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Short communication

Modifications to a plumb staff beam trawl for sampling uneven, complex habitats

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Abstract

A small (5.1 m footrope) plumb staff beam trawl was modified to sample demersal fauna in uneven, complex habitats. Several SCUBA dives were made to observe and measure the modified trawl while being towed. Additionally, an underwater camera system was used to observe footrope contact with the bottom at varying amounts of scope ratio on several bottom types including pure sand, mixed sand with emergent biotic structure, sand with shell fragments, mud with shell fragments, and gravel and shell bedforms. Net modification tests were followed by field collections at 55 stations in which 49 species of fish were captured. The modified beam trawl appears to be an effective tool for sampling demersal fishes in a variety of habitats, including those with emergent biotic structure.
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Keywords: Beam trawl; Small-meshed; Juvenile fish; Complex habitat

1. Introduction

The plumb staff beam trawl system (hereafter referred to as PSBT) developed by Gunderson and Ellis (1986) is highly effective for stock assessment sampling of demersal fauna, especially Dungeness crab (*Cancer magister*) and flatfishes that burrow into the substrate. The PSBT has proven to be an extremely useful tool off the coast of Alaska for measuring relative abundance of juvenile and adult flatfishes (Norcross et al., 1995; Norcross et al., 1997; Abookire and Norcross, 1998; Nichol, 1998) and juvenile groundfishes (Mueter and Norcross, 1999; Abookire et al., 2000, 2001; Litzow et al., 2000). However, in all applications of the PSBT, sampling has been limited to relatively flat, smooth habitats with low relief and little or no emergent structure. Likewise, other studies which have employed the PSBT have been limited to trawling on smooth, even seafloors (Armstrong et al., 1995; Shi et al., 1997).

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Compared to otter trawls, beam trawls are favorable because they can be towed from a single wire and winch. Because the rigid beam maintains a constant net-mouth opening, Gunderson and Ellis (1986) prefer beam trawls over otter trawls for estimating the relative abundance of demersal fauna. In addition, the PSBT can be managed from a small vessel by hand and is equally effective during the day and night (Gunderson and Ellis, 1986). Effectiveness of the trawl is constant among fish lengths ranging from 20 to 200 mm (Gunderson and Ellis, 1986; Shi et al., 1997), and Gunderson and Ellis (1986) reported no gear avoidance by Pacific tomcod (*Microgadus proximus*) to the PSBT. The PSBT is an effective design and serves as a good base net for specific modification, as done by Dennis et al. (2001) to sample plankton in the upper 50 cm of the water column. In this study, we modified the PSBT to trawl on uneven, complex habitats.

Although juvenile Pacific cod (*Gadus macrocephalus*) and juvenile walleye pollock (*Theragra chalcogramma*) were captured with the PSBT on relatively smooth, even benthic habitats (Mueter and Norcross, 1999; Abookire et al., 2000, 2001), we wanted to sample a variety of habitats including bottom types that were uneven and had emergent structure. Certain gadid species, such as Atlantic cod (*Gadus morhua*), are known to be more cryptic in their juvenile stage and to use complex habitats for refuge from predation (Fraser et al., 1996; Gregory and Anderson, 1997). Given that Arimitsu et al. (2003) encountered excessive gear damage when towing the PSBT on the irregular seafloor in Glacier Bay, Alaska, complex habitats with emergent structure would be untrawlable with the PSBT. Additionally, Armstrong et al. (1995) attributed differences in Dungeness crab densities between eelgrass and shell habitats to the fact that the PSBT was designed to operate on a fairly uniform sand-mud substrate and was likely to have been less efficient over the shell habitat.

Our primary objectives were (1) to modify the PSBT for trawling in uneven, complex habitats and (2) to modify the PSBT to capture juvenile gadids effectively. SCUBA divers and underwater cameras were employed to assess net efficiency in several habitats. Our goal was not to make direct comparisons between the efficiency of PSBT and the modified beam trawl, but rather to document the effectiveness of the modified beam trawl at sampling demersal fauna in complex habitats with emergent structure.

2. Methods

2.1. Net modifications

Trawl modifications addressed three goals: (1) to deter the footrope from snagging on bottom obstructions or scooping rocks into the net, (2) to reduce the likelihood of damage to the beam, and (3) to improve access and retention for fish that are further off-bottom than juvenile flatfish. In conjunction with trawl modifications, the positive features of the PSBT were retained as much as possible, including consistent net opening, easy handling and effective capture of small on-bottom fish.

To improve footrope performance over rougher grounds, the two tickler chains (4.9 and 4.3 m in length; Gunderson and Ellis, 1986) attached to the PSBT footrope were removed. Additional ground-gear, composed of 10.2 cm (4 in.) disks extending 489 cm in length over a central steel chain, was added below the footrope (Fig. 1). The additional ground-gear attached to the footrope in 10 evenly spaced locations, including at each end of the footrope where the wingtip weights (9.5 kg each) were also attached.

The beam height of the original PSBT has not been reported previously. However, given the equal connection distances between the beam and the top and bottom wings of the PSBT, we assumed the beam is towed off the bottom at a distance equal to half the vertical net opening (60 cm) at approximately 30 cm above the seafloor (Fig. 1). Such a low beam height might stimulate gear avoidance by near-bottom fishes and subject the beam to damage from large obstructions. If the beam was made of heavier, less buoyant material to reduce damage, we would expect an even lower beam height with the above problems exacerbated.

