that the rate of recolonization after a disturbance would be similar for all patch sizes less than kilometers in diameter. An experiment by Thrush et al. (1996) suggests, however, that even much smaller disturbed areas may show size-dependent recolonization. They defaunated intertidal sand patches of 0.203 m², 0.81 m², and 3.24 m² and sampled for 9 months to assess recovery. They found surprisingly slow recovery after defaunation, particularly in the larger patches. Because the sandflat in the experiment was prone to disturbance by wind-driven waves, sediments were unstable after defaunation removed a dense mat of polychaete tubes, hampering recolonization. This suggests that larger disturbances that destroy organisms that maintain habitat stability are likely to recover very slowly, particularly in wave-disturbed soft bottoms.

Several mechanisms can be invoked to explain slow recolonization of even small patches. First, colonization of patches is affected by patch type: type I patches—those surrounded by undisturbed communities—are colonized both from the perimeter and by dispersed propagules (Connell & Keough 1985; Sousa 1985), whereas type II patches—undisturbed spots surrounded by vast disturbed areas—are the source of colonizers, especially over short distances. Key components of benthic ecosystems, including amphipods, isopods, and other small crustaceans do not have planktonic larvae but have direct development and characteristically short-distance dispersal across the seabed. In addition, in temperate waters at least, production of propagules is seasonal, so disturbed patches may sit for some time before recolonization can occur. Second, disturbance alters the seabed physically and chemically. Watling et al. (unpublished data) have shown that scallop dredging in Maine muddy sand sediments removed the top 4 cm of sediments. They found that this upper sediment layer contains the highest-quality food but is easily resuspended and carried away by mobile fishing gear, so sediment food quality decreases. Several groups of invertebrates did not recolonize the disturbed patch until the food quality had recovered. Third, there are likely to be nonlinear changes in recolonization, depending on the aggregation of individual disturbances and the resulting fragmentation of the landscape (Hall et al. 1994).

**Adaptation to Disturbance Frequency**

The severity of a disturbance can range from damaging only the most sensitive organisms to destruction of all multicellular life. The prevailing disturbance regime and the degree to which it is ameliorated by biotic structures (e.g., tube mats of polychaetes that bind sand grains together) are key factors determining the impact of anthropogenic disturbances (Brylinsky et al. 1994; Kaiser & Spencer 1996). In communities visited by severe disturbances at frequent intervals, only the most resistant or resilient species are likely to be present as adults when the next disturbance occurs. Thus, an event that resuspends the upper 10 cm of sediment in a sandy beach is likely to have minimal effects because organisms living there must have adaptations that confer resistance (such as rapid burrowing) or else must recolonize disturbed areas quickly; organisms lacking these abilities would have been eliminated by previous disturbances. Conversely, communities that rarely experience severe disturbance are likely to lose many species because their selection regimes have not filtered out organisms with low resistance or resilience. In general, the frequency of severe disturbances decreases sharply with increasing depth; continental slopes (except in high relief areas such as submarine canyons, where turbidity currents can occur) have few or no natural agents of severe, large-scale physical disturbance.

**Agents of Benthic Disturbance**

Agents of benthic disturbance include abiotic processes such as lava flows and volcanic ashfalls, mass-slumping on steep slopes in submarine canyons, wave-generated turbulence, currents generated by tides, winds, or waves, and icebergs. Biological disturbance processes include bioturbation—sediment movement by animal burrowing and tunneling—and digging for food by whales, walruses, fishes, and crabs. Anthropogenic disturbances include harbor dredging and dredge disposal, gravel extraction, anchoring and ship grounding, fishing using explosive, muro ami (in which weighted bags smash reef corals to scare fishes from their hiding places so they can be netted by divers), and bottom trawling and dredging.

Although the size, shape, and types (I or II) of disturbed patches (Sousa 1985) affect recolonization and succession after disturbance, a useful first-order estimate of the global impact of a disturbance is the product of severity and frequency. If either is low, then impact overall is low; for example, the global impact of a severe local disturbance is not high if its frequency is low when averaged over the vast area of the world's continental shelves. Severity can be measured as the proportion of
individuals damaged, removed, or killed or by the energetic cost and time required for rebuilding burrows, tubes, or shells. Frequency (analogous to fire frequency in Agee 1993) is the percentage of area disturbed per year. The inverse is what fire ecologists call return interval, the time between successive events at a given place. We can begin to quantify the effects of disturbance on continental shelves worldwide by examining these factors for natural and anthropogenic disturbances.

Natural Disturbances

Very large storm waves can affect the seabed at maximum depths of about 30–40 m, with increased current velocities at 60–70 m (Hall 1994), perhaps even deeper. Wave impacts are most important in the narrow intertidal and shallow subtidal zones, especially near exposed outer coast headlands. For example, Witman (1987) noted that Northwest Atlantic horse mussels (*Modiolus modiolus*) are excluded from depths below 9 m at many wave-exposed sites and that storm-related dislodgement is the most significant source of mortality. Although wave intensity is high during major storms, severity is low because most species living in storm-affected areas are adapted to resisting these events or to recovering quickly. Hurricane-force storms can increase wave pressure in bands hundreds of kilometers wide, but the seabed is physically disturbed mainly in the shallows. The frequency of major storms can vary from several per month along exceptionally stormy coasts to one per century or longer. Averaged over the world’s continental shelves, storm frequency is fairly low, and we rate the impact of wave disturbance as low.

Nearshore tidal currents can resuspend and remove all but the largest sediment particles, leaving bottoms of boulders, cobbles, or pebbles. In deeper waters offshore, currents are rarely strong enough to remove even fine, silt-sized particles (Nowell et al. 1981). Where high currents are nearly constant, severity is generally low because organisms are adapted to deal with—and benefit from—currents, and they are seldom lost. As with waves, because of low severity, we rate the impact of current disturbance on benthic communities as low.

Icebergs can plow deep gouges in the seabed as winds and currents move them. They are important agents of disturbance along the coasts of Antarctica, in the Arctic Ocean and even occasionally on the Grand Banks of Newfoundland. Few if any organisms can withstand the tremendous forces icebergs generate. In nearshore Antarctic and Arctic waters, iceberg scour is frequent enough that communities are structurally more complex and more diverse below the depth of scour. The frequency of iceberg scour averaged over the world’s continental shelves is very low, however, so impact is low.

Animals moving through marine sediments shift sediment particles through the process of bioturbation, thereby disrupting the lives of smaller sediment-dwellers. Digging by large, deep-dwelling polychaetes, bivalve mollusks, and thalassinid crustaceans can slow or stop recruitment by covering newly settled larvae repeatedly with layers of sediment. But most sediment movement from bioturbation is extremely local, occurring over a scale of millimeters to a few centimeters (Wheatcroft et al. 1990)—except, perhaps, for the large mounds produced by thalassinid crustaceans (Suchanek 1983). Therefore, although sediment movement rates may be remarkably high (to thousands of litres of sediment shifted annually per square meter), sediment particles and the binding organic matrix are generally not removed, and most animals are not affected by movements of the individual mineral grains. Severity is low because sediment dwellers have time to repair burrows or tubes as other animals are shifting sediment particles. Although frequency can be very high, severity is low, and therefore impact is low.

In some regions, foraging by animals such as California gray whales (*Eschrichtius robustus*) can remove up to 1 m² of the sediment surface in one bite (Oliver & Slattery 1985), whereas fishes and birds can disturb patches on the order of tens of square centimeters (Hall et al. 1994). This type of foraging can be successful only where the bottom supports dense aggregations of prey (amphipod crustaceans of the genus *Ampelisca* in the case of the gray whales). Blue crabs (*Callinectes sapidus*) seeking bivalves and polychaetes dig pits that can be an important source of disturbance where their populations are high (Virnstein 1977). Severity from foraging is high but very local (e.g., near hauling-out sites used by walrus [*Odobenus rosmarus*]), and frequency is low when averaged over the continental shelf. The impact of foraging predators, therefore, is low.

Anthropogenic Disturbances

Dredging of the seabed in harbors and navigation channels completely removes upper sediment layers and resident biota and often redeposits them onto an area of seabed that can differ geologically and biologically. Recolonization of dredged and disposal sites can be rapid, but new colonizers are unlikely to be the same species as the original inhabitants, and it can take years for the dredged site to return to a community composition approximating that of pre-dredge conditions (Rhoads et al. 1978). Further, because harbor sediments are often heavily polluted, this issue is as much one of contaminant dispersal as it is one of physical disturbance. Although severity is high and individual disturbances may be large—tens to hundreds of meters wide along a channel that can be kilometers in length—dredging occurs only in shallow waters; the vast majority of the shelf is never dredged, so frequency is low and impact, overall, is low.
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<th>Gear</th>
<th>Substrate type, depth</th>
<th>Region</th>
<th>Study conditions</th>
<th>Results</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam trawl, 2 m</td>
<td>sand, 20 m</td>
<td>Southern North Sea</td>
<td>site hauled once; number of tickler chains altered</td>
<td>sessile organisms such as hydroids, tube-making polychaetes, light-shelled bivalves, and echinoids were badly damaged; mobile macrofauna not affected decreased abundance of small heart urchins and various polychaetes; increased abundance of small tellinids and mageloniids, possibly due to redistribution in sediment density of sessile epifauna reduced 50%</td>
<td>de Groot &amp; Apeldoorn 1971</td>
</tr>
<tr>
<td>Beam trawl, 12 m</td>
<td>sand, well packed, 30 m</td>
<td>Southern North Sea</td>
<td>area trawled 3 times; sampling by box core before and immediately after drag</td>
<td>benthos of less mobile sediments showed a 58% reduction in abundance and 50% reduction in species; least abundant species suffered most severe losses surface sediment lost</td>
<td>Bergman &amp; Hup 1992</td>
</tr>
<tr>
<td>Beam trawl, 4 m</td>
<td>gravel, cobble, 32 m</td>
<td>Irish Sea</td>
<td>10 hauls with 4-m and 3 with 2-m beam trawl; catches compared</td>
<td>experimental lines trawled 10-20 times</td>
<td>Kaiser &amp; Spencer 1994</td>
</tr>
<tr>
<td>Beam trawl, 4 m</td>
<td>sand, 30 m</td>
<td>Irish Sea</td>
<td>site hauled once; samples 1 day after drag</td>
<td>experimental lines trawled 10-20 times</td>
<td>Kaiser &amp; Spencer 1996</td>
</tr>
<tr>
<td>Otter trawl, 20-m footrope and 90-kg doors</td>
<td>very fine mud, 20 m</td>
<td>Maine, U.S.A.</td>
<td>site hauled once; sampled 1 day after drag</td>
<td>site hauled once; sampled 1 day after drag</td>
<td>Mayer et al. 1991</td>
</tr>
<tr>
<td>Otter trawl</td>
<td>sand, 10 m</td>
<td>New South Wales, Australia</td>
<td>area trawled repeatedly for 1 week; samples before and after trawl by grab</td>
<td>most infauna were rare, making comparisons difficult, but there appeared to be no difference in the faunal composition before and after trawling heavy damage only to barrel sponges; slight damage to octocorals; all recovered after 12 months</td>
<td>Gibbs et al. 1980</td>
</tr>
<tr>
<td>Roller-rigged otter trawl</td>
<td>gravel, cobble, 20 m</td>
<td>Georgia, U.S.A.</td>
<td>area trawled once; area surveyed by divers</td>
<td>upper 4 cm of sediment lost and sediment coarsened; recovery took 9 months for amino acids, total microbial biomass, total abundances of cumaceans, and phoxocephalid and photid amphipods infauna numbers tended to increase with increasing dredging activity, but biomass decreased; sessile polychaetes, heart urchins, and sand eels suffered greatest decreases</td>
<td>Van Dolah et al. 1987</td>
</tr>
<tr>
<td>Scallop dredge</td>
<td>muddy sand, 4 m</td>
<td>Maine, U.S.A.</td>
<td>site hauled many times; sampled 3 times over 5 months before drag and 3 times over 9 months after drag</td>
<td>upper 4 cm of sediment lost and sediment coarsened; recovery took 9 months for amino acids, total microbial biomass, total abundances of cumaceans, and phoxocephalid and photid amphipods infauna numbers tended to increase with increasing dredging activity, but biomass decreased; sessile polychaetes, heart urchins, and sand eels suffered greatest decreases</td>
<td>L.W. et al., unpublished data</td>
</tr>
<tr>
<td>Scallop dredge</td>
<td>sand, 5 m</td>
<td>Scotland</td>
<td>several tows over the same track over 9 days; samples at 1-5 and 9 days</td>
<td>upper 4 cm of sediment lost and sediment coarsened; recovery took 9 months for amino acids, total microbial biomass, total abundances of cumaceans, and phoxocephalid and photid amphipods infauna numbers tended to increase with increasing dredging activity, but biomass decreased; sessile polychaetes, heart urchins, and sand eels suffered greatest decreases</td>
<td>Eleftheriou &amp; Robertson 1992</td>
</tr>
<tr>
<td>Scallop dredge</td>
<td>poorly sorted mud with shell hash, 8 m</td>
<td>Maine, U.S.A.</td>
<td>site hauled once; sampled 1 day after drag</td>
<td>surface labile organic matter (especially chlorophyll and protein) lost from upper 2 cm, some due to resuspension and some to burial; surface layers also became enriched in anaerobic microbota immediately after dredging, 50% of the macrofauna showed significant abundance reductions; community composition also differed between control and experimental plots; some plots remained different for 3 months</td>
<td>Mayer et al. 1991</td>
</tr>
<tr>
<td>Scallop dredge</td>
<td>sand, 24 m</td>
<td>New Zealand</td>
<td>5 parallel tows in experimental site</td>
<td>most species showed reductions of 20-30% in abundance after dredging; recovery strong with seasonal recruitment, although some species had not returned 14 months after impact</td>
<td>Thrush et al. 1995.</td>
</tr>
<tr>
<td>Scallop dredge</td>
<td>sand, 15 m</td>
<td>Victoria, Australia</td>
<td>each site towed twice</td>
<td>most species showed reductions of 20-30% in abundance after dredging; recovery strong with seasonal recruitment, although some species had not returned 14 months after impact</td>
<td>Currie &amp; Parry 1996</td>
</tr>
<tr>
<td>Hydraulic dredge</td>
<td>silt and clay to silty sand, 2 m</td>
<td>Italy</td>
<td>site dredged nearly completely once</td>
<td>fine sediments were resuspended and removed, resulting in change in grain size; furrows 10 cm deep persisted up to 2 months; all larger macrobenthos were removed by dredging; after 2 months site recolonized by small individuals</td>
<td>Pranovi &amp; Giovannardi 1994</td>
</tr>
</tbody>
</table>
Table 2. Some observational studies on trawled or dredged sites, with inferences being drawn about disturbance mechanism.

