North American Journal of Fisheries Management 28:710–721, 2008

DOI: 10.1577/M06-272.1

[Article]

The Value of Applying Commercial Fishers' Experience to Designed Surveys for Identifying Characteristics of Essential Fish Habitat for Adult Summer Flounder

H. WARD SLACUM, JR.,* JON H. VØLSTAD,[1] EDWARD D. WEBER, AND WILLIAM A. RICHKUS
Versar, Inc., 9200 Rumsey Road, Columbia, Maryland 21045, USA

ROBERT J. DIAZ AND CHRISTINA O. TALLENT
Virginia Institute of Marine Science, Post Office Box 1346, Gloucester Point, Virginia 23062, USA

Abstract.—Identifying the habitat requirements of marine fish is necessary to conserve and manage their populations, but these requirements are poorly understood for many species. One method of screening for important habitat characteristics is to identify differences in habitat features between areas of high and low fish abundance. We tested the association between abundance of adult summer flounder *Paralichthys dentatus* and benthic habitat features at two study areas in the Middle Atlantic Bight in summer 2004. The study included trawl and remote-sensing surveys that were designed and conducted with the assistance of commercial fishers. Within each area, a local commercial fisher designated specific locations a priori as productive or unproductive for fishing. Summer flounder abundance, as measured by mean catch per area swept, was significantly greater at sites designated as productive than at sites designated as unproductive (6.5 times greater in Maryland and 4.7 times greater in Rhode Island). These results indicate that summer flounder were attracted consistently to localized habitats that must have had different characteristics than other nearby locations. Habitat variables associated with the substrate (e.g., particle size, bottom shape, and presence of sessile organisms) were measured along trawl paths using underwater video imagery. The measured variables did not explain abundance well, suggesting that microscale characteristics of the substrate did not affect summer flounder distribution. Summer flounder were most abundant at depths of 10–20 m; however, both high and low catch rates occurred in this depth range, indicating that other factors also were important. These results suggest that additional localized variables merit further investigation to determine their importance to summer flounder. This study demonstrates the importance of combining fishers' knowledge and experience with planned surveys to identify essential habitat features for fish.

Understanding the habitat requirements of demersal fish is essential to conserve and manage their populations because of the role that particular environmental characteristics play in recruitment, growth, and survival. Consequently, a large scientific and legislative effort has been devoted to identifying and conserving fish habitat in recent years. Mechanistic relations between fish production and specific habitat features are poorly understood for many species because these links are complex and difficult to study. Habitat requirements may change with life history stage, migration period, stock abundance, and geographic location (Packer and Hoff 1999; Packer et al. 1999). Another difficulty is that links between habitat and fish production may be indirect via predators, prey, or other biota that interact with physical habitat features (e.g., reefs; Coen et al. 1999). Because of these difficulties, the habitat variables that limit fish populations at all life stages are unknown for many species, yet agencies have been required by legislation to define habitats that are important for fish by use of whatever data are available.

The summer flounder *Paralichthys dentatus* is a managed species that supports important commercial and recreational fisheries. Summer flounder range from Nova Scotia to Florida and are most abundant in the Middle Atlantic Bight. The National Oceanic and Atmospheric Administration (NOAA) and regional fisheries councils are required to designate and conserve essential fish habitat (EFH) for the summer flounder under the Magnuson–Stevens Fishery Conservation and Management Act (1996). Under this act, EFH is defined broadly as "those waters and substrate necessary to fish for spawning, breeding, feeding and growth to maturity." Summer flounder occur along the inner and outer continental shelf and within shallow estuarine waters but exhibit seasonal and latitudinal migrations (Kraus and Musick 2001). Habitat needs of

---

* Corresponding author: wslacum@versar.com

[1] Present address: Institute of Marine Research, Postboks 1870 Nordnes, 5817 Bergen, Norway.

Received November 30, 2006; accepted August 2, 2007

juveniles have been quantified relatively well, but little specific habitat information is available for adult life stages (cf., Packer and Hoff 1999).