To increase the net-mouth opening and to reduce damage to the beam, the beam was strengthened and rigged to fish higher above the bottom. We used heavier aluminum pipe (33 and 26 mm outside and inside diameters (1.31 and 1.06 in.)) for the beam and added a 20 cm (8 in.) diameter plastic trawl float at each end of the beam for positive net buoyancy. Top bridles from the beam to the net were shortened to 196 cm and bottom bridles lengthened to 224 cm (including wingtip weights) to allow the beam to fish at approximately the height of the trawl headrope (Fig. 1). Ahead of the beam, a middle bridle (260 cm) was added for additional support when encountering obstructions.

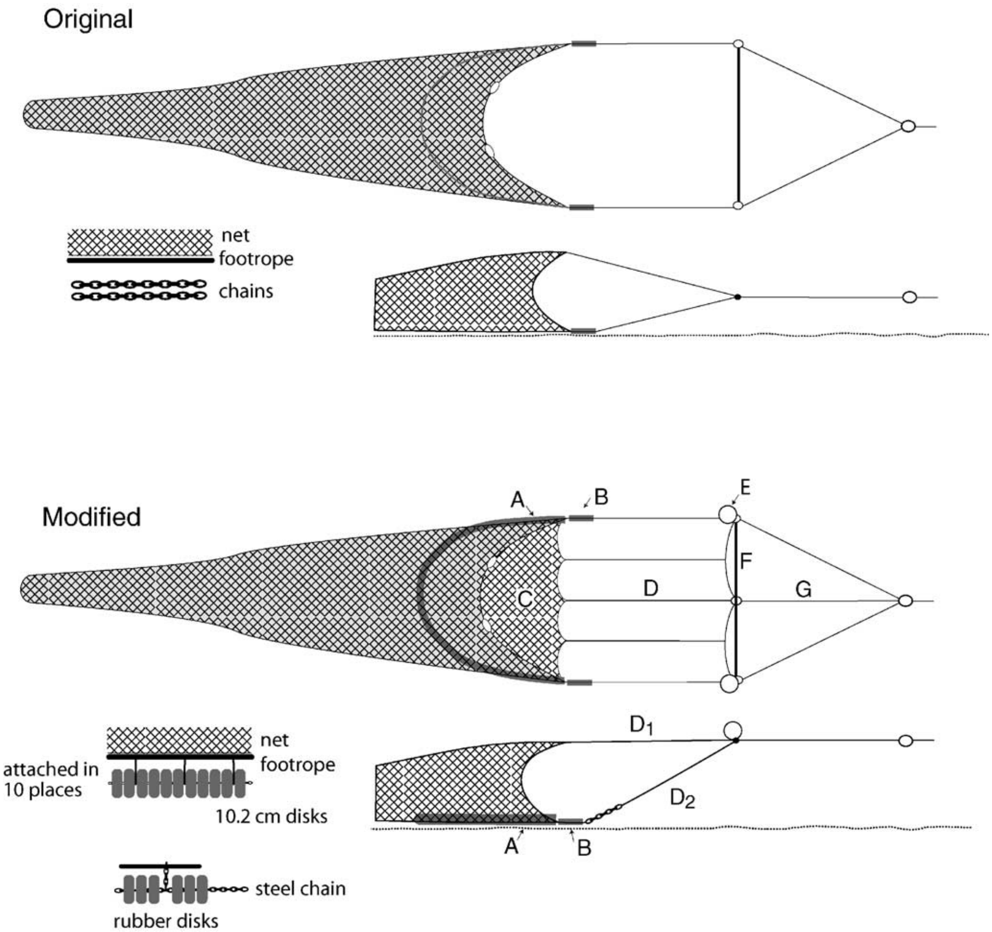

Fig. 1. Schematic diagrams of the original plumb staff beam trawl described by Gunderson and Ellis (1986) in the upper panel and the modified beam trawl developed in this study (lower panel). In each panel, the top diagram is the trawl viewed from above, the lower right diagram is the trawl viewed from the side of the wing, and the lower left diagram is an enlargement of the trawl footrope. Labels denote the following: A: 5.1 m footrope; B: 9.5 kg wingtip weight; C: additional 'ceiling' made from net panel with 32 mm mesh; D: five support lines the outermost two of which are the top bridles; D_1: top bridle from beam to headrope and upper wing tip; D_2: lower bridle from beam to wingtip weight; E: 20 cm diameter plastic trawl floats; F: 3.1 m beam; G: additional middle bridle added ahead of the beam. As shown in the lower right diagrams, beam height is higher in the modified trawl and the headrope ceiling extends ahead of the footrope. The modified footrope has both tickler chains removed and additional ground-gear of 10.2 cm disks over a central steel chain.

Because gadids tend to have more of an upwards escape response in comparison to flatfishes (Rose, 1995), a 'ceiling' of 32 mm (1.25 in.) mesh (stretched mesh including one knot) was added between the headrope and the upper wing tips to block upward escapes by fish. Five equally spaced lines (196 cm length, 11 mm diameter) from the beam supported the forward edge of the mesh 'ceiling' panel. Of these five lines, the outermost two were top bridles (Fig. 1).

2.2. SCUBA and underwater camera observations of the net

On May 29, 2002, three series of SCUBA dives were employed to evaluate the effectiveness of the net while being towed. All dives were conducted at depths of 7–10 m where there was enough ambient light to measure the net, and each dive had 5–8 min of bottom time. The net was towed past a stationery buoy, and both divers descended once the towline passed them. Divers measured the effective width of the footrope, the height of the headrope, the height of the beam, and visually observed contact between the footrope and ocean floor.

From May 29 to 30, 2002, we conducted eight tows in Chiniak Bay off Kodiak Island, Alaska, in a variety of habitats and depths (7–43 m). During these tows, we tested the scope ratio (warp out: bottom depth) from 4:1 to 7:1 with a camera mounted on the headrope of the net. The camera typically faced toward the ground-gear to observe contact with the seafloor, except in one tow where the camera faced toward the top of the net and the support lines. Haul duration varied among tows, but the average tow was 15 min. There was sufficient ambient light at all depths so no camera lights were used. All trawling was done from a 15.2 m commercial purse seine vessel equipped with a trolling clutch that enabled a slow (<1 kt), controlled towing speed.