<table>
<thead>
<tr>
<th>Gear</th>
<th>Substrate type, depth</th>
<th>Region</th>
<th>Observations</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Otter trawl with chains and rollers</td>
<td>sand and cobble, with extensive bryozoan beds, 10-35 m</td>
<td>New Zealand</td>
<td>no trawling in the grounds until synthetic fibers were available; extensive trawling from 1960s to 1970 then destroyed almost all bryozoan beds, considered to be a nursery area for snapper; trawling prohibited in 1980</td>
<td>Bradstock &amp; Gordon 1983</td>
</tr>
<tr>
<td>Otter trawls</td>
<td>sand with extensive epibenthic organisms, 50-200 m</td>
<td>Australia, NW shelf</td>
<td>area not trawled until 1959; extensive trawling by Japanese and Taiwanese produced tons of by-catch and resulted in shift of major fish species caught; preferred species associated with epibenthic colonial invertebrates; half of shelf closed to trawling by 1987; recovery is being monitored</td>
<td>Sainsbury 1991; Sainsbury et al. 1993</td>
</tr>
<tr>
<td>Otter trawls</td>
<td>gravel bank with mud overlay, 100 m</td>
<td>Gulf of Maine, Jeffreys Bank</td>
<td>extensive sponge community observed in 1987; repeat observations in 1993 showed overturned boulders and reduced cover of sponges; area may be a refuge for juvenile gadoids</td>
<td>Auster et al. 1996; unpublished data</td>
</tr>
<tr>
<td>Scalloped dredge and otter trawl</td>
<td>sand, cobble, and shell, 30-40 m</td>
<td>Gulf of Maine, Swans Island</td>
<td>reference and fished sites surveyed by ROV video; epifaunal organisms dominant in reference areas; cover of these species decreased in fished areas</td>
<td>Auster et al. 1996</td>
</tr>
<tr>
<td>Scalloped dredge and otter trawl</td>
<td>gravel and cobble, 40-90 m</td>
<td>Georges Bank</td>
<td>areas close to fishing compared with fished sites; compared with the disturbed sites, undisturbed areas had higher numbers of organisms, biomass, species richness and species diversity; undisturbed sites had higher numbers of bushy organisms, making the benthic environment structurally more complex</td>
<td>Collice et al. 1997</td>
</tr>
<tr>
<td>Scalloped dredge</td>
<td>sand, boulders 80 m</td>
<td>Gulf of Maine, Fippenes Ledge</td>
<td>area fished for scallops showed reduced densities of scallops, polychaetes (Myxicola) and tube-dwelling anemones (Cerianthus) as observed by submersible photos</td>
<td>Langton &amp; Robinson 1990</td>
</tr>
<tr>
<td>Scalloped dredge</td>
<td>sand</td>
<td>Gulf of Maine, Stellwagen Bank</td>
<td>dredge path and adjacent areas examined with ROV video; dredge path identified as linear strips devoid of benthic microalgae; hydroids were dense in undisturbed area but eliminated from dredge path; shrimp density increased with increased hydroid density outside of dredge path but shrimp absent in dredge path</td>
<td>Auster et al. 1996</td>
</tr>
<tr>
<td>Prawn trawl</td>
<td>sand</td>
<td>Gulf of Carpenteria, Australia</td>
<td>areas fished for 20 years were surveyed before and after opening for prawn trawl fishery; numerical abundance of 52 of 82 fish species remained unchanged; 30 taxa changed in abundance, some decreased (benthic) and others (benthico-pelagic) increased; impacts on invertebrates not reported</td>
<td>Harris &amp; Poiner 1991</td>
</tr>
<tr>
<td>Prawn and scallop trawls</td>
<td>sand</td>
<td>SW Australia</td>
<td>areas open and closed to trawling were surveyed for bycatch (primarily fish); trawled and untrawled areas not significantly different in their catch; one area, with seagrass and not trawled had very high biodiversity; impact of trawling considered low because the target species live primarily on open sand bottoms</td>
<td>Laurenson et al. 1993</td>
</tr>
</tbody>
</table>

*Sites in all studies chosen have high probability of having been disturbed by fishing activities.*

Marine gravel deposits are mined for building, but gravel beds can have high species diversity because the individual sediment particles are quite large and pack loosely, leaving interstitial spaces large enough to be inhabited by infauna. Gravels also offer hard substrate for epibiota. When gravel is mined, severity is great: the entire fauna is removed. Moreover, the pits left by gravel mining operations are large (tens to hundreds of meters), but gravel mining is so localized that the average frequency for the continental shelf is low. The overall impact of this activity is therefore low.

**TRAWLING AND DREDGING SEVERITY**

Two types of studies have examined effects of mobile fishing gear: (1) experimental studies in which an area of the sea bottom is disturbed by fishing gear and the post-disturbance biota is compared with an undisturbed...
nearby area and (2) observational studies in which a fished area is compared with an area that is either off-limits to fishing or where such fishing has not yet commenced. Results from the two types of studies are summarized in Tables 1 and 2. Table 1 contains only those studies where there was evidence of a reasonably undisturbed control site that could be compared to the experimentally fished site, thereby omitting much published research done in areas where fishing was still occurring.

All experimental studies were done in shallow waters on substrates that are generally hard or clean, that is, with very little silt or clay, or in areas that were not fished because on most bottoms that can be fished control sites are unavailable. Because the bottoms studied are primarily sands, most of these sites either have strong currents or are swept by storm waves. Because these bottoms have infaunal communities dominated by species adapted to frequent physical disturbance, it is hardly surprising that the impacts of trawling and dredging seen in these studies were limited. Even so, each community studied showed the loss of some species, usually the larger-bodied species living buried in the sand. Notably different is the study of Watling et al. (unpublished data) of a muddy sand community subject to scallop dredging, where exclusion of species from the dredged site due to the loss of low-density, high-quality food particles from the sediment persisted until the food value of the surface layer improved.

Missing from these experimental studies are those that might be conducted at depths below the storm-wave base or in areas of significant epifaunal growth. A number of the observational studies, on the other hand, were conducted in just those areas where experimental studies would be difficult. In the heavily trawled North Sea, Riesen and Reise (1982) and Reise (1982) noted that the epifauna, especially the large Sabellaria reefs, have already been removed. In areas where there has been substantial fishing pressure on bottoms with large epifaunal, colonial invertebrates—especially sponges and cnidarians—there is clear evidence that epifauna were removed by the fishing gear (e.g., Bradstock & Gordon 1983 in New Zealand; Sainsbury 1991 in Western Australia). On Jeffreys Bank in the Gulf of Maine, large sponges disappeared from bottom communities at 100 m depth (Auster et al. 1996) between July 1987 and August 1993. The presence of overturned boulders in 1993 suggests that the cause was mobile fishing gear. In a comparison before and after the start of a large trawl fishery in Northwestern Australia, Sainsbury (1987, 1988) found that the proportion of commercial fishes in the high-value genera Lethrinus (emperors), Lutjanus (snappers or sea perch), and Epinephelus (groupers or rockcod) dropped from 45-77% of the catch before trawling to 15% afterward. Fishes that are much less prized commercially, including the genera Nemipterus (threadfin-bream) and Saurida (lizardfishes or grinners), became far more important. Sainsbury concluded that the effects of trawling on habitat were most likely responsible because the catch rates of structure-forming sponges and gorgonians had also decreased dramatically. Photographs showed emperors and snappers often associated with sponges, whereas threadfin-bream and lizardfishes were associated with open sandy bottoms. In all the cases in Table 2, evidence for biodiversity loss is seen either as a drop in structure formers in bycatch, a decrease in catch of target species using structurally complex bottoms, or a loss of large structure formers observed from submersibles or remotely operated vehicles.

In areas inhabited by species adapted to being excavated or resuspended, such as sandy beaches or current-swept channels between islands, trawling and similar fishing methods might approximate natural physical disturbances. But the extent of these ecosystems is very limited. Elsewhere, trawling kills seabed organisms by crushing them, by burying them under sediment, and by exposing infauna and under-rock cryptofauna to predators. Bergman et al. (1998) found marked differences in resistance among species in the path of beam and ottertrawls in different substrates. For example, a 12-m beam trawl towed on silty sediment killed none of the jackknife clams (Ensis spp.) but 82% of sanguin clams (Garii fervensii), and a Norway lobster (Nephrops norvegicus) otter trawl on silty sand killed 34-100% of individuals among various groups of smaller benthic crustaceans.

The effects of mobile fishing gear where severe disturbances are naturally rare or absent depend on substrate type. In "hard-bottom" areas, where the seabed consists of various combinations of rocky reefs, boulders, cobbles, and pebbles and there is an abundance of emergent epibionts, mobile fishing gear removes large epifaunal invertebrates such as sponges, cnidarians, and bryozoans and moves boulders along the bottom. This reduces habitat for myriad small species and food for others. Second, on pebbles, sands, and muds, homogenization of the bottom eliminates habitat features important to recruits of the exploited fish populations and to many other species, including ones that commercial fishes eat. Loss of nursery habitat can mean a progressive decline in economically important fisheries. Third, on muddy bottoms, mobile gear passing over and through the upper 10 or so centimeters of the seabed collapses burrows and breaks the tubes that house small invertebrates. Many of the resident species cannot excavate new burrows or construct new tubes in later life-history stages.

Thus, mobile fishing gear reduces the structural complexity of bottom communities. Hydraulic clam dredging is as severely disturbing as harbor dredging or iceberg scour. Depending on the substratum, community type, and the way trawls are rigged, trawling is not always as severe because it kills only a portion of the megafauna in its path. Use of other mobile gear, such as scallop dredging, falls between hydraulic clam dredging...
Table 3. Frequency of trawling in several areas.

<table>
<thead>
<tr>
<th>Location (area)</th>
<th>Percent trawled annually (years)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limfjord, Denmark</td>
<td>200</td>
<td>Riemann &amp; Hoffmann 1991</td>
</tr>
<tr>
<td>Irish Sea (3 ICES rectangles)</td>
<td>4, 12, and 50</td>
<td>Kaiser et al. 1996</td>
</tr>
<tr>
<td>Southern North Sea</td>
<td>150-200</td>
<td>Lindeboom &amp; de Groot 1998</td>
</tr>
<tr>
<td>Georges Bank (37,000 km²)</td>
<td>21 (1970)</td>
<td>Caddy 1973</td>
</tr>
<tr>
<td>Georges Bank (40,806 km²)</td>
<td>200 to nearly 400 (1976-1991)</td>
<td>Auster et al. 1996</td>
</tr>
<tr>
<td>Gulf of Maine (65,013 km²)</td>
<td>100 (1976-1991)</td>
<td>Auster et al. 1996</td>
</tr>
<tr>
<td>Gulf of Maine and Georges Bank, U.S. vessels only</td>
<td>0-450 (1993)</td>
<td>Pillsaln et al. 1998, this issue</td>
</tr>
<tr>
<td>Shelf south of Nantucket and Nantucket Shoals, Massachusetts 30 X 30 minute rectangles</td>
<td>up to 413 (1985)</td>
<td>Churchill 1989</td>
</tr>
</tbody>
</table>

and trawling in severity. Overall, we rate the severity of mobile fishing gear as high.