Summer flounder EFH is currently delineated as occurring in New England and the Middle Atlantic Bight based on abundance data from fishery-independent trawl surveys (Reid et al. 1999) rather than specific habitat criteria. Because of the paucity of data available for adult summer flounder, trawl data are used to define EFH for relatively large geographic areas (i.e., 10 × 10-min latitude–longitude squares) where, on average, the species has been captured commonly. The underlying assumption of this approach is that density of a species, as reflected in trawl catch per unit effort (CPUE), is related to habitat quality for that species. This approach is protective of summer flounder because it results in nearly their entire range being listed as EFH. However, the approach has several disadvantages. First, it prevents managers from predicting how changes in ocean conditions will affect summer flounder abundance in the future because mechanistic relations are unknown. Second, it does not contribute to the identification and conservation of specific habitats that may be of particular importance to a species on smaller scales. Such information is vital when the potential for effects from anthropogenic habitat alterations (e.g., offshore drilling or mining) must be addressed.

One means of ascertaining features of the habitat that are important for a species is to (1) identify characteristics that differ between locations where the species occurs in high versus low abundance and then (2) test the importance of such characteristics using additional controlled studies. Commercial fishers are particularly aware of locations in which they can reliably harvest their target species. Such knowledge is essential to ensure the financial viability of their fishing ventures and is generally based on years of experience. If fishers are willing to share their expertise, they can identify areas of varying productivity within fishing grounds. This information can be used to develop geographic strata in formal surveys. Such surveys could then be used to quantify relations between fish abundance (assuming that it is correlated with fishing productivity) and specific habitat features with known precision. In this study, we used fishers' knowledge of summer flounder distribution to design a trawl survey of this species' abundance. We then coupled the survey with sampling of the benthic substrate in the same areas using established underwater video imagery techniques. The general strategy was to identify features of the benthic habitat that were correlated with high abundance of summer flounder and thus might constitute essential elements of the species' habitat. Any features identified in this study could then be examined using controlled follow-up studies to establish causal relationships.

Methods

Study areas, selection of fishers, and stratification.—Two general areas in the Middle Atlantic Bight on the inner continental shelf were selected for the study. The first area was located offshore of Ocean City, Maryland, and the second was located offshore of Point Judith, Rhode Island. Both of these areas were known to support a nearshore day fishery for summer flounder during the summer months. A local commercial fisher from each area was chosen from the fishery to participate in the study as part of the NOAA Northeast Regional Office Cooperative Research Partners Initiative, a program designed to better utilize the knowledge of commercial fishers through collaboration with scientists and fishery managers. In Maryland, the fisher was selected based on the knowledge of the senior author and his previous participation in fisheries surveys. The fisher in Rhode Island was suggested by A. Valliere of the Rhode Island Division of Fish and Wildlife (personal communication) as someone who could be a willing and knowledgeable study participant. Both fishers were dependent on the fishery for livelihood and had participated in the fishery for more than 20 years.

Fishers chose areas where they typically captured summer flounder in the nearshore day fishery during the summer months but that were large enough to include locations where the fishery had historically been both productive and unproductive. The length of the Maryland area (Figure 1A) was approximately 20 km perpendicular to the shoreline, and the area extended from the shoreline to approximately 30 km offshore. Depth ranged from approximately 5 to 20 m. The length of the Rhode Island area (Figure 2A) perpendicular to the shoreline was approximately 55 km, and the area extended from just offshore to approximately 45 km offshore, including Block Island. Water depth in the Rhode Island site ranged from approximately 5 to 30 m. Fishers used National Ocean Service navigational charts to delineate locations within each site that they predicted to be productive for summer flounder fishing and nearby locations that they predicted to be unproductive (hereafter, productive and unproductive locations, respectively). Predictions were based on their professional judgment, past experience, and previous sampling of the area. The areas were then stratified into productive and unproductive locations, and participating fishers trawled in each stratum as described below.