The camera system attached to the trawl transmitted video through cable to the vessel, allowing us to observe contact of the footrope with the bottom at varying amounts of scope ratio on several bottom types including pure sand, mixed sand with emergent biotic structure, sand with shell fragments, mud with shell fragments, and gravel and shell bedforms. We either towed in a uniform depth strata or perpendicular to depth contours letting out more line at each depth until the footrope and wingtip weights had continuous contact with the bottom. Videotape footage (124 min total) was watched a second time in the laboratory to confirm field observations of bottom type and effectiveness of scope ratio.

2.3. Application of the modified net

The modified beam trawl was used to sample juvenile groundfish, specifically gadids, from August 10 to 22, 2002, in Chiniak Bay, Alaska (from 57°38′N, 152°19′W to 57°42′N, 152°28′W). A total of 55 stations were sampled, and all fishing was conducted from the same vessel employed for testing net modifications. Prior to each fishing tow, an underwater camera with real-time video was used to observe the bottom habitat. The modified net was subsequently towed along the underwater camera path for 5 min at each station. Fishing depth ranged from 10 to 30 m depth, target speed was 1 kt (range 0.6–1.7 kts), and scope ratio was according to the results listed below (see Section 3.1). All fish and invertebrates captured in the trawl were identified to the lowest possible taxon and counted. Fishes were measured to the nearest millimeter for fork length (FL); however, when >100 individuals of the same species were captured at a station, a random subsample was measured. Each minute of videotape footage was later analyzed for habitat complexity (emergent structure type and percentage cover, bottom substrate type, macroalgae species and percentage cover, invertebrate species, and count).

3. Results

3.1. SCUBA and underwater camera observations of the net

The fishing dimensions of the net changed as intended, with higher beam and headrope positions while maintaining good bottom contact. SCUBA divers measured the effective width of the footrope as 2.1 m, the height of the headrope as 78 cm, and the height of the beam as 82 cm. No observations were made of beam avoidance in the modified trawl. Visual observations of the net while being towed confirmed there was continuous contact between the ground-gear and the ocean floor, the wingtip weights were typically flat on the bottom with at most a 5° angle upward, and the bridle pulled the net evenly. The modified net was heavier than the PSBT due to the ground-gear, and thus impractical to deploy by hand off a boat without a lifting winch.

At depths ≤15 m, a scope ratio of 5:1 was insufficient to maintain contact with the wingtip weights and the ocean floor, although the ground-gear was still in continuous contact. With a scope ratio of 7:1, we observed full bottom contact of the wingtip weights and the ground-gear at depths ≤15 m. For depths >15 m, a scope ratio of 5:1 was sufficient to ensure continuous contact with the ground-gear and wingtip weights on the ocean floor in all habitats sampled.

3.2. Application of the modified net

The modified beam trawl captured 49 species of fish ranging from 9 to 492 mm FL (Table 1). The seven most abundant species captured were northern rock sole (*Lepidopsetta polyxystra*), snake prickleback

Table 1
Fishes and selected invertebrates captured in the modified plumb staff beam trawl in May and August 2002, listed in alphabetical order (minimum and maximum fork length (to the nearest mm) is given for fishes, and carapace width is given for crabs.)

Scientific name	Common name	Minimum length (mm)	Maximum length (mm)
Ammodytes hexapterus	Pacific sand lance	110	138
Anoplagonus inermis	Smooth alligatorfish	34	47
Atherestes stomias	Arrowtooth flounder	45	354
Bathyagonus infraspinatus	Spinycheek starsnout	57	79
Bathymaster caeruleofasciatus	Alaskan ronquil	70	–
Bathymaster leurolepis	Small mouth ronquil	67	125
Bathymaster signatus	Searcher	86	89
Blepsias cirrhosus	Silverspotted sculpin	70	135
Cancer magister	Dungeness crab	34	179
Chionoecetes bairdi	Tanner crab	11	128
Enophrys bison	Buffalo sculpin	33	–
Gadus macrocephalus	Pacific cod	42	110
Gymnocanthus galeatus	Armorhead sculpin	26	241
Hemilepidotus hemilepidotus	Red Irish lord	211	387
Hemilepidotus jordani	Yellow Irish lord	44	211
Hexagrammos decagrammus	Kelp greenling	212	–
Hexagrammos lagocephalus	Rock greenling	62	94
Hexagrammos octogrammus	Masked greenling	64	318
Hexagrammos stelleri	White-spotted greenling	65	325
Hippoglossoides elassodon	Flathead sole	30	423
Hippoglossus stenolepis	Pacific halibut	31	232
Icelinus borealis	Northern sculpin	29	33
Isopsetta isolepis	Butter sole	91	425
Lepidopsetta polyxystra	Northern rock sole	23	447
Leptocottus armatus	Pacific staghorn sculpin	298	–
Limanda asper	Yellowfin sole	65	352
Liparis bristolensis	Bristol snailfish	100	–
Liparis sp.	Snailfish	9	55
Lumpenus fabricii	Slender eelblenny	67	251
Lumpenus sagitta	Snake prickleback	74	368
Myoxocephalus polyacanthocephalus	Great sculpin	27	492
Nautichthys oculofasciatus	Sailfin sculpin	46	–
Nautichthys pribilovius	Eyeshade sculpin	38	46
Ophiodon elongates	Lingcod	79	93
Pallasina barbata	Tubenose poacher	41	158
Parophrys vetulus	English sole	73	114
Pholis laeta	Crescent gunnel	107	155
Platichthys stellatus	Starry flounder	427	478
Pleuronectes quadrituberculatus	Alaska plaice	332	341
Podothecus acipenserinus	Sturgeon poacher	113	281
Psettichthys melanostictus	Sand sole	147	419
Psychrolutes paradoxus	Tadpole sculpin	27	42
Radulinus asprellus	Slim sculpin	106	113
Raja binoculata	Big skate	279	–
Ronquilus jordani	Northern ronquil	72	–
Sarritor frenatus	Sawback poacher	28	63
Sebastes polyspinis	Northern rockfish	86	93
Stichaeus punctatus	Arctic shanny	45	140
Theragra chalcogramma	Walleye pollock	47	89
Trichodon trichodon	Pacific sandfish	82	151
Triglops pingeli	Ribbed sculpin	63	154