TRAWLING AND DREDGING FREQUENCY

Estimates of trawling and dredging frequency have appeared in a few sources (Table 3). Because the data are of varying quality and several sources are old, these values should be considered rough indicators of disturbance from mobile fishing gear. Estimating the frequency of bottom trawling, the most extensively used mobile gear, as a percentage of the world’s continental shelves (which constitute 7.4% of the ocean’s area, or 28 million km²) is more difficult because data are few and assumptions can be off the mark. Nonetheless, we can give two estimates. McAllister (1995) assumed that there were 12,000 active trawlers (of 23,000 over 100 tons) towing nets 25 m wide at 5 km/hour for 6 hours a day for 175 days per year, thus covering 1.575 million km² per year. This figure, equivalent to 5.6% of the total area of continental shelf, is too low, in part because it omits the large majority of trawlers, those under 100 tons.

Other data and assumptions can produce a very different estimate. Slavin (1981) noted that in 1978 Mexico’s 3000 shrimp trawlers caught 67,000 tons. If shrimp trawlers from other nations caught an equivalent tonnage per boat, then the 1978 world shrimp catch of 1.324 million tons was caught by 59,292 boats. Assuming that shrimpers constituted two-thirds of the world’s trawlers, the number of trawlers of all kinds was 88,939 worldwide. Assuming that two-thirds of those were active and that they towed nets 25 m wide at 5 km/hour for 10 hours a day for 200 days per year, then the area they swept annually was 14.8 million km², or 53% of the world’s continental shelf area, an order of magnitude higher than McAllister’s (1995) estimate. Moreover, this estimate might be too low, for three reasons. First, Pillsaln et al. (this issue) used “realistic estimates” of 40-m trawl track widths and 5.5 km/hour trawl speeds; use of these figures would raise our estimate another 76%. Second, we omitted other towed gear; their inclusion would further raise estimates. Third, because fishing effort and fishing power have increased considerably since 1978, our estimate likely errs on the low side. Until more reliable data are available, it is reasonable to assume that an area equivalent to the world’s continental shelf is swept by trawlers every 2 years. Even if our estimate is high by a factor of two, trawling an area equivalent to the entire world’s continental shelf every 4 years is nonetheless a disturbance to the biosphere on a scale that had not previously been imagined. Of course, trawl frequency is unevenly distributed; in an area that is trawled an average of 100% annually, a substantial fraction might not get trawled in a given year, whereas some spots can be trawled an astounding 40,000% annually (Rijnsdorp et al. 1991). Figure 1 in Pillsaln et al. (this issue) hints at the variability in trawling effort in the Gulf of Maine.

Not all trawling occurs on the shelf. As the most accessible fisheries continue to decline, trawlers are focusing increasingly on “underutilized species” of the deeper continental slope and remote oceanic seamounts, such as orange roughy (Hoplostethus atlanticus) and grenadiers or rattails (Macouridae) (Merrett & Haedrich 1997). Deep-water trawling must profoundly alter ecosystems whose species generally are not adapted to resisting or recovering from severe physical disturbances.

In unaltered benthic ecosystems, severe disturbances tend to be low in frequency: they are either large and rare or common but restricted spatially (Connell & Kough 1985). This is also true in forest ecosystems: “Where fires burn frequently, they are seldom highly destructive; infrequent burns, on the other hand, tend to be catastrophic” (Perry 1994). But use of mobile fishing gear is exceptional among agents of disturbance: its effects are severe, yet it occurs at a frequency orders of magnitude higher than other severe disturbances.

Other Effects of Mobile Fishing Gear on Sediments

Mud bottoms comprise sediments with very small mineral grains bound loosely with organic material and associated microorganisms, on and in which live epifaunal and infaunal macroorganisms. Anoxic conditions commonly occur within a few millimeters of the sediment-
water interface, except where pumping by burrow dwellers oxygenates the surrounding sediment. Although the impacts of mobile fishing gear on structural complexity are clear, their effects on sedimentary microenvironments are less certain. Using knowledge of fundamental biological oceanographic processes, we can hypothesize that repeated use of mobile fishing gear has several consequences. First, the homogenization of mudrier sediments decreases the sediment-water interface area by collapsing burrows and destroying tubes made by species dwelling within the sediment. This could have consequences for carbon and nitrogen cycling that are presently unknown (Pilskaln et al. 1998, this issue). Second, trawling on the continental shelf south of Georges Bank (Churchill 1989) and in Wilkinson Basin (C. H. Pilskaln, personal communication) results in a much-thickened bottom nepheloid layer of resuspended sediment. When resuspended, organic material with high-quality as food is oxidized to some extent in the water column and settles to the bottom much lower in food value. Diminished availability of high-quality food on the seabed might reduce the species diversity of these muddy bottom areas. Third, the removal of organic material by mobile fishing gear is biogeochronally analogous to the common post-clearcutting practice of broadcast burn or pile-and-burn site preparation, which oxidizes large amounts of slash (remains of logged trees) and forest floor (organic detritus), exporting the ecosystem’s nutrients as ash into the atmosphere. Given the high frequency of trawling, the increased resuspension and subsequent oxidation of carbon that would otherwise be buried in sediments could be a significant source of carbon to the water column and atmosphere.

Trawling and dredging for shellfish resuspend large amounts of sediments (Pilskaln et al. 1998, this issue). Riemann and Hoffmann (1991) found short-term increased suspended sediment loads of 960-1361%. The sediment plume and organisms (e.g., polychaetes, amphipods) entrained within it affect water clarity, oxygen content, and the energy relations of organisms living or feeding where the plume interacts with the bottom. High suspended sediment loads in shallow waters affect photosynthesizers in the water column and on the seabed. High suspended sediment loads are associated with shifts in fish communities from domination by visual predators to those that find food by touch and chemosensation, as well as alteration of the benthic community from one dominated by suspension-feeders to one dominated by deposit-feeders. Once deposit-feeders become dominant, they can prevent recovery of suspension-feeders by feeding on and smothering settling larvae (Dayton et al. 1995).

Resuspension of buried organic material by trawlers increases oxygen demand in the water column; in areas where dissolved oxygen is already limiting, this increase could significantly affect plankton and nekton species composition, even contributing to the growth of anoxic areas such as “the dead zone” in the Gulf of Mexico. Indeed, it could be a substantial unaccounted source of atmospheric carbon dioxide. In polluted areas, resuspension can also increase exposure of water column and benthic species to toxic materials adsorbed on sediment grains which were previously sequestered in the sediment. Resuspended sediment and pore water can also add to the nutrient loading of the water, perhaps triggering phytoplankton blooms.

**Trawling and Clearcutting**

Trawling disturbs the seafloor in ways that can be compared to terrestrial disturbances. Like surface mining, it displaces large amounts of surface organic material, but it doesn’t necessarily kill all macroscopic life. Like plowing, it disturbs the upper several centimeters of substrate at return intervals of years or months; but it is not conducted on private lands where harvested species are reseeded but in areas that are under public ownership and considered “natural.” It is more similar to clearcutting (Table 4), but there is one great difference: whereas forest loss is estimated at 100,000 km² per year worldwide (Food and Agriculture Organization of the United Nations [FAO] 1995), the area tumbled annually is about 150 times as great. The FAO’s estimate of annual worldwide forest loss, however alarming, is smaller than the combined area of Georges Bank and the Gulf of Maine (Auster et al. 1996), which is tumbled each year.

**Mobile Fishing Gear as a Conservation Issue**

Since the dimensions of the biological diversity crisis became clear (Myers 1979; Lovejoy 1980; Norse & McManus 1980), biologists have told decision makers and the public that physical disturbance—particularly habitat loss from forest clearcutting—is the leading cause of biological diversity loss. Until this decade, however, biodiversity loss in the sea was largely overlooked, with the scant attention focused mainly on the important threats of overexploitation of fisheries and pollution. Now, with growing understanding that marine biodiversity is imperiled, we have shown that the sea is experiencing physical alteration from bottom trawling and other towed fishing gear on a scale that was not previously appreciated. The use of mobile fishing gear, whose effects resemble those of clearcutting, occurs at a rate two orders of magnitude higher than forest loss worldwide. With the possible exception of agriculture, we doubt that any other human activity physically disturbs the biosphere to this degree. The lack of scrutiny of bottom trawling until now is indicative of the mis-

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Table 4. A comparison of the impacts of forest clearcutting and trawling of the seabed.*

<table>
<thead>
<tr>
<th>Impact</th>
<th>Clearcutting</th>
<th>Bottom trawling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effects on substratum</td>
<td>exposes soils to erosion and compresses them</td>
<td>overturns, moves, and buries boulders and cobbles, homogenizes sediments, eliminates existing microtopography, leaves long-lasting grooves crushes and buries some fauna; exposes others, thus stimulating scavenger populations removes, damages, or displaces most structure-forming species above sediment-water interface</td>
</tr>
<tr>
<td>Effects on roots or infauna</td>
<td>stimulates, then eliminates, saprotrophs that decay roots removes or burns snags, down logs, and most structure-forming species aboveground</td>
<td>eliminates most late-successional species and encourages pioneer species in early years to decades releases large pulse of carbon to atmosphere by removing and oxidizing accumulated organic material; eliminates nitrogen fixation by arboreal lichens</td>
</tr>
<tr>
<td>Effects on emergent biogenic structures and structure formers</td>
<td>eliminates most late-successional species and encourages pioneer species in early years to decades releases large pulse of carbon to atmosphere by removing and oxidizing accumulated organic material; eliminates nitrogen fixation by arboreal lichens</td>
<td></td>
</tr>
<tr>
<td>Effects on associated species</td>
<td>decades to centuries</td>
<td>years to centuries</td>
</tr>
<tr>
<td>Recovery to original structure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Typical return time</td>
<td>40-200 years</td>
<td>40 days to 10 years</td>
</tr>
<tr>
<td>Area covered per year</td>
<td>~0.1 million km² (net forest and woodland loss)</td>
<td>~1.8 million km²</td>
</tr>
<tr>
<td>globally</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Latitudinal range</td>
<td>subpolar to tropical</td>
<td>subpolar to tropical</td>
</tr>
<tr>
<td>Ownership of areas where it occurs</td>
<td>private and public</td>
<td>public</td>
</tr>
<tr>
<td>Published scientific studies</td>
<td>many</td>
<td>few</td>
</tr>
<tr>
<td>Public consciousness</td>
<td>substantial</td>
<td>very little</td>
</tr>
<tr>
<td>Legal status</td>
<td>activity increasingly modified to lessen impacts or not allowed in favor of alternative logging methods and preservation</td>
<td>activity not allowed in a few areas</td>
</tr>
</tbody>
</table>

*Sources include Norse (1990), Food and Agriculture Organization (1995), and discussions at the 1996 trawling workshop of the Marine Conservation Biology Institute.

match between humankind’s environmental impacts and priorities.

An activity that each year severely disturbs an area of seabed as large as Brazil, the Congo, and India combined must affect the structure, species composition, and biogeochemistry of benthic ecosystems on both local and global scales. It is disheartening that scientists have not yet done the research necessary to determine whether trawling has caused large numbers of extinctions, and that sequential overfishing, improved technologies, and the lack of marine protected areas make it difficult or impossible to find suitable control areas.

Our marine conservation ethic is far less advanced than our land ethic. For example, recent decades have seen a dramatic change in attitude in many countries about killing apex predators such as tigers, wolves, and eagles, whereas there has been much less concern about killing sharks, tunas, and marlin. In the United States (SeaWeb 1996) and many other countries, public concern about maintaining marine biodiversity seems to be increasing but has not yet become deep or pervasive. But even in the face of compelling evidence for concern about the effects of trawling on benthic biodiversity, the pivotal question for many people will be economic: how does trawling affect fisheries? In Australia, on the other hand, perhaps because of a widespread acceptance that its biodiversity is truly unique, there is a more balanced view. Recently, for example, the president of the South East Trawl Fishing Industry Association proposed a voluntary interim closure of a 370-km² region of seamounts south of Tasmania until a biodiversity assessment could be made (The Australian, Sydney, 9 June 1998:8).