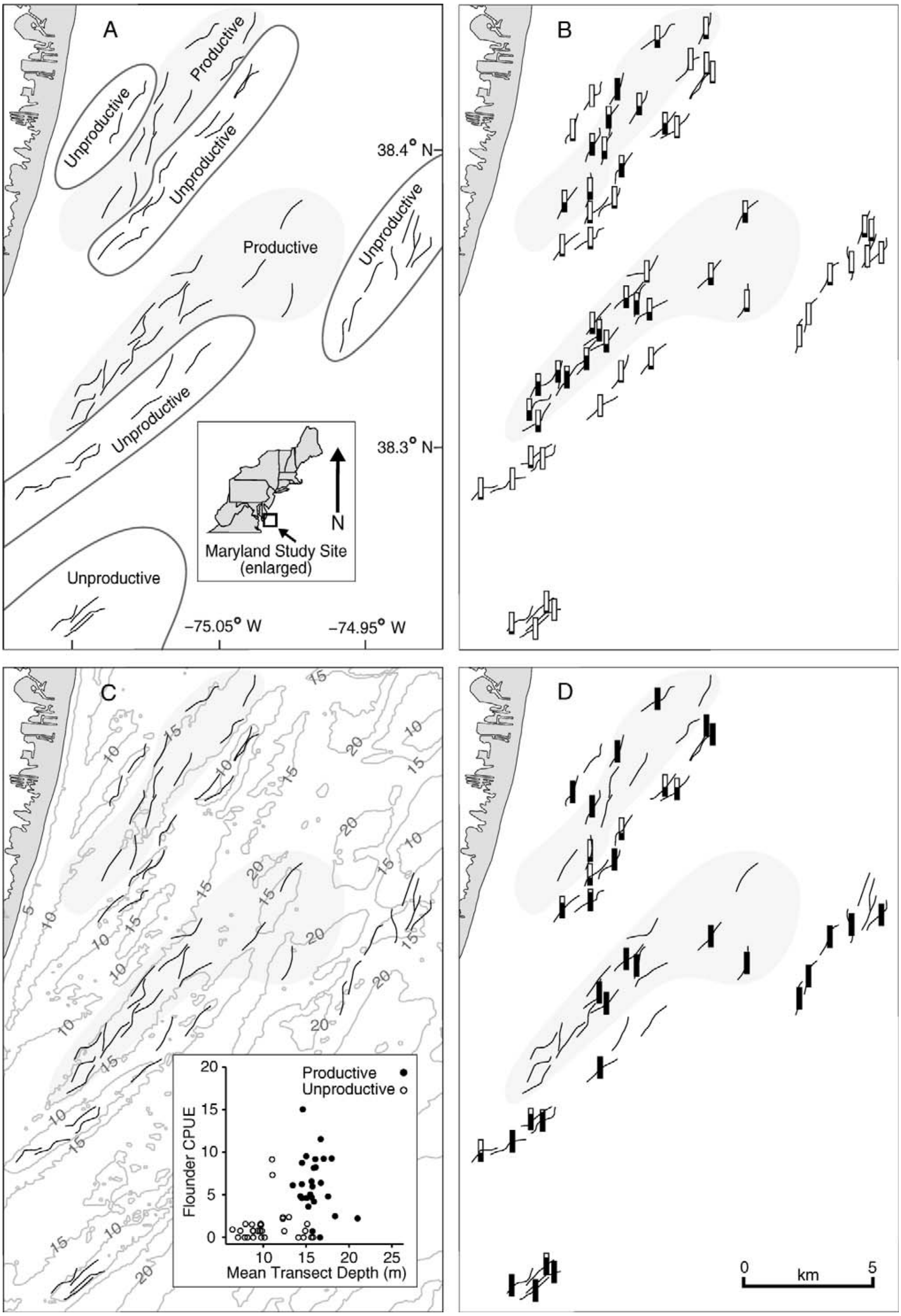

FIGURE 1.—Maps of the Maryland study site where summer flounder distribution and trawl catch rates were analyzed (black lines = locations of trawls): **(A)** approximate areas designated a priori by an experienced commercial fisher as productive or unproductive for the fishery during summer; **(B)** proportion (0.0–1.0; bars) of summer flounder catch per unit effort (CPUE; fish/1,000 m) relative to the maximum observed at the site (15.1 fish/1,000 m); **(C)** bathymetry contours in 5-m increments, and inset depicting CPUE versus mean trawl depth for productive and unproductive areas; and **(D)** proportion (bars) of underwater video samples within each trawl path that indicated a habitat composition of 100% sediment (≤1 mm in diameter); lines without an accompanying bar represent trawls that were not video sampled.