A dash (–) in the maximum length column indicates that only one individual was captured.

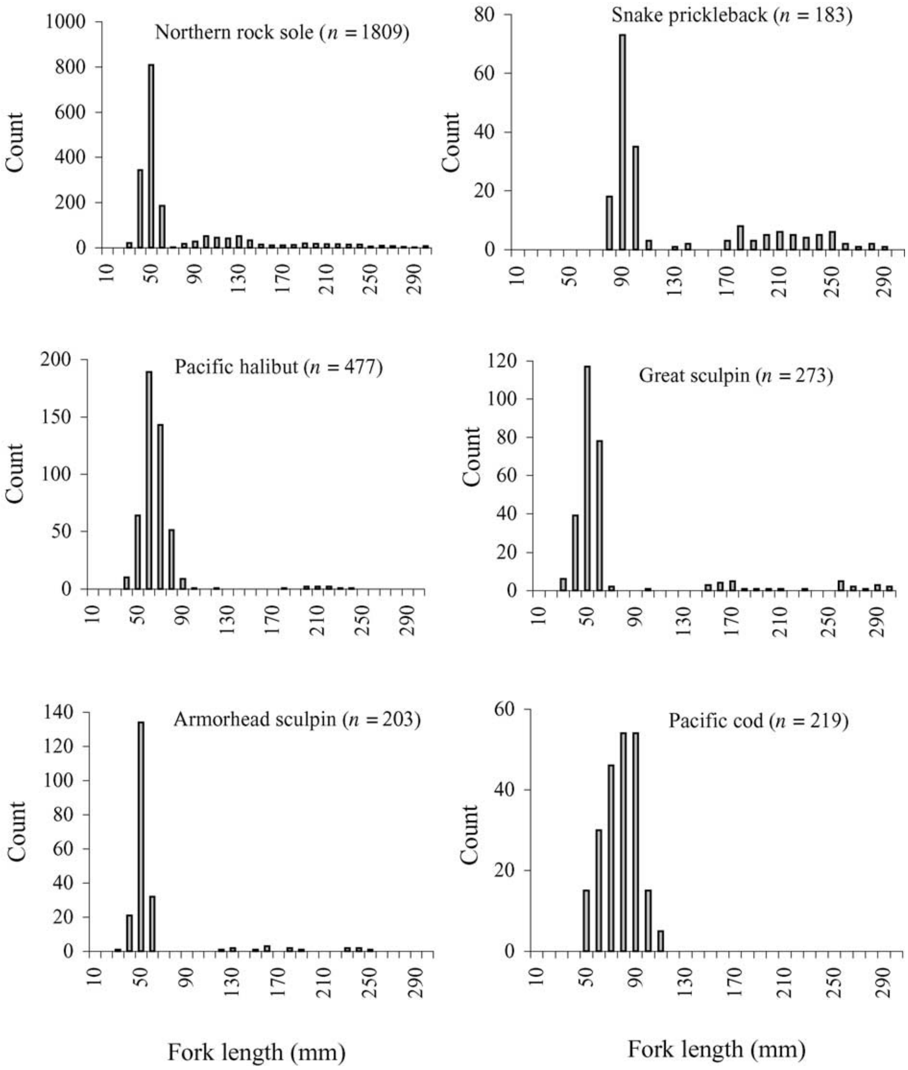

Fig. 2. Length frequency histograms for the most abundant species captured with the modified beam trawl. Fork lengths (FL) were grouped in 10-mm intervals and fish lengths >300 mm FL were not graphed. The number of fish measured is given in parentheses. Lengths for the tadpole sculpin, which ranked fourth in abundance, are not graphed because they only ranged from 27 to 42 mm FL.

(*Lumpenus sagitta*), Pacific halibut (*Hippoglossus stenolepis*), tadpole sculpin (*Psychrolutes paradoxus*), great sculpin (*Myoxocephalus polyacanthocephalus*), armorhead sculpin (*Gymnocanthus galeatus*), and Pacific cod. Several length-classes of these abundant species were captured in the modified trawl (Fig. 2), except for the tadpole sculpin, which had a small length range of 27–42 mm FL.

The modified net was ‘snagged’ at only 2 of the 55 stations sampled. One of those stations could not be sampled successfully with the modified trawl due to the presence of boulders larger than 0.5 m that did not bend the beam but ‘snagged’ the net and tore the majority of the belly. The second trawl ‘snag’ occurred immediately after we deployed the net on a reef with boulders >0.5 m; there was no gear damage to the net or beam. The modified beam trawl fished successfully in all other habitat types including pure sand, mixed sand with emergent structure (sea anemones, sea pens, worm tubes, and eelgrass (*Zostera marina*)), sand with >50%

macroalgae cover, sand with shell fragments, mud with shell fragments, and gravel and shell bedforms. As an indication of durability, the modified beam trawl captured an automobile tire in one tow and sustained no gear damage.