Like clearcutting, use of mobile fishing gear does not eliminate biological activity. Rather, it converts ecosystems dominated by disturbance-intolerant equilibril species to ones dominated by disturbance-tolerant opportunistic species. In general, trawling undermines fisheries for species that benefit from complex benthic structure. For fish that do not need benthic structure, however, some trawling is likely to increase their populations by encouraging opportunistic prey species or reducing disturbance-intolerant competitors. Thus, increasingly, trawled seabeds might have fewer sabellariid polychaete reefs but more cirratulid and capitellid polychaetes, fewer sponges and gorgonians but more pe- naeid shrimps and brytle stars, fewer groupers and snap-
pers, but more threadfin-bream and lizardfishes, fewer cod but more plaice. In general, where structure-forming species have life spans of years or more but the chronic disturbance of trawling occurs at shorter return intervals, benthic succession will not proceed to climax and fish communities that need a structurally complex seabed will disappear. A terrestrial analogue is the change in animal species when virgin forest is converted to cattle pasture. Thus, trawling could prevent recovery of diminished fish stocks, such as Georges Bank and Grand Banks Atlantic cod, whose juvenile stages have higher survivorship in structurally complex habitats, but it can benefit fisheries for some other species. This kind of anthropogenic change—which foresters call "type conversion"—has occurred in an intensively trawled offshore area in the Irish Sea, of which Lindeboom and de Groot (1998) say "[t]he present species-poor and low biomass fauna may represent an artificial man-made community adapted to the regular fishing disturbance experienced at this site." They conclude that "if trawling intensity remains high, these communities may never recover."

At present, people trawl almost anywhere they want, and the sea's equivalents of ancient forests are becoming cattle pastures by default, not by design. Merrett and Haedrich (1997) put it this way: "there still seems to be a general frontier mentality that operates in high-seas fisheries." Governments generally do not apply the precautionary principle to the sea; individuals and corporations do what they wish unless some governing authority demonstrates conclusively that they should not, decides to prohibit the activity, and enforces its prohibition. As highly structured benthic ecosystems and fisheries continue to decline, fishery managers must make more conscious choices about the mix of disturbance-intolerant communities (including fishes) and disturbance-tolerant ones under their jurisdiction.

In general, fisheries managers regulate the use of varying kinds of fishing gear by trying to determine the influence of the gear on the population parameters of target species. When disputes arise, the common response has been to look at the issue as a "gear conflict." This is especially true for mobile fishing gear, which were not used on hard bottoms in northern waters such as the Gulf of Maine, the Grand Banks, and the Bering Sea until the mid-1980s. Rather, those ecosystems were typically fished with hook and line gear, which has far less physical impact on the bottom community. As the fishing industry developed rockhopper trawls, topographically rough bottoms were no longer unfishable, and longline fishermen saw their fishing grounds produce progressively fewer fish. The response from the New England Fishery Management Council, as an example, has been to consider the complaints of the long-liners under the rubric of gear conflict, thus escaping the need to look at the more fundamental question of whether trawling is reducing the economic value of the fisheries overall as a result of reduced habitat complexity, or the even broader question of what trawling is doing to biological diversity.

Typically, people who catch and process fish have been considered the primary stakeholders in this conflict, and decisions have often been driven by short-term economic factors. Because of the long-term—even irreversible—changes that mobile fishing gear can bring to benthic communities, all those with an interest in the sea's biological diversity and integrity should consider themselves stakeholders in this debate. In the U.S. Pacific Northwest, the political decisions that governed logging of ancient forests, on federal lands began to change in the late 1980s, when citizens beyond Northwest timber towns became aware and involved. Examining the use of mobile fishing gear from the viewpoint of a broader group of stakeholders might produce very different solutions. To serve the public interest, meaningful input on managing the seabed has to involve people with interests broader than fisheries alone.

Recent developments suggest that concern about fishing effects is increasing in the United States. The recently reauthorized Magnuson-Stevens Fishery Conservation and Management Act (National Marine Fisheries Service 1997) contains provisions for the first time that require regional Fishery Management Councils to identify essential fish habitat (EFH), which is "those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity." This law requires the National Marine Fisheries Service and the Fishery Management Councils to identify "activities with known or potential adverse effects on EFH," and it allows them to impose fishing-gear restrictions or to close areas to fishing.

Still, management of the living resources of the U.S. seabed is effectively controlled by the Department of Commerce's National Marine Fisheries Service, which is responsible for determining which aspects of the habitat are important for fish production. We have seen, however, that some benthic communities can have productive fisheries in the face of continual physical disturbance by mobile fishing gear. The question, therefore, is who is responsible for maintaining the overall biodiversity of the seabed. To date, maintenance of biodiversity has hardly been a priority of fisheries managers.

Some management options could stem the loss of biodiversity and fisheries dependent on benthic structure, could benefit all fishers and consumers in the longer term, and could minimize the short-term economic harm to trawlers and dredgers:

1. Using a precautionary approach to management: the burden of proof should rest with those who would alter the sea's biodiversity and integrity. This might lead to lessened use of mobile fishing gear in structurally complex benthic ecosystems.

2. Matching fishing gear types to the disturbance-
vulnerability of the seabed, thus minimizing the long-
term impacts of all types of gear. This most likely would
give preference to some gear types over others in each
bottom type but would maintain species diversity and
fisheries production in each.

(3) Establishing "no trawling zones" in a portion of all
continental shelf and slope ecosystems, allowing the re-
covery of benthic communities to their pre-trawling
state. Such reserves would offset, to some extent, the
loss of de facto reserves in areas that could not previ-
ously be fished with mobile gear and where commer-
cially important fishes were more abundant. This would
provide crucial information on the effects of mobile gear
and requirements for sustainable fisheries over the long
term.

(4) Educating the public about the nature of the sea-
bed and its importance for biodiversity, including its
role in supporting fisheries.

(5) Ensuring opportunities for more sectors of society
(beyond fishing interests) to influence the policy-making
process and to hold positions of authority, in recogni-
tion that all of us are stakeholders when it comes to pub-
licly owned marine resources.

Conclusions

Mobile fishing gear exceeds other natural and anthropo-
genic disturbances on the marine continental shelf and
slope. By crushing, burying, and exposing benthic or-
ganisms to predation and by altering sediment and water-
column biogeochemistry, trawling and dredging disrupt
the structure of benthic communities from high lati-
tudes to the tropics in ever-deeper waters. Many marine
species, including the young of commercially caught
fishes, use lithic and biogenic structures to avoid predation,
so loss of these structures due to use of mobile fishing
gear could be a major factor—in addition to overfishing—
underlying diminishing demersal fish stocks worldwide.
Indeed, trawling and other mobile fishing gear have ef-
fects resembling a disturbance—forest clearcutting—that
has generated far more comment yet occurs on a scale
two orders of magnitude smaller than use of mobile fish-
gear. Thanks to improvements in fishing technolo-
gies and inadequate regulation, there are few places in
the world's continental shelves with commercially valu-
able fishery resources that have not been trawled or
dredged. Given the rapid, progressive collapse of com-
mercial fish stocks and the less-noticed but even more
worrisome loss of biodiversity worldwide, it seems pru-
dent to devote more resources to understanding the ef-
fects of mobile fishing gear and to act decisively to ame-
liorate their impacts on commercial fishery resources
and other species comprising the world's marine biodi-
versity.

Acknowledgments

We thank the participants and observers of the work-
shop on the Effects of Bottom Trawling on Marine Eco-
systems for providing insights and references. Darling
Marine Center staff and students, particularly C. Chish-
holm and A. Palma, provided crucial logistical support
and served as rapporteurs. The workshop and this paper
could not have happened without dedicated financial
support to the Marine Conservation Biology Institute
(MCBI) from the Curtis and Edith Munson Foundation,
the Natural Resource Defense Council, and three com-
ponents of the National Oceanic and Atmospheric Ad-
ministration—Auke Bay Fisheries Laboratory of the Na-
tional Marine Fisheries Service, Stellwagen Bank National
Marine Sanctuary, and the Office of Strategic Policy and
Planning—nor without general support to MCBI from
the Heart of America Fund, Sun Hill Foundation, Rock-
feller Brothers Fund, Bullitt Foundation, Geraldine R.
Dodge Foundation, Educational Foundation of America,
Horizons Foundation, Surdna Foundation, Bay Founda-
tion, DuPont, New England Biolabs, E. Stanley, A. Row-
land, B. Cohn, and two anonymous funders. We com-
pleted this paper while serving as Pew Fellows in Marine
Conservation, and we thank the Center for Marine Con-
servation, where E.A.N. planned the workshop, and C.
Green, E. Linen, J. Schorr, T. Steiner, A. Tinker, and E.
Bermston, who provided valuable information. Drafts of
the paper benefited greatly from critical reviews by P.
Auster, M. Kaiser, S. Thrush, P. Valentine, D. Gordon,
and A. Matthews-Amos. The figures are the work of S.
Gerken. This is Marine Conservation Biology Institute
contribution 17.

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A Conceptual Model of the Impacts of Fishing Gear on the Integrity of Fish Habitats

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Abstract: Fishing gear is used over large regions of continental shelves worldwide, but studies of the effects of fishing on seafloor habitats are generally conducted on a limited number of sediment types, making the wider application of particular studies difficult. Fishing gear can reduce habitat complexity by smoothing bedforms, removing emergent epifauna, and removing species that produce structures such as burrows. I developed a conceptual model of gear impacts across gradients of habitat complexity and levels of fishing effort to provide a more holistic understanding of the effects of fishing gear. Each habitat type, in an unaffected state, was categorized and scored numerically based on the components of habitat structure. Values for highly affected habitats, based on observations, were integrated into the model and represented the most affected state. The model predicts linear reductions in complexity based on linear increases in fishing effort. For example, the complexity value of pebble-cobble with emergent epifauna decreases linearly to half the unaffected value (i.e., 10 to 5) in the most affected condition. Research is needed to refine the model and develop improved predictive capabilities. For example, threshold effects may occur that depend on habitat type, fishing gear, and fishing effort. Adding feedback loops to the model, based on recovery rates of habitats, will greatly increase the value of such models to managers. The model can be used directly for management in the current iteration by adopting a well-conceived adaptive management strategy. The objective of such an approach must include both the sustainable harvest of fishes and the maintenance of biodiversity.

Modelo Conceptual de los Impactos de Artes de Pesca en la Integridad de Hábitats de Peces

Resumen: Los equipos de pesca han sido usados en grandes regiones de la plataforma continental a nivel mundial, pero los estudios de los efectos de la pesca en hábitats del lecho marino han sido conducidos generalmente a un número limitado de tipos de sedimento basándose en la aplicación amplia de estudios particulares sea difícil. Las artes de pesca pueden reducir la complejidad del hábitat al suavizar formas de lecho rocoso, removiendo la epibiose emergente y removiendo especies que producen estructuras como son las madrigueras. Desarrollé un modelo conceptual de impacto de artes de pesca a lo largo de gradientes de complejidad de hábitat y niveles de esfuerzo pesquero para proveer un entendimiento más completo de los efectos de las artes de pesca. Cada tipo de hábitat en un estado de no afectación fue categorizado y catalogado numéricamente en base a los componentes de la estructura de hábitat. Valores altos de hábitats altamente afectados basados en observaciones fueron integrados al modelo y representaron los estados más afectados. El modelo predice reducciones lineales en la complejidad en base a incrementos lineales en el esfuerzo pesquero. Por ejemplo, la complejidad del valor de guijarro-adquiñón con epibiose emergente disminuye linealmente a la mitad del valor de no afectado (i.e., de 10 a 5) en las condiciones más afectadas. Se necesita investigación para refinrar el modelo y desarrollar capacidades predictivas mejoradas. Por ejemplo, efectos límite pueden ocurrir dependiendo del tipo de hábitat, tipo de arte de pesca y esfuerzo pesquero. La adición de rutas de retroalimentación al modelo en base a tasas de recuperación de hábitats podría incrementar grandemente el valor de estos modelos para los maneñadores. El modelo puede ser usado directamente para el manejo en su forma actual, adoptando una estrategia adaptable y bien concebida. El objetivo de este tipo de aproximación deberá incluir tanto la caza sostenible de peces, como el mantenimiento de la biodiversidad.

Paper submitted July 3, 1997; revised manuscript accepted July 1, 1998.

Conservation Biology, Pages 1198-1203
Volume 12, No. 6, December 1998
Researchers from the Australian Maritime College (AMC) and the Queensland Department of Primary Industries (QDPI) have spent over 16 months onboard prawn trawlers trialling turtle excluder devices (TEDs) in the NPF. These trials are providing fishers with an opportunity to test a range of TEDs prior to their use becoming compulsory in 2000. The work has been conducted as part of a collaborative project funded by the Fisheries Research and Development Corporation and includes the CSIRO Division of Marine Research.

In 1998, 20 vessels conducted trials during commercial fishing operations in the Northern Prawn Fishery (NPF). During these trials, fishers trialed a total of five TED designs, primarily in the NPF from Joseph Bonaparte Gulf, the west to Weipa, in the east. Of the 20 vessels undertaking trials, 11 took the opportunity to conduct trials with the help of the authors.

TEDs used in 1998

Five TED designs were trialed during the 1998 NPF season. These were the Super Shooter TED, the Seymour TED, the NAFTED, the Wick’s TED and the Pyramid TED.

Turtles were effectively excluded from all nets fitted with a TED, regardless of the design used. Some TEDs were more successful than others at maintaining prawn catch. When prawn loss was evident, it occurred in areas where bottom debris or large animals were abundant.

Bottom-shooting TEDs such as the Super Shooter, were more efficient in “dirty” areas, while top-shooting TEDs, such as the Wick’s TED, are well suited to clean areas as they are able to exclude all large animals whilst maintaining a higher percentage of prawn catch than a bottom-shooting TED.

Impact on prawn catch

Commercial testing has shown that the effect of a TED on the prawn catch of a net varies, depending on the design of the TED and the composition and quantity of bycatch encountered in various fishing grounds. Catch rates can be maintained, or even increased, when fishing with TEDs in clean grounds. Catch loss occurs when fishing in areas where the number of large or bulky animals, such as rays or sponges, is high.

Prawn loss caused by TEDs can usually be attributed to two main causes: 1. Grid blockage by large animals, sponges, rocks and other debris which either impede the passage of prawns into the codend or locate the prawns too close to the escape opening.

The Wick’s TED has been used with good results as a top-shooter in the North Moreton area. These TEDs are relatively inexpensive and easy to install.

2. Exclusion of large animals and debris results in a momentary opening of the escape flap providing an escape route for prawns.

If a TED has difficulty in excluding a particular type of bycatch, then it may become more susceptible to prawn loss given the points outlined above. It is important to understand which TED design is most efficient in excluding particular types of bycatch if catch rates are to be maintained.

continued on following page
Another year of TED and BRD tests
in the Northern Prawn Fishery

Aspects of TED design affecting efficiency

There are several technical aspects of TED design that need to be considered when choosing a TED.

Firstly, bar spacing is critical to the effectiveness of the grid. Bar spacing determines the size of the animals that can pass through the grid and into the codend. Should the bar spacing be too narrow, larger prawns and some by-product, such as bugs, may be excluded by the grid. However, should a wider bar spacing be used, sponges and other undesirable bycatch may enter the codend. Therefore, a compromise is needed. A good place to start is 100mm (four inches).

In the cleaner fishing grounds of the Gulf of Carpentaria, a top-shooting TED will lose fewer prawns than a bottom-shooting TED. However, if a vessel is working in “dirty” areas, bottom-shooters are able to exclude animals and debris which would tend to clog a top-shooting TED. Therefore, the choice will depend on the grounds fished and the debris likely to be encountered.

Codends should be as long as possible so that the contents of the codend are located as far aft of the grid as possible. Where practicable, codends should extend at least 100 meshes from the rear of the TED. If fishing for banana prawns it would be advisable to use 150 mesh-long codends.

Grid size is another aspect that needs to be considered when choosing a TED. Large grids are difficult for one person to manœuvre around the deck of a boat. Smaller grids are easier to handle but tend to clog more rapidly. Furthermore, larger grids allow generously proportioned escape holes to be cut, which will result in less problems when excluding very large animals such as hammerhead sharks and shovel nose rays.

An extremely important aspect of TED design is grid angle. If the grid angle is too shallow, prawn loss will occur. Clogging will be a problem if the grid angle is too steep. Forty-five degrees is a good starting point. Results from one trial showed that a grid installed at 52° would exclude about 25 per cent of the sponges encountered by the grid – the remaining 75 per cent would sit forward of the grid and have to be removed on the surface. During another trial, the same grid installed at 42° would exclude approximately 80 per cent of sponges encountered.

The authors prefer to manufacture TEDs from solid aluminium rod welded together using Metal Inert Gas (MIG). TIG welding tends to weaken the aluminium and bending can result. Stainless steel grids have been trialed, but were too heavy. Hollow aluminium tube was also used to construct TEDs, particularly US-style Seymour TEDs, with good reports.

No matter what material is used, the weld joining the outer frame should be placed on the side of the frame. This lessens the risk of bending or cracking at the weld due to stresses placed on the grid.

Industry-developed TEDs

The last few years has seen an increase in the development of new TED designs by industry. Some notable examples include the Wick’s TED and the Pyramid TED.

The Wick’s TED is primarily a top-shooting TED, designed for the Moreton Bay fishery to exclude turtles and jellyfish. This design has been adopted by the majority of the Moreton Bay fleet as the TEDs are inexpensive, easy to maintain and very effective. The Wick’s TEDs trialed in the NPF were scaled-up versions of the devices used in Moreton Bay and have returned encouraging results.

The Pyramid TED is new to Australia and has been used by fishers in the NPF. This TED enables large animals to be excluded either through the top or the bottom of the codend by providing two escapes openings. It was developed by a netmaker in Cairns and has also been used on the Queensland east coast.

BRDs will be compulsory in 2000

Fishers in the NPF should be aware that it is proposed that TEDs will be compulsory from April 15, 2000. Fishers should be aware that bycatch reduction devices (BRDs) will also be required from that date. BRDs have been tested in the NPF but only on a limited basis.

BRDs are used to reduce the amount of unwanted fish caught in a prawn trawl net. This is achieved by placing holes in a net, through which fish can escape.

BRDs can be classified into one of the following categories:

1. Fisheyes – specially-shaped metal frames sewn into a net so that an escape hole is formed. These devices are easy to install and remove from a net but, because of the design, limit the size of the fish that can escape.

2. Bigeys – constructed by cutting and sewing a net so that escape holes are formed. These devices can be of any size, are easy to install and have no hard parts.

3. Square Mesh Panels – constructed by sewing mesh into a codend “on the square” rather than “on the diamond”. Square Mesh Panels are easy to install and have no hard parts. The efficiency of these devices is dependent on their position on the codend in relation to the bag size.

4. Radial Escape Sections – consist of an interior funnel surrounded by large (four- to ten-inch) mesh or windows and are located in the codend, aft of a TED. The construction of a Radial Escape Section is time consuming but preliminary trials have shown they reduce bycatch whilst maintaining prawn catch.

5. Square Mesh Codends – by sewing the codend “on the square” rather than “on the diamond”, the meshes remain open and allow small fish and prawns to escape. The size of the fish that can escape is restricted to the mesh size used in the codend.

The fisheye BRD is designed to provide an area of low flow, encouraging fish to exit the trawl. The fisheye is sewn into the net with apex pointing forward.
New video available

A video entitled “Reducing Bycatch in Prawn Trawl Fisheries: Current Knowledge and Status” was sent to the licence holders of vessels in the NPF and the east coast otter trawl fishery during August 1999. This video was produced to give fishers an idea as to what TEDs and BRDs are currently used in prawn trawl fisheries in Australia. It also offers some information concerning the construction of bigeyes, a BRD favoured by some east coast fishers. Additional copies are available in limited numbers from the Southern Fisheries Centre.

What is the best TED or BRD?

... Trialng various TEDs and BRDs is the best method for determining the device most suited to any one fishing ground. Both the AMC and the QDPI have extensive gear libraries where fishers can borrow TEDs or BRDs to trial at their leisure or with the help and guidance of technicians. Similarly, if help is required in designing or testing new TEDs, both the AMC and the QDPI can provide technical advice and assistance.

The TEDs in the gear libraries are now available for fishers to borrow on an indefinite basis. If you would like to own one of the TEDs in the gear libraries, please contact the authors at the numbers below.

Garry Day is a research officer with the Australian Maritime College (AMC) and Matthew Campbell is a technical officer with the Queensland Department of Primary Industries (QDPI). Both are presently employed to develop and test BRDs for northern Australian prawn trawl fisheries in collaboration with industry.

For further information contact:
AMC: PH: +61 3 6335 4424,
FX: +61 3 6335 4459
or QDPI: PH: +61 7 3817 9500,
FX: +61 7 3817 9555.

The Super-Shooter TED utilises bent deflector bars which aid in the exclusion of debris such as sponges and rocks.

The square-mesh panel consists of larger mesh, in this case six-inch mesh, sewn in on the square which allows small fish to escape.

CONVENTION

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Report of the Expert Scientific Panel on Study on the Distribution of Sea Turtles, their Incidental Mortalities in Fishing Nets and use of Turtle Excluder Device in Fishing Trawlers submitted to the Ministry of Agriculture (Department of Animal Husbandry & Dairying), Government of India

Summary

In pursuance of the US ban on import of shrimps from countries not complying to the use of turtle excluder device in shrimp trawlers, the Government of India, Ministry of Agriculture, Department of Animal Husbandry and Dairying constituted an Expert Scientific Panel (ESP) to conduct detailed study on the distribution of sea turtles, their incidental mortalities in fishing nets and use of TED in fishing trawler, etc. The Study was coordinated by Director, Central Marine Fisheries Research Institute, Kochi.

Five of the seven species of marine turtles found worldwide reportedly occur in the Indian coastal waters – the Olive ridley (Lepidochelys olivacea), Green (Chelonia mydas), Hawksbill (Eretmochelys imbricata), Leatherback (Dermochelys coriacea) and Loggerhead (Caretta caretta), with only the Loggerhead not known to nest in the coasts off mainland India and the Bay islands. Olive ridley is the most common marine turtle in Indian waters and very heavy concentration of this species nests in Orissa coast during certain parts of the year.

The data collected by CMFRI during the period January, 1997 to December 1998 and subsequently during 1999 on incidental catch of marine turtles along the Indian coast (barring Gahirmatha coast) indicated that the incidental catches/stranding of turtles were few and confined to some maritime States. However, at the mass nesting areas off the coast of Orissa (Gahirmatha, etc.), landings/strandings were higher during the breeding period. Based on the Study conducted by the ESP and other studies on marine turtles carried out in the country, both long-term and short-term management measures have been suggested. The Report has also proposed recommendations for declaration of mass nesting areas as sanctuaries and for mandatory use of TEDs in coastal areas where higher landing/stranding of turtles have been recorded.

Based on the data furnished by the Central Marine Fisheries Research Institute, Kochi and the information provided by the Members of the ESP, the Report has been prepared by Dr. Y. S. Yadava, Fisheries Development Commissioner & Member Convenor of the ESP.
Proceedings of the Meeting of the Expert Scientific Panel held at CMFRI, Cochin on 23rd July, 1998 under the Chairmanship of Director, CMFRI, Cochin

The first meeting of the Expert Scientific Panel was held at CMFRI, Cochin on 23rd July 1998 to discuss and finalise the composition of the expert team to be sent to Bhubaneswar for discussion with the officials of the Department of Fisheries and trawlers operators on the issue of finalising design, installation and demonstration of TEDs to the shrimp trawlers operating on the Orissa coast.

The following decisions were taken:

1. To conduct trial fishing operations with and without TED (designed and developed by both CIFT and CIFNET by using CIFT's vessel off Cochin) to study the efficacy of the introduction of TED in the shrimp trawlers at an early date. The experts from CIFNET, CIFT and CMFRI will be participating in the cruise programme.

2. Director CIFNET, Kochi agreed to fabricate two types of TEDs immediately, one with aluminum and another with steel costing Rs.1500/- and Rs.500/- respectively, Director, CIFNET, further agreed to transport these two types of TEDs to Bhubaneswar for display and demonstration. The ten CIFT made TEDs, now available at Kochi could also be used for this purpose.

3. A team comprising of experts would visit Bhubaneswar during the 3rd week of August 1998 to meet the Secretary (Fisheries), Orissa State, State Fisheries officials and the representatives of the Trawler owners Association.

4. To convene a meeting at Bhubaneswar during the time of the visit of the experts involving members of the Expert Scientific Panel constituted by the Ministry of Agriculture, Government of India, officials from Orissa State Fisheries, Orissa State Forest Department, Coast Guard (Ministry of Defence, Government of India), representatives of Trawler Owners Association.

5. The Fisheries Development Commissioner, New Delhi may arrange to approve the project proposal entitled "Study on distribution, incidental catch, mortality of sea turtles in Indian waters and efficacy of Turtle Excluder Device at selected centres" submitted by the CMFRI and release the funds immediately to take up the programme.

6. The Department of Fisheries, Government of Orissa may arrange suitable shrimp trawlers of various sizes at selected centres (Bhitarkanika, Rushikulya, Paradeep, Puri, etc) to conduct studies to assess the efficacy of TED.

7. The team of experts identified for the conduct of the efficacy studies should be fully involved in assessing the results and the preparation of the reports to be submitted to Government of India within the stipulated time.
Proceedings of the Expert Team’s Visit to Orissa during April, 1999

A team of Experts comprising Dr. M. Rajagopalan, Senior Scientist, Madras Research Centre of CMFRI and Shri. N. Subramania Pillai, Senior Scientist, CIFT were deputed to proceed to Bhubaneswar in April 1999 for discussion with the officials and trawler operators on the operations of the TED. On the afternoon of 24th April 1999 at the CIFA campus Kausalyaganga, Bhubaneswar, the experts had discussion with the officials of the Orissa State Fisheries Department. The following officials participated in the discussion.