4. Conclusions

The modified beam trawl designed in this study captured juvenile gadids as well as very small flatfishes (23 mm FL) and Dungeness crab (Table 1), which was surprising given that the tickler chains from the original design (Gunderson and Ellis, 1986) had been replaced with disk ground-gear. The modified beam trawl had a higher vertical opening (0.78 m) and smaller effective width (2.1 m) than the original PSBT (0.6 and 2.3 m, respectively; Gunderson and Ellis, 1986). The beam on the modified trawl was raised to 82 cm, from an estimated PSBT beam height of 30 cm (Fig. 1), and functioned well over a range of substrates without damage. However, fishing a site with boulders larger than 0.5 m damaged the net. We recommend a scope ratio of 7:1 at depths ≤15 m and 5:1 at depths >15 m. Whether or not the modified trawl is as effective as the PSBT cannot be determined from our collections, and comparisons of trawl efficiency would be a worthy goal of future research. However, given that juvenile flatfishes, gadids, and Dungeness crab were captured regularly in this study, the modified beam trawl is an effective tool for sampling demersal fishes in a variety of habitats including uneven, complex habitats with emergent biotic structure.

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References

Abookire, A.A., Norcross, B.L., 1998. Depth and substrate as determinants of distribution of juvenile flathead sole (*Hippoglossoides elassodon*) and rock sole (*Pleuronectes bilineatus*) in Kachemak Bay. Alaska J. Sea Res. 39, 113–123.

Abookire, A.A., Piatt, J.F., Robards, M.D., 2000. Nearshore fish distributions in an Alaskan estuary in relation to stratification, temperature and salinity. Estuar. Coast. Shelf Sci. 51, 45–59.

Abookire, A.A., Piatt, J.F., Norcross, B.L., 2001. Juvenile groundfish habitat in Kachemak Bay, Alaska, during late summer. Alaska Fish. Res. Bull. 8, 45–56.

Arimitsu, M.L., Litzow, M.A., Piatt, J.F., Robards, M.D., Abookire, A.A., Drew, G.S., 2003. Inventory of Marine and Estuarine Fishes in Southeast and Central Alaska National Parks, Nat. Park. Serv. Alaska Region. Inventory and Monitoring Program Final Rep., USGS Alaska Science Center, Anchorage Alaska, 79 pp.

Armstrong, J.L., Armstrong, D.A., Mathews, S.B., 1995. Food habits of estuarine staghorn sculpin, *Leptocottus armatus*, with focus on consumption of juvenile Dungeness crab, *Cancer magister*. Fish. Bull. U.S. 93, 456–470.

Dennis, D.M., Pitcher, C.R., Skewes, T.D., 2001. Distribution and transport pathways of *Panulirus ornatus* (Fabricius, 1776) and *Panulirus* spp larvae in the Coral Sea. Aust. Mar. Freshwater Res. 52, 1175–1185.

Fraser, S., Gotceitas, V., Brown, J.A., 1996. Interactions between age-classes of Atlantic cod and their distribution among bottom substrates. Can. J. Fish. Aquat. Sci. 53, 305–314.

Gregory, R.S., Anderson, J.T., 1997. Substrate selection and use of protective cover by juvenile Atlantic cod *Gadus morhua* in inshore waters of Newfoundland. Mar. Ecol. Prog. Ser. 146, 9–20.

Gunderson, D.R., Ellis, I.E., 1986. Development of a plumb staff beam trawl for sampling demersal fauna. Fish. Res. 4, 35–41.

Litzow, M.A., Piatt, J.F., Abookire, A.A., Prichard, A.K., Robards, M.D., 2000. Monitoring temporal and spatial variability in sandeel (*Ammodytes hexapterus*) abundance with pigeon guillemot (*Cepphus columba*) diets. ICES J. Mar. Sci. 57, 976–986.

Mueter, F.J., Norcross, B.L., 1999. Linking community structure of small demersal fishes around Kodiak Island, Alaska, to environmental variables. Mar. Ecol. Prog. Ser. 190, 37–51.

Nichol, D.G., 1998. Annual and between-sex variability of yellowfin sole *Pleuronectes asper* spring-summer distributions in the eastern Bering Sea. Fish. Bull. U.S. 96 (3), 547–561.

Norcross, B.L., Holladay, B.A., Müter, F.J., 1995. Nursery area characteristics of Pleuronectids in coastal Alaska. U.S.A. Neth. J. Sea Res. 34, 161–175.

Norcross, B.L., Müter, F.J., Holladay, B.A., 1997. Habitat models for juvenile Pleuronectids around Kodiak Island, Alaska. Fish. Bull. U.S. 95, 504–520.

Rose, C.S., 1995. Behavior of North Pacific groundfish encountering trawls: applications to reduce bycatch. In: Solving Bycatch: Considerations for Today and Tomorrow. Alaska Sea Grant College Program Report No. 96-03, University of Alaska Fairbanks, pp. 235–242.

Shi, Y., Gunderson, D.R., Sullivan, P.J., 1997. Growth and survival of 0^+ English sole *Pleuronectes vetulus*, in estuaries and adjacent nearshore waters off Washington. Fish. Bull. U.S.A. 95, 161–173.

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DEVELOPMENT OF A PLUMB STAFF BEAM TRAWL FOR SAMPLING DEMERSAL FAUNA

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ABSTRACT

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A small (5.1-m footrope) plumb staff beam trawl system was developed for sampling fish and shellfish in shallow coastal waters. Several SCUBA dives were made to observe it in operation, and compare it with an otter-trawl design that had previously been employed. Day—night comparisons of catch rates and size composition of the catch were conducted, and indicated that the beam trawl performed equally well in daylight and darkness. The plumb staff beam trawl system appears to be a far more effective stock assessment tool than the otter-trawl design that has previously served as a standard in this region.