1. Shri A. C. Mishra, Joint Director (Fisheries), Cuttack
2. Smt. L. Behera, Deputy Director (Fisheries), Cuttack
3. Shri B. C. Mishra, Asst. Director (Marine), Puri
4. Shri G. B. Parida, Asst. Director (Marine), Balasore
5. Shri P. Behera, Asst. Director (Marine), Kujang
6. Shri Rachal Mishra, Deputy Director (Extension)
7. Shri Arjun Nayak, Deputy Director (Marine South), Cuttack

Shri Subramania Pillai, CIFT, Cochin explained about the trails already made by the CIFT team at Cochin and Visakhapatnam with the improved models of TED designed by CIFT to suit conditions prevailing along the Indian coast. The State Fisheries officials are of the unanimous view that there is need to modify the TED according to the conditions prevailing along the Orissa coast. It was decided to make suitable changes in the grid design, flapper position etc., The mass nesting of Olive ridley, Lepidochelys olivacea along Orissa coast already completed during March 1999 and approximately 3.4 lakhs of Olive ridley nested along the Gahirmatha coast during 1999 season. With regard to mortality 9047 olive ridley got stranded during December 1998 to March 1999 along the nesting beaches such as Gahirmatha coast, Mahanadi mouth, Devi river mouth and Chilka mouth.

The Expert Team from CMFRI and CIFT visited Paradip on 26th April April 1999 and examined the available TED at the Office of the Superintendent, State Fisheries Department, Paradip. The State Fisheries officials showed 2 TED (Georgia Grid Type) available with them and explained about the trials made with and without TED. They have requested to reduce the fish catch loss.

Based on the discussion with Director, State Fisheries Department, Cuttack and other Fisheries officials the following decisions were taken:

(i) CIFT, Cochin will modify the TED as per the suggestions rendered by the officials of the Orissa State Fisheries Department.

(ii) One or two officials of State Fisheries Department, Government of Orissa will visit CIFT, Cochin around July - August 1999 to examine the improved models of TED and trials will be made at Cochin utilizing the vessel facility of CIFT and CMFRI.
(iii) The improved TED will be taken to Orissa during November - December 1999 and continuous trials will be made with and without TED from Dhamra and Paradip base jointly by Orissa State Fisheries officials and CIFT and CMFRI team. The Department of Fisheries, Government of Orissa will arrange suitable shrimp trawlers to conduct study to assess the efficacy of TED along Orissa coast.
Proceedings of the Meeting of the Expert Scientific Panel held at CMFRI, Cochin, on 7th January, 2000 under the Chairmanship of Dr. V. N. Pillai, Director, CMFRI, Cochin

The meeting started at 4.20 PM on 7.1.2000. The following members were present.

1. Dr. Y. S. Yadava, Fisheries Development Commissioner, New Delhi
2. Dr. M. Rajagopalan, Sr. Scientist, Madras Research Centre of CMFRI
3. Dr. E. Vivekanandan, Sr. Scientist, Madras Research Centre of CMFRI
4. Shri George Mathai, Sr. Scientist, CIFT, Cochin
5. Dr. K. Ravindran, Director, CIFT, Cochin
6. Dr. R. S. Manohar Doss, Sr. Scientist, CIFT, Cochin
7. Dr. B. C. Chaudhary, Scientist SF, Wildlife Research Institute, Dehradun
8. Shri K. P. Philip, FSI, Cochin
9. Shri C. Haridas, Assistant Commissioner (Fisheries), Deptt. of Animal Husbandry and Dairying, New Delhi
10. Dr. C. P. Varghese, Director, Cochin

While going through the report prepared by Dr. M. Rajagopalan, to be submitted to the Secretaries' meeting, Dr. Yadava pointed out that some of the items required clarifications and more details. As the Ministry was given very limited time to finalise the report (the deadline to submit the report was November, 99) we have to finalise the same immediately and submit to the Secretaries' Committee, Government of India. He wanted to include some data also (at least 1998-99 data of incidental catch of sea turtles) in the report. He mentioned that the incidental catch was high off Tamil Nadu. Regarding the mortality and destruction of sea turtles, Dr. Chaudhary pointed out that for example: out of 100 numbers of adult turtles congregating off Gahirmatha, only 30 numbers are males and the rest females. While making the report Dr. Rajagopalan mentioned about the report on Andamans & Nicobar Islands, wherein an authentic study has been made earlier by Dr. Satish Bhaskar and mentioned that the same was reflected in his report. Dr. Yadava asked Dr. Rajagopalan regarding the catch and mortality caused by different gears which have been already mentioned in his earlier report submitted to the MPEDA. He added that this information may be added to this report also and further suggested to choose the hot spot areas. He further stated that the report should be authentic and we should not give chance for others to raise unnecessary questions and clarification.

While replying to the FDC, Dr. K. Ravindran, Director, CIFT, pointed out that all the other items/ accessories/ arrangements are ready from CIFT side except the arrangements of vessels. He wanted the same to be hired for the purpose. Dr. V. N. Pillai requested Dr. Yadava to appraise the Secretaries about the effort taken by us on this issue in the final report. Further FDC stated that whatever trials are undertaken so far, the results should be reflected in this report. Based
on the discussions, it was decided that the following actions are to be taken for inclusion in the final report.

1. Regarding the operations of TED carried out by the CIFNET, CIFT and FSI, a consolidated report may be prepared for inclusion in the final report (Action: Directors: CIFNET and Director General: FSI).

2. Conservation and management measures to prevent incidental catch of sea turtles have to be included in the final report (Action: Directors: CMFRI, CIFT and Wildlife Research Institute, Dehradun).

3. Estimated number of sea turtles in the incidental catch to be updated up to June, 1999 (Action: Director CMFRI).

Dr. B. C. Chaudhury, Scientist, Wildlife Research Institute presented some slides in the subject matter and gave descriptions of each slide. The meeting came to an end around 1730 hrs.
Minutes of the Meeting of the Expert Scientific Panel held at CMFRI, Cochin on 20.8.1999

The following were present

1. Dr. V. N. Pillai, Director, CMFRI, Cochin
2. Dr. Y. S. Yadava, Fisheries Development Commissioner
3. Dr. K. Ravindran, Director, CIFT, Cochin
4. Dr. C. P. Varghese, Director, CIFNET, Cochin
5. Dr. V. S. Somvanshi, Director General, FSI, Mumbai
6. Dr. R. S. Manohar Doss, Sr. Scientist, CIFT, Cochin

Dr. V. N. Pillai briefly explained the background and request the Director, CIFT and Director, CIFNET, to give an account of the progress made in the fabrication of TEDs. Regarding the delay for undertaking trials, Dr. Ravindran, Director, CIFT, informed that even though they have sent three letters to the Government of Orissa for their collaboration for the proposed study (turtles distribution, its catch and mortality, etc.), there was no response from them. According to him six numbers of TEDs are already fabricated and kept ready for trials. He added that in another 15-20 days six more TEDs can be got ready for operation from CIFT side. Dr. Varghese, Director, CIFNET mentioned that since six TEDs from CIFT and two large TEDs from CIFNET are ready for operation, we may inform the Orissa Government for their collaboration.

It was decided that FSI will be using one of their trawlers off Orissa coast and CIFNET off Andhra Coast (Vishakhapatnam) for the study. The Expert Panel decided to start the operation w.e.f. 10th September, 1999. Dr. Yadava, FDC, will intimate both the Governments of Andhra Pradesh and Orissa and ensured participation from their side along with the required number of vessels. Dr. Yadava suggested that initially TEDs fabricated by CIFT can be fitted on fishing gear operated onboard, 10 trawlers each off Dhamra and Paradeep along the Orissa Coast.

It was also decided that the first three chapters of the Report pertaining to items (i) to (iii) under the Terms of Reference of the Committee may be prepared by CMFRI before end of September, 1999. The trials using TEDs onboard different types of vessels can be continued between September and December, 1999 and results could be compiled and incorporated under chapters (iv) to (vi) of the Report for items (iv) to (vi) of the Terms of Reference of the Committee. The Report of the Committee can be finalised and submitted towards the end of December, 1999.

The meeting concluded with a vote of thanks to the Chair.
Impacts of Mobile Fishing Gear: The Biodiversity Perspective

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Abstract.—The increasing concern about impacts of bottom trawling, scallop dredging, and other mobile fishing methods has focused primarily on effects on commercial fisheries, but these fishing activities also act more broadly on benthic biological diversity. Because the seabed is erroneously envisioned as a featureless, nearly lifeless plain, impacts of commercial fishing gear have long been underestimated. Structures on and in the seabed, including biogenic structures (reef corals, kelp holdfasts, shells, tubes, and tunnels), create a diversity of habitat patches. They provide refuges from predation and feeding places for demersal fishes and other species. Benthic structural complexity is positively correlated with species diversity and postsettlement survivorship of some commercial fishes. Mobile fishing gear disturbs the seabed, damaging benthic structures and harming structure-associated species, including commercially important fishes, although some other commercial fish species can persist where seabed structures have been removed. Bottom trawling is therefore similar to forest clear-cutting, but it is far more extensive and is converting very large areas of formerly structurally complex, biologically diverse seabed into the marine equivalent of low-diversity cattle pasture. In contrast with the U.S. National Forest Management Act, which governs use of living resources in federally owned forestlands, the 1996 Magnuson-Stevens Fishery Conservation and Management Act does not prevent ecosystem "type conversion" and ignores the need to maintain biological diversity. Preventing further loss of marine biodiversity and key fisheries will depend on our willingness to protect marine areas from effects of mobile fishing methods.

I'd like to be under the sea in an octopus' garden with you.—Beatles (rock group), "Octopus' Garden" (song)

The ocean is a desert with its life underground and the perfect disguise above.—America (rock group), "A Horse with No Name" (song)

Human activities are rapidly reducing the Earth's biological diversity (the diversity of genes, species, and ecosystems). Since Myers (1979), Lovejoy (1980), and Norse and McManus (1980) revealed that the loss of biological diversity is a massive worldwide phenomenon, especially in tropical forests, studies—including the most comprehensive biodiversity status report to date (Heywood 1995)—have found that physical destruction of ecosystems is the most pervasive cause of biodiversity loss. But such studies have focused mainly on land. In the sea, overfishing and pollution have long been considered leading threats to biodiversity, but more comprehensive examination shows that these are only two of five major threats (Norse 1993); one of the other threats is physical destruction of ecosystems. In the sea the leading cause of ecosystem destruction is use of mobile fishing gear such as bottom trawls and dredges, which smooth, crush, and uproot benthic structures (Auster and Langton 1999, this volume; Watling and Norse 1998). To help readers gauge the impacts of mobile fishing gear, we first discuss the importance of seabed structures and the relationship between habitat structural complexity and biodiversity. We then discuss management approaches designed to maintain and restore marine biological diversity.

People who study conservation in benthic ecosystems have much to learn from forests, which cover 38 x 10^6 km^2 (Perry 1994)—about 7.5% of the Earth's surface—because forests are the best-studied wildlife habitat. Many of the canonical findings in wildlife biology, conservation biology, and landscape ecology, such as the realization that island biogeography theory applies to ecosystems that have been fragmented (Terborgh 1974; Diamond 1975), have come from studies of organisms in forests. In contrast, the seafloor of the world's continental shelves, which cover 28 x 10^6 km^2 (Sharp 1988), is far less familiar to the human species. Indeed, even many marine scientists rarely or never see the seafloor in person. In the minds of the public, the seabed is ei-
ther a lush garden or a desert, but the truth is more subtle and complex. Marine ecosystems dominated by large (>1 m), living three-dimensional structures, including kelp forests, mangrove forests, and coral reefs, are actually a very small (albeit very important) part of the marine realm (for example, coral reefs occupy only 0.6 × 10⁶ km² or 0.1% of the Earth's surface [Reaka-Kudla 1997]). The rest of the seabed that the public sees consists mostly of sandy beaches and muddy plains and may appear featureless to the untrained eye. This perception is mainly a function of people's peculiar perspective; the narrow bands of sandy beaches that people visit are pounded by waves that prevent the growth of most biogenic structures (e.g., sponges, clam shells, amphipod colonies, cerianthid anemone tubes, polychaete worm tunnels, sea cucumber fecal deposits), while the vastly greater areas covered by mud (primarily silt- and clay-sized particles) are home to structures that are often too small to be resolved by cameras towed meters above the seabed. Yet, no less than on land, structures on and in the seafloor are crucial habitat features for most of the world's marine species. Coral reefs alone host 25% of the world's marine fish species (McAllister 1991).

People who study or manage species in the terrestrial realm have long known that avoiding loss of exploited wildlife populations goes beyond limiting mortality through bag, season, and size limits. It is at least as important to maintain features in the habitat such as cover and food that are essential to species' reproduction and growth. Wildlife biologists and other conservation biologists have built a substantial understanding of the three-dimensional spatial structure needed by species from leopards to spotted owls. For example, in the U.S. Pacific Northwest, structurally complex late-successional forests provide the myriad kinds of spaces—holes, cavities, chimneys, overhangs, thickets, lookout posts, and bridges—that many wildlife species need. The clearcuts and tree plantations (i.e., even-age monocultures of trees that are created after ancient forests are clear-cut) that replace them are structurally far simpler and cannot support many of the species found in ancient forests (Norse 1990).