INTRODUCTION

Otter trawls are quite effective for sampling demersal fauna, and they are of proven effectiveness in resource assessment surveys (Hayes, 1983). However, the horizontal net mouth opening is maintained through hydrodynamic forces generated by trawl doors, and is highly variable. The mouth opening has been shown to vary with water depth, scope ratio, bottom conditions, towing speed and rigging features (Wathne, 1977; Main and Sangster, 1979; West, 1982).

This is probably a minor problem with full-scale commercial trawls, but is of greater significance in the case of scaled-down otter trawls that have been developed for use off small boats (Mearns and Allen, 1978; Gibbs and Matthews, 1982) in shallow coastal waters. This is particularly true when the doors are rigged so that only a short distance separates them from the net itself.

Commercial otter trawls also rely on a "herding" effect by the doors and rigging to enhance catches, a feature which complicates their use in scientific sampling. The effective area sampled varies with the response of fish to the trawl doors and bridles (Main and Sangster, 1981; Wardle, 1983), and is difficult to quantify (Harden Jones et al., 1977). During diving trials by one of the authors (I.E.), the effectiveness of herding has also been observed to increase with fish density. When numerous flatfish (including English sole, *Parophrys vetulus*, and sand sole, *Psettichthys melanostictus*) swim just ahead of the dandyline cables (sweeplines) in a moving band (Ellis, 1973), the herding characteristics of the gear are enhanced.

Traditional beam trawls (Carney and Carey, 1980), where the mouth of the trawl is completely surrounded by a rigid metal frame, provide an alternative to the otter trawl in small-boat sampling, but are more awkward to store and deploy. The plumb staff beam trawl has a long history of commercial use (Amos, 1984), and offers an additional alternative. A nearly constant mouth opening is maintained by a rigid "beam" (aluminum conduit in our application), which can be removed after each set. Little storage space is required, and the net can be deployed and retrieved from a small vessel by hand.

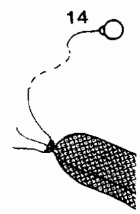
METHODS AND MATERIALS

The Ellis Highliner demersal sampling system, a modified plumb staff beam trawl developed for our work on Dungeness crab (*Cancer magister*) is shown in Fig. 1. This system was scaled for use aboard a 6.4-m (150 Hp) Boston Whaler within coastal estuaries, and for larger commercial fishing vessels (11—21 m; 300—700 Hp) in near-shore areas of the open coast. Larger models could readily be designed it they were to be used exclusively by commercial vessels, since the beam length for commercial plumb staff beam trawls frequently approximates the length of these vessels.

Small juvenile Dungeness crab (down to 6 mm carapace width) and flatfish (down to 20 mm total length) were the principle targets in our surveys, and the sampling system was designed to sample than as effectively as possible. The net was designed and rigged to follow the contours of the seabed closely, while the "tickler" chain array scrubs the bottom in advance of the net. The net is of relatively light construction and was fished with 30—100 m of 3/8-inch (0.95 cm) nylon towline. Nylon stretches when under strain, acting as a shock absorber when the net "hangs up" on the bottom and reducing gear damage or loss. The bottom of the cod-end was covered with a loosely attached section of large-mesh (7.6 cm) polypropylene to provide additional protection.

Three series of SCUBA dives were undertaken in order to evaluate the effectiveness of the net when pulled from the Boston Whaler and to measure its mouth opening. In addition, the net was compared with a shrimp try-net (headrope length = 4.9 m) used previously in Dungeness crab survey work (Gotshall, 1978; Stevens, 1982).

A series of day—night comparisons of trawl efficiency was conducted



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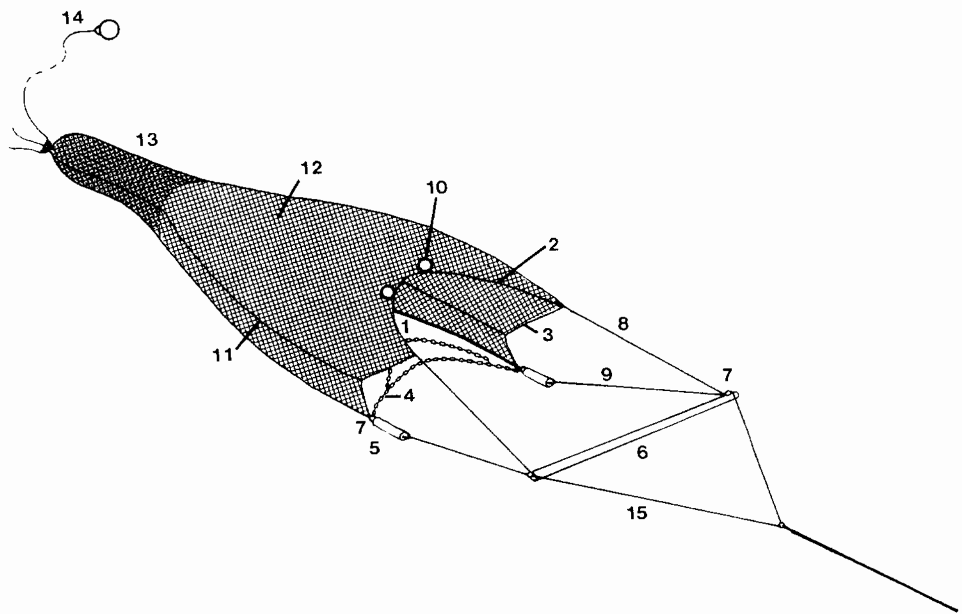

Fig. 1. System developed for sampling juvenile Dungeness crabs and flatfish. 1, 5.1-m footrope; 2, 4.1-m headrope; 3, 1.0-m breastlines; 4, tickler chain arrays (4.3 and 4.9-m sections of 1.9-cm chain); 5, wingtip weight, 6.0 × 40.6 cm, 9.5 kg; 6, beam, 3.8 cm × 3.1 m aluminum conduit; 7, quick-release snap; 8, upper net bridle, 1.0 cm × 1.8 m; 9, lower net bridle, 1.3 cm × 1.4 m; 10, 7.6-cm cork float, 11, ribline; 12, main body of net, 7—9 mm (lumen) square knotless nylon; 13, cod-end, with 4.0-mm liner; 14, emergency retrieval line, with 20-cm float; 15, beam bridle, 1.3 cm × 3.1 m. Total length, wings to cod-end, is 7.9 m. Further information is available from Ellis Highliner Fishing Gear, P.O. Box 55028, Seattle, WA 98153, U.S.A.

during 12—14 September 1983 to examine the sampling efficiency of the trawl. These comparisons were all conducted from the 15-m offshore fishing vessel "Spirit", and 15 pairs (total 30) of usable tows were made. The tows were made outside the entrance to Grays Harbor, Washington (Latitude 46°50′—46°56′ depth 23—38 m), within an 8 × 2 nautical-mile survey area. Mean towing speed was 2.0 kn during the daytime hauls and 1.8 kn at night, although the gear was designed to be towed more slowly (1—1.5 kn). A 5 : 1 scope ratio (warp out : bottom depth) was used during these tows, although this was increased at shallow depths (50 m of warp for depths less than 5 m; 100 m for depths of 5—20 m).

Mean day—night catch rates were compared statistically using both a t-test, after $\log(x + 1)$ transformation (Sissenwine, 1978) and a non-parametric Mann—Witney test. Size composition data were also collected during the day—night studies, in order to evaluate size-specific differences in capture efficiency. Size data were collected from either the entire catch (Dungeness crab, butter sole), or from random sub-samples of the catch, and were compared statistically by using χ^2 tests for homogeneity.

RESULTS

SCUBA observations were invaluable in fine-tuning prototypes of the beam trawl, trying out modifications and evaluating their effectiveness. These observations showed that the final trawl design (Fig. 2) maintained the desired shape and configuration under operational conditions, with good bottom contact along the entire length of the footrope. The footrope tended to dig into the substrate where it was sandy, and the main crossing chains in the tickler chain array also maintained good bottom contact. The tickler chain array, together with the turbulent zone created behind it, dislodged small organisms from the substrate and lifted them into the water column, where they could be trapped by the net.

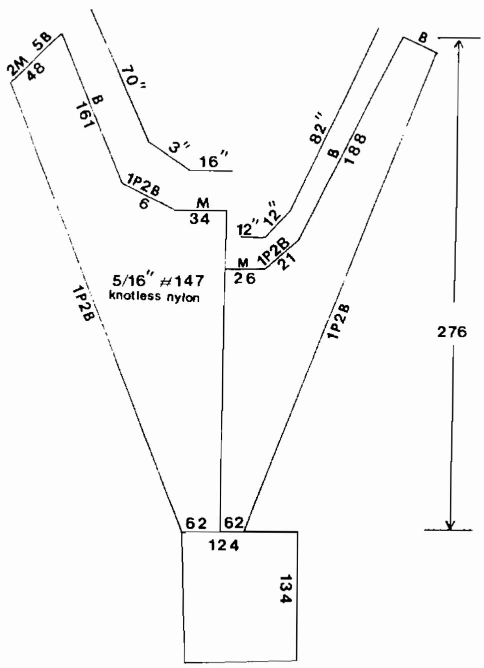

Fig. 2. Net plan for the plumb staff beam trawl.

The horizontal spread (net width) could be readily determined either by measuring the net-opening itself while the gear was in operation, or by measuring the distance between tracks left in the sand by the two lower wingtip weights. The effective width was determined to be 2.3 m, while the vertical opening was estimated at 0.6 m.

The shrimp try-net used in previous Dungeness crab surveys failed to contact the bottom adequately: a feature which greatly reduces its utility for species such as Dungeness crab and flatfish. The footrope never got closer to the bottom than about 5 cm, and only the loops of chain attached to it actively contacted the substrate. This was true even with scope ratios in excess of 10 : 1 and towing speeds as slow as 1 kn.

The day—night comparisons failed to detect any statistically significant differences (0.05 level) in catch per nautical mile (Table I) for either Dungeness crab, butter sole (*Isopsetta isolepus*) or Pacific tomcod (*Microgadus proximus*), the three most abundant species encountered in the study area. This suggests that the net was equally effective during both periods.

TABLE I

Mean catch rates (number km^{-1}) for the major species sampled during day—night trawl comparisons

Species	Day	Night	Significance level	
			t-test	Mann—Whitney test
Pacific tomcod	57.3	45.6	0.234	0.125
Dungeness crab	23.1	37.2	0.242	0.141
Butter sole	21.2	21.2	0.904	0.633

Day—night differences in size composition were minor in the case of Dungeness crab and Pacific tomcod (Fig. 3), and were non-significant statistically ($P > 0.05$). The butter sole caught during the day, however, were larger than those caught during the night. Although statistically significant