Intuitive understanding of the importance of structural complexity underlies much of the scientific and public concern about clear-cutting, but there is also ample scientific evidence. Nearly four decades ago, MacArthur and MacArthur (1961) pointed out that songbird diversity is higher in forests that are more structurally complex. On land it is not difficult to observe the relationship between structure, which wildlife biologists call "cover," and species that need it, and studies of structure--diversity relationships are now quite sophisticated (e.g., Hansen et al. 1995). In the sea, however, scientific knowledge has depended far less on direct observation than on remote sampling (often using fishing gear) from the decks of vessels. This sampling practice has tended to limit understanding to structure-formers that come up in sampling gear. Fishery biologists have long known that kelp forests, coral reefs, and rocky reefs attract many commercially important fishes and the species they eat. Yet, as Thrush et al. (1998:876) note, "Fishery models often fail to include the potential role of interactions between habitat features and the survivorship of juveniles of exploited stocks." Fishery biology (in contrast to ichthyology and benthic ecology) has been slow to appreciate the importance of small structures on the seabed as habitat and the consequences of their destruction.

The diverse smaller structures of the seabed include cobble- and pebble-sized rocks; sand ripples; thalassinid crustacean mounds; sea cucumber fecal deposits; pits left by feeding rays and crabs; sea-grass blades; the spines of living sea urchins; kelp holdfasts; sponge, sea pen, and bryozoan colonies; many kinds of tunnels; and annelid worm, amphipod crustacean, vermetid gastropod, and cerianthid anemone tubes. These structures are naturally abundant in most marine ecosystems (see synopses in Gage and Tyler 1991 and Giere 1993). Seabed structures can result from past events (e.g., cobbles deposited by melting glaciers) or from ongoing processes (e.g., reef-building by mytilid mussels and sabellariid polychaetes). Some of the most important structures occur below the sediment--water interface, riddling the seabed with a complex of tunnels and tubes (summarized in Wheatcroft et al. 1990). Other structures, ranging from polychaete worm and amphipod crustacean tubes to corals and kelps, reach millimeters to tens of meters into the water column. Although seabed structures are generally far smaller than the ones in terrestrial forests, they are at least as important as habitat features for a myriad of species, including postsettlement young of commercially important fishes. Because structural complexity is so vital in benthic ecosystems, reduction of complexity affects all aspects of benthic biological diversity, including fisheries. Of the many natural and anthropogenic factors that disturb the seabed and reduce structural complexity, the leading factor is fishing with mobile gear (Watling and Norse 1998).
Importance of Seabed Structures: A Fish-Eye View

Why is seabed structure so important? Biological activity is most pronounced at interfaces, and the interface between the water column and the seabed is no exception. The species diversity and biomass of life in the half-meter above and below the sediment–water interface are usually orders of magnitude higher than in the overlying several meters of the water column (this has long been recognized by paleontologists who study ancient benthic communities [Ausch and Bottjer 1982]). Not only does the seabed collect the rain of detrital particles from above, but it also has the three-dimensional lithic and biogenic structures that provide habitat for innumerable species. Thus, these structures—even ones as small as one or a few centimeters in size—provide cover and food for invertebrates and fishes that eat them. Virtually everybody who has watched marine animals has observed that juvenile and adult fishes, crabs, lobsters, and octopuses stay close to rocks and hide in holes or interstices between rocks when potential predators approach (Bohnsack 1991).

As Ebeling and Hixon (1991) noted, without the shelter that complex structures provide, juvenile fishes are highly vulnerable to predators in both tropical and temperate reef ecosystems. Postsettlement Atlantic cod Gadus morhua, for example, show strongest survivorship on rugose bottoms (Gotceitas and Brown 1993). Lithic features such as boulders, rock ledges, and sand waves also play important roles in feeding. For example, juvenile red hake Urophycis chuss hover just downstream of sand wave crests, where they catch zooplankton carried by bottom currents (P. J. Auster, National Undersea Research Center for the North Atlantic and Great Lakes, personal communication), much as trout hover in the lee of sunken logs, catching stream drift. Moreover, the troughs between sand ripples and the pits dug by infaunal-feeding rays and crabs often accumulate organic material and become feeding places for detritivores and their predators. In the Gulf of Maine, areas not frequently disturbed by mobile fishing can have large numbers of redfish Sebastes fasciatus, each individual occupying space near the bottom of individual boulders (Auster, personal communication; L. Watling, personal observations).

In the marine realm, the relationship between habitat structural complexity and biodiversity has been best documented for fishes in coral reefs, where structures are conspicuous and direct observation is comfortable for divers. Ormond and Roberts (1997:233) noted, "There is often, for example, a striking relationship between fish species richness and habitat structural complexity or heterogeneity" and went on to note that "such a relationship is well known from terrestrial...as well as other marine studies," although this relationship might not always be strong in coral reefs. In perhaps the earliest study that quantified this relationship in the sea, Risk (1972) found higher fish species richness as coral rugosity increased. In the Tuamotu Archipelago in the South Pacific, Bell and Galzin (1984) found that slight changes in live coral cover resulted in dramatic increases in fish species diversity. Some 68% of the 115 fish species investigated were found only at sites with some live coral. Following the loss of live coral cover on the reefs of the island of Okinawa due to an outbreak of the sea star Acanthaster planci, Sano et al. (1984) were able to predict the subsequent loss of fish species. Some species were coral polyp feeders and so disappeared due to an absence of food, but many others declined as the structural complexity of the habitat decreased due to erosion of the dead coral substratum. There are also studies showing strong correlation between structural complexity and species recruitment, abundance, or diversity in ecosystems other than coral reefs (e.g., Hicks 1980; Connell and Jones 1991; Fernandez et al. 1993; Carr 1994; Herrnkind and Butler 1994; Szedlmayer and Able 1996).

Structural complexity provides smaller species with living space, increased food abundance, and refuge from predation (Sebens 1991). For example, Bros (1987) found that species diversity increased when artificial barnacle shells were added to a smooth surface. Presumably the increased surface area and presence of small spaces provided habitat for additional species. Lowered vulnerability to predators is another important aspect of habitat structural complexity. Prey abundance was greater in seagrass beds (Nelson 1979), worm tube aggregations (Woodin 1978), mussel clumps (Witman 1985), and algal turfs (Coulil and Wells 1983; Marinelli and Coulil 1987) than in less-structured bottoms when predators were present. It is now almost axiomatic that the more diverse marine habitats have higher species diversity (Sebens 1991).

The reasons why structural complexity is essential for many benthic species become clearer upon examining the relationship of organisms to the fluid dynamics just above the seabed. Most of the world's seabed consists of unconsolidated, fine, muddy sedi-
ments, where the sediment–water interface would be essentially flat but for the living things that increase structural complexity both above and below the sediment surface. Many seabed organisms are suspension feeders, orienting themselves with currents that bear food particles. Drag sharply decreases current velocities in the few centimeters above the sediment, decreasing opportunities for suspension-feeding (see reviews by Butman 1987; Snedgrove and Butman 1994). As a result, benthic organisms that raise their feeding structures even one or a few centimeters into the water column are better situated to capture plankton and detritus carried by currents. Furthermore, because the oxygen content of seawater is more than four orders of magnitude lower than that of air, respiration in and on the seabed rapidly depletes oxygen in the millimeter-to-centimeter-thick bottom boundary layer that sits just above the seabed (Jørgensen 1996), with the result that, on mud bottoms, sediment 1 cm or more below the sediment–water interface is almost always devoid of oxygen (see review by Watling 1991). Because anoxia is inimical to nearly all benthic animals, many infauna that make tunnels or tubes within the seabed generate currents that break through the bottom boundary layer, bringing the infauna oxygenated water and food particles. Other infauna and many epibionts avoid the oxygen-poor conditions of the sediment by placing their respiratory structures above the bottom boundary layer.

The structures that benthic species create increase seabed structural complexity. Many other species, including species sought as food by fishes, that do not colonize soft substrata per se live on or in these biogenic structures. For these reasons, structures—even small ones—are more important for epibionts on the seabed than on the land. Hard surfaces in the sea are generally far more densely colonized than hard surfaces on land, including rainforests, with their abundance of epiphytes and associated animals (E. A. Norse, personal observations). The diversity of benthic infauna and epibionts, therefore, provides essential habitat features including structures and food that sustain many of the world's commercial fishes (Boehlert 1996).

Changes in Species Composition at Reduced Structural Complexity

In terrestrial ecosystems, species composition is determined largely by the spatial configuration of structure-forming species; ancient coniferous forests, tallgrass prairies, and sandy deserts have very different assemblages of species. Structures that are essential to some species are unnecessary or even disadvantageous to others; removing structures frees up resources for species that do not need structures. For example, a Pacific Northwest wildfire or logging operation that eliminates ancient western red cedars Thuja plicata and northern flying squirrels Glaucomys sabrinus creates opportunities for fireweeds Epilobium angustifolium and creeping voles Microtus oregoni. Species composition is so closely tied to structure that terrestrial wildlife biologists have long manipulated habitat structure to maximize populations of species they consider desirable, such as deer Odocoileus spp.

Because fishery biologists have (until very recently) been less attuned to effects of small seabed structures, habitat relationships of fishes, especially postsettlement stages, are far less known in the sea and have largely been overlooked in fishery management. However, ecological theory and ubiquitous observations both suggest that severe disturbances that remove structure from the seabed will profoundly change species composition, harming many species but favoring some others, thereby decreasing species diversity. In this regard, trawling and dredging have effects similar to organic enrichment, which reduces species diversity and produces communities comprised of large numbers of a few opportunistic species (Pearson and Rosenberg 1978). A small but growing body of studies from places where scientists have looked at effects of mobile fishing gear, including Northern Europe, Australia, New Zealand, and the Atlantic and Pacific coasts of North America, support this hypothesis.

In the North Sea, where all the large Sabellaria spinulosa polychaete reefs were deliberately removed, species typical of open sands now dominate and support significant flatfish fisheries (Riesen and Reise 1982). In Loch Gàe loch on the Irish Sea, trawling significantly reduced populations of some infauna (e.g., the nut clam Nucula nitidosa), while opportunistic cirratulid and capitellid polychaetes became more abundant (Lindeboom and de Groot 1998). In northwestern Australia, Sainsbury (1987, 1988) found high-value Lethrinus (emperors), Lutjanus (snappers or seaperch), and Epinephelus (groupers or rockcod) dropped from 45 to 77% of the catch to 15% after trawling removed structure-forming sponges and gorgonians. At the same time, commercially less-valued species characteristic of sandy bottoms in the genera Nemipterus (threadfin-
bream) and Saurida (lizardfishes or grinners) became more abundant. In Hauraki Gulf, New Zealand (North Island), Thrush et al. (1998) found that areas with the least disturbance from trawling, seining, and scallop dredging had the most long-lived surface-dwelling invertebrates, the smallest proportion of opportunistic species, and the highest species diversity (using one kind of sampling gear) and highest density of large individuals and most organisms (using another type of gear). On Georges Bank off New England, Collie (1998) reported that mobile fishing gear on gravel bottoms removed the three-dimensional cover provided by epifauna, with undisturbed areas having higher abundance, biomass, and species diversity as indicated by the presence of fragile species such as sponges, nudibranchs, worms, and small fishes, while areas subjected to bottom trawling and scallop dredging were characterized by scavengers such as hermit crabs and sea stars. Finally, off the Big Sur coast of California, Engel and Kvitek (1998) found that heavily trawled areas have a low diversity of polychaete worms but large populations of an opportunistic amphipod polychaete Chloea pinnata, which the authors found to be the dominant prey item of several flatfish species. In these cases, trawling tended to eliminate competitively dominant, long-lived but disturbance-sensitive structure-forming benthic species, freeing up food and space for shorter-lived, disturbance-insensitive, opportunistic (weedy) species. In the absence of needed benthic structures or foods, groupers and cod disappear but lizardfishes and flatfishes fare better. Trawling and dredging decrease species diversity but increase populations of disturbance-tolerant benthic species and fishes that eat them, just as clear-cutting eliminates ancient forests and spotted owls and shifts production toward grasses and grazers.

Mobile Fishing Gear Effects, Type Conversion, and Sustainability

Bottom trawls and dredges used to catch benthic and demersal fishes, crabs, lobsters, shrimps, bivalves, sea urchins, and corals disturb the seabed in ways that overturn rocks, flatten sand waves, and crush, bury, and expose benthic organisms and biogenic structures (see reviews by Auster and Langton 1999 and Watling and Norse 1998). In the past, sizable structures (e.g., boulders) prevented trawling, but the advent of rockhopper and streetsweeper gear now allows trawling on virtually any kind of bottom, and fish finders and global positioning systems allow fishers to locate good spots and relocate them accurately until the spots are no longer so good. Moreover, the progressive disappearance of high-value commercial fishes in shallow waters has pushed fishing ever deeper; Merrett and Haedrich (1997) noted that trawling occurs as deep as 2,000 m, covering a total area of approximately 2.5 km² during each tow. Trawlers are more powerful than in the past, and improved technologies allow trawlers to fish deeper, farther offshore, and on rougher bottoms (Mirarchi 1998). The technological and economic forces that have increased fishing power and intensity have brought unprecedented disturbance to the seabed worldwide. Ecosystems with high structural complexity are likely to change most as fishing pressure increases (Auster 1998).