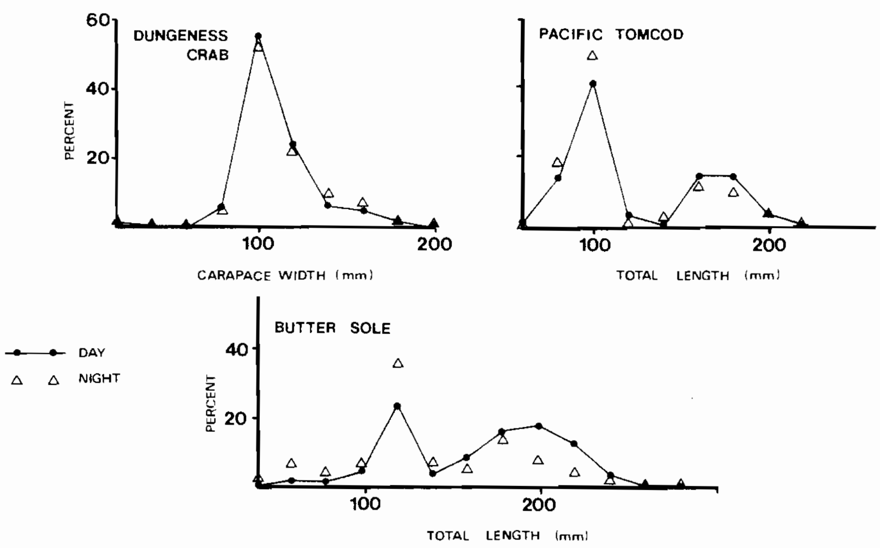

Fig. 3. Size composition of Dungeness crab, Pacific tomcod and butter sole in daytime (n = 408, 130 and 357, respectively) and night-time (n = 568, 307 and 342, respectively) catches.

($P < 0.01$), the differences seen in butter sole size composition are the opposite of what we would expect (i.e., larger fish are less facile at avoiding the net in darkness) if net avoidance were responsible.

DISCUSSION

The plumb staff beam trawl system designed for this study (Fig. 1) appears to be highly effective for sampling demersal fauna. Dungeness crab are known to burrow into the substrate during the day (Barr, 1980), and the system was designed to dislodge them. A single night-time SCUBA dive by Barr (1980) indicated that burrowing did not occur at night, so that the failure to detect any significant day—night difference in either catch rate or size composition for Dungeness crab suggests that the system design tended to successfully overcome any burrowing behavior.

In contrast, Gotshall (1978) found highly significant (0.05 level) differences in catch-rate between 6 pairs of day—night tows for Dungeness crabs when using a try-net similar in size and design (4.9 m headrope, 3 m mouth-width) to the one observed during our SCUBA work. Catch per tow was 75% greater during the night than it was during the day.

Gotshall also made direct SCUBA observations along transect lines, and found that the density observations obtained during night-time fishing operations approached those obtained through SCUBA observation, although the SCUBA estimates of density were still 26% greater.

Further examination of the efficiency of the plumb staff beam trawl would be desirable; perhaps using direct SCUBA observations in a manner similar to the methodology used by Gotshall. The observations and analyses completed to date, however, provide clear evidence that the plumb staff beam trawl is superior to the otter trawls that have previously been employed in shallow-water demersal sampling.

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REFERENCES

Amos, D., 1984. Different varieties of beam trawl could be used in American fisheries. Nat. Fisherman, May: 53—55.

Barr, L., 1980. Population and behavior studies of Dungeness crabs at Steamer Bay, Alaska. Monthly Report Northwest and Alaska Fisheries Center, April: 1—10.

Carney, R.S. and Carey, A.G., Jr., 1980. Effectiveness of metering wheels for measurement of area sampled by beam trawls. Fish. Bull., 78: 791—796.

Ellis, I.E., 1973. A progress report on the development of a selective shrimp trawl. FAO Fish. Rep. No. 139, pp. 34—49.

Gibbs, P.F. and Matthews, J., 1982. Analysis of experimental trawling using a miniature otter trawl to sample demersal fish in shallow estuarine waters. Fish. Res., 1: 235—249.

Gotshall, D.W., 1978. Relative abundance studies of Dungeness crabs, *Cancer magister*, in northern California. Calif. Fish Game, 64: 24—37.

Harden Jones, F.R., Margetts, A.R., Greer Walker, M. and Arnold, G.P., 1977. The efficiency of the Granton otter trawl determined by sector-scanning sonar and acoustic transponding tags. Rapp. P.-v. Reun. Cons. Int. Explor. Mer., 170: 45—51.

Hayes, M.L., 1983. Active fish capture methods. In: L.A. Nielsen and D.L. Johnson (Editors), Fisheries Techniques, American Fisheries Society, Bethesda, MD, pp. 123—145.

Main, J. and Sangster, G.I., 1979. A study of bottom-trawling gear on both sand and hard ground. Scott. Fish. Res. Rep., 14: 1—15.

Main, J. and Sangster, G.I., 1981. A study of the fish capture process in a bottom trawl by direct observations from a towed underwater vehicle. Scott. Fish. Res. Rep., 23: 1—21.

Mearns, A.J. and Allen, M.J., 1978. Use of small otter trawls in coastal biological surveys. Environ. Prot. Agency Rep., EPA-600: 1—33.

Sissenwine, W.P., 1978. Using the USA research vessel spring bottom trawl survey as an index of Atlantic mackerel abundance. ICNAF Selected Papers, No. 3, pp. 49—55.

Stevens, B.G., 1982. Distribution, abundance, and food habits of the Dungeness Crab, *Cancer magister*, in Grays Harbor, Washington. Ph.D. Dissertation, University of Washington, Seattle, 213 pp.

Wardle, C.S., 1983. Fish reactions to towed gears. In: A.G. MacDonald and I.G. Priede (Editors), Experimental Biology at Sea, Academic Press, London, pp. 167—195.

Wathne, F.W., 1977. Performance of trawls used in resource assessment. Mar. Fish. Rev., 39(6): 16—23.

West, C.W., 1982. Development and application of bottom trawl instrumentation systems in fisheries resource assessment. "Oceans 82" Conference Record, Marine Technology Society, Washington, DC, pp. 266—272.