The use of mobile fishing gear is now the most important source of anthropogenic disturbance of the seabed and the principal agent of disturbance (anthropogenic or natural) in deep shelf, slope, and seamount waters where disturbance frequencies are naturally low. Watling and Norse (1998) have now shown that trawling occurs on a scale that had not previously been imagined; worldwide, an area equaling about half of the continental shelf—an area twice as large as the lower 48 U.S. states combined—is trawled every year. The few specific areas for which data are available are trawled at return intervals (average time between successive disturbances) ranging from years down to months.

In gauging the impact of a disturbance, it is useful to compare its return time with the time required for succession to restore the ecosystem's original structure. Impacts are more worrisome as return intervals become a significant fraction of the time until successional climax, because these return intervals shift the successional mosaic toward one dominated by recently disturbed patches. In many forest communities, biologists know the time needed for communities to attain late-successional characteristics. Much less is known about succession in many continental shelf, slope, and seamount areas, but a very crude estimate can come from knowing the life span of key structure-forming species. This assumes that these structure-forming species can colonize recently disturbed patches; alternatively, they could require intermediate successional stages before becoming established. Pacific Northwest Douglas-fir and western hemlock communities start to develop late-successional (ancient forest) attributes at about 200 years, and the dominant structure-formers have maximum life spans of 500–1,200
years, so disturbance return times (logging rotations) of anything less than 200 years essentially eliminate late-successional forests from the landscape matrix.

Life spans of marine structure-forming species are less known than they are for forest trees, but they range from months or years to several centuries (maximum estimated longevity for ocean quahog clams *Arctica islandica* is 221 years [Kraus et al. 1989]) or even more (gorgonian corals in the genus *Primnoa* can reach 500 or perhaps even 1,500 years in age [Risk et al. 1998]). It is reasonable to assume that recovery times in benthic ecosystems range from months to millennia, typically (on the continental shelf) ranging from years to decades. Because disturbance return times are short in comparison—for example, four months on Georges Bank (Auster et al. 1996), one year in the Gulf of Maine (Auster et al. 1996), and a worldwide continental shelf average of roughly two years (Watling and Norse 1998)—mobile fishing gear often disturbs the seabed much faster than succession and other benthic processes can restore seabed structure, converting ecosystems dominated by structure-forming and structure-needling species to ecosystems dominated by other species. The terrestrial equivalent of this would be wholesale, worldwide, unplanned, and unchronicled conversion of virgin forest to cattle pasture.

In the Irish Sea, where trawling has occurred intensively, the IMPACT-II report (Lindeboom and de Groot 1998:361) stated, “The present species-poor and low biomass fauna may represent an artificial man-made community adapted to the regular fishing disturbance experienced at this site” and concluded (p. 364), “if trawling intensity remains high, these communities may never recover.” Foresters call this kind of anthropogenic change “type conversion,” a practice prohibited except in extraordinary circumstances under the U.S. National Forest Management Act, the federal law that governs extraction and replacement of trees on most federally owned multiple-use forestlands. Strangely enough, the Magnuson-Stevens Fishery Conservation and Management Act of 1996 (also called the Sustainable Fisheries Act) does not even address ecosystem conversion, despite the fact that mobile fishing gears are converting structurally diverse benthic ecosystems to essentially featureless plains at a rate two orders of magnitude faster than forests are being converted worldwide. Trawling and dredging could be one of the least-known factors affecting the world’s biological diversity.

It has become clear in this decade that marine biodiversity is increasingly threatened (Norse 1993; Butman and Carlton 1995). At the same time, many of the world’s demersal fisheries have shown alarming downward trends (FAO 1997). Although it is clear that many fish species are being caught at rates their populations cannot sustain, it is no less clear that demersal fish habitat is being stripped of its essential structural complexity. Which of these two contributing factors is more important is not yet known (Fogarty and Murawski 1998), but it is the height of folly to think that overexploitation is the only way that fishing decreases fisheries yields. It is also apparent that areas supporting some demersal fisheries, including brown shrimp *Peneaus aztecus* in the northern Gulf of Mexico and plaice *Pleuronectes platessa* in the North Sea, have been trawled for many years without marked decreases in catch after their initial conversion. These may be canonical examples of fisheries based on opportunistic, disturbance-tolerant species.

In view of the profound effects of mobile fishing gear on benthic ecosystems, it is remarkable that there is no management structure in place in the United States (or anywhere else that we know about) charged with maintaining the seabed’s biological diversity. As Boelhert (1996:33) noted, “Legal authority under the Magnuson Fishery Conservation and Management Act (under which fishery management plans are developed) gives no consideration to genetic, species, or ecosystem biodiversity except as it affects protected species or critical habitats.” This situation remained unchanged when the Magnuson Fishery Conservation and Management Act was reauthorized as the Sustainable Fisheries Act of 1996; only habitat essential to the well-being of fishes is given consideration. Areas of the seabed where fish are likely to roam, but are not known to be essential to any life history stage, are outside the management requirements of the Sustainable Fisheries Act. Consequently, there are no provisions to limit habitat destruction and biodiversity loss anywhere that is not designated as essential fish habitat. Nobody is safeguarding the seabed from fishing.

In January 1998, 1,605 marine scientists and conservation biologists from 70 nations issued a statement called “Troubled Waters: A Call for Action” (MCBI 1998), The statement called upon citizens and governments worldwide to “Ameliorate or stop fishing methods that undermine sustainability by harming the habitats of economically valuable marine species and the species they use for food and shelter.” The question that fishery biologists, fishers, conservationists, managers, legislators, and the public must ask is whether we are willing to live in
a world where spotted owls, cod, and groupers become as vanishingly rare as their rugose habitats, to be superceded by cattle, plaice, and lizardfishes. To people concerned only about the gross tonnage of meat produced, such questions might not be troubling; there are almost always some organisms opportunistic enough to survive even where disturbance is severe and chronic. But to a growing number of people, including thousands of leading scientists, the loss of marine biodiversity is an appalling prospect.

Any alternative to the current approach must take legislative and management steps to both protect substantial areas of seabed from becoming structurally simplified and to restore the seabed’s structure, species composition, and functioning. The actions we take ultimately hinge on whether we value the living sea as anything more than a wet, salty cattle ranch.

The difficult task of balancing short-term economic gains with maintenance of biodiversity and longer-term economic benefits involves recognizing economic behaviors of people who take wild living resources. Loggers prefer large, high-quality, high-value trees and focus their attention in forest areas having them. As Norse (1990) noted, U.S. National Parks and Wilderness Areas tend to be located in areas of low biological and economic productivity, such as scenic, craggy snow-covered mountains that lack trees sought by loggers; these areas have a low diversity of forest species. In a similar way, fishers concentrate trawling and dredging effort in certain areas (see Figure 1 in Mirarchi 1998). Some other areas (quite likely areas with the lowest habitat value for fishes) escape disturbance from fishing. However, protecting areas that nobody wants because they are biologically unproductive does little to maintain biodiversity.

Lessons Learned

Marine conservation lags behind terrestrial conservation, both in terms of what scientists know and in the creation and implementation of laws to protect resources. Lawmakers and marine fisheries managers are only now awakening to something their terrestrial counterparts have known for two decades: that human-caused disturbance is dramatically reducing biological diversity, and that to avoid undesirable losses, disturbance frequency or severity must be reduced. Although the seabed is a crucial component of the Earth’s biological diversity, the prevailing marine fisheries paradigm focuses on managing populations in isolation from their environment. This paradigm has pushed populations of many high-value fishes so far below maximum sustainable populations that the world’s fish catch is increasingly comprised of low-trophic-level “baitfishes” rather than higher-trophic-level fishes (Pauly et al. 1998). Foot-dragging and “more-of-the-same” fishery legislation, management, and scientific research are a guaranteed recipe for further losses, not only of the commercial fisheries that are the focus of U.S. laws, but, more broadly, of the biological diversity that supports fisheries.

In the nearly two decades since biological diversity loss was defined as the world’s premier conservation challenge, scientific and managerial advances have strengthened conservation in the terrestrial and freshwater realms. Yet the United States has no federal laws focused on maintaining biological diversity in the sea and nothing remotely approaching the multidisciplinary analysis and decision making that led to conservation of spotted owls and their Pacific Northwest ancient forest habitat. The biodiversity ethic that has become the driving force in nonmarine conservation has yet to make substantial inroads in the marine realm; marine conservation is still largely about maximizing the fish catch or preventing a few other preferred species (especially marine mammals) from harm. As the sea loses biological diversity at an accelerating rate, it is clear that a different approach is needed.

Although some die-hards will undoubtedly deny the importance of trawling and scallop dredging impacts no matter how strong the evidence is, there are fishermen—at least when they are speaking anonymously—who know what marine scientists have only recently learned, as the following quotes from Nova Scotia and New Brunswick fishermen reveal (Fuller and Cameron 1998):

“Draggers have leveled off Western Bank. During the ’70s and ’80s they tore all the plant life off it. This has the same effect as clearcutting.” (Respondent 1)

“There used to be an awful mess of [reef-like corals] and the nets got tore to pieces. We got them pretty much cleaned up. We used to clean out the trees when hauling back the nets.” (Respondent 14)

“There shouldn’t be dragging, it tears the plant life off the bottom. It might take ten years to come back. You can’t take a plow through a field and expect the grass to grow back right away.” (Respondent 29)

“Rockhopper gear changes the bottom and gets rid of places fish can hide.” And “Now they scallop 24 hours a day, all winter long. There are more boats and more power to tow with, this causes the gear to dig in better ... They drag up everything and it doesn’t
have a chance to come back." And "If the system were left alone, it will recover somewhat. It needs time to heal." (Respondent 3)

We believe that the United States and other nations need to make all human activities in the sea—whether shipping, oil and gas production, recreation, or fishing—compatible with maintaining and restoring biological diversity. As on land, we need intelligent, flexible, scientifically sound, and carefully monitored limits on our take of marine wildlife as well as a comprehensive system of protected areas that are managed to maintain marine biodiversity. In practical terms, that means that a substantial portion of the sea (the signers of "Troubled Waters" called for 20%) must be off-limits to any activity, including trawling and dredging, that significantly reduces biological diversity. The essential fish habitat provisions in the 1996 Magnuson-Stevens Fishery Conservation and Management Act are a step in the right direction, but unless the provisions are strengthened to address broader biodiversity needs, they are not sufficient. There need to be zones in the sea where people can fish and other zones where the marine life can recruit, grow, and spawn free from fishing pressure, just as wildlife can in terrestrial national parks.

Acknowledgments

Ideas and information for this chapter came from a workshop on "Effects of Bottom Trawling on Marine Ecosystems" held by Marine Conservation Biology Institute in June 1996 at the University of Maine’s Darling Marine Center. We thank the other workshop participants: Peter Auster (University of Connecticut, USA); Jeremy Collie (University of Rhode Island, USA); Paul Dayton (Scripps Institution of Oceanography, USA); Eleanor Dorsey (Conservation Law Foundation, USA); Jonna Engel (Moss Landing Marine Laboratory, USA); Donald Gordon (Department of Fisheries and Oceans, Canada); Richard Langton (Maine Department of Marine Resources, USA); Larry Mayer (University of Maine, USA); Cynthia Pilskaln (University of Maine, USA); Ian Poiner (Commonwealth Scientific and Industrial Research Organization, Australia); Peter Schwinghamer (Department of Fisheries and Oceans, Canada); Simon Thrush (National Institute of Water and Atmospheric Research, New Zealand); Page Valentine (U.S. Geological Survey, USA); and Waldo Wakefield (Rutgers University, USA). We are grateful to the workshop’s funders: the Curtis and Edith Munson Foundation, Natural Resources Defense Council, and three components of the National Oceanic and Atmospheric Administration: Auke Bay Fisheries Laboratory of the National Marine Fisheries Service, Stellwagen Bank National Marine Sanctuary, and the Office of Strategic Policy and Planning. We thank the Geraldine R. Dodge Foundation, Educational Foundation of America, Surdna Foundation, Sun Hill Foundation, David and Lucile Packard Foundation, Horizons Foundation, Pew Fellows Program in Marine Conservation, New England Biolabs, the DuPont Company, Ted Stanley, Anne Rowland, and Bert Cohn for support during the writing of this chapter. We also thank Peter Auster, Ewann Bernston, Caroline Gibson, and Lee Benaka for astute comments on various drafts. This is Marine Conservation Biology Institute contribution Number 26.

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