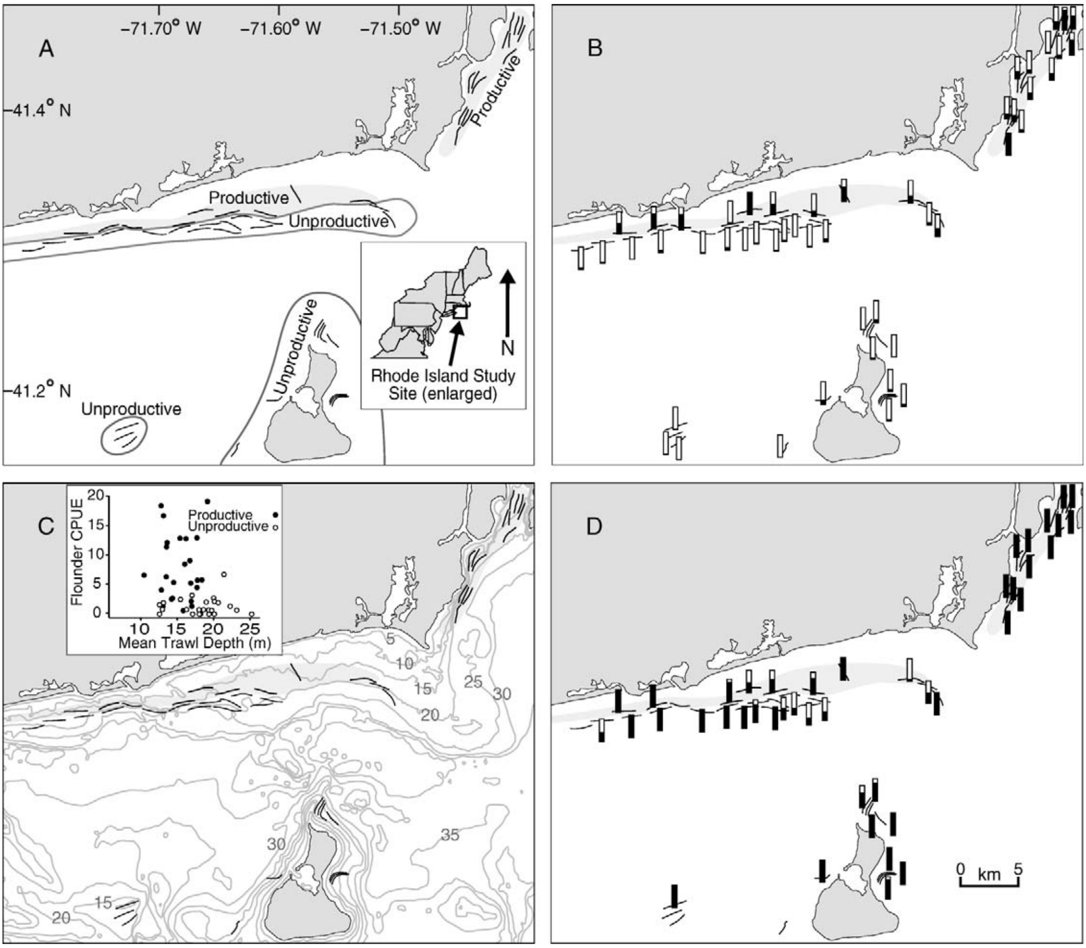

FIGURE 2.—Maps of the Rhode Island study site where summer flounder distribution and trawl catch rates were analyzed (black lines = locations of trawls): **(A)** approximate areas designated a priori by an experienced commercial fisher as productive or unproductive for the fishery during summer; **(B)** proportion (0.0–1.0; bars) of summer flounder catch per unit effort (CPUE; fish/1,000 m) relative to the maximum observed at the site (19.3 fish/1,000 m); **(C)** bathymetry contours in 5-m increments, and inset depicting CPUE versus mean trawl depth for productive and unproductive areas; and **(D)** proportion (bars) of underwater video samples within each trawl path that indicated a habitat composition of 100% sediment (≤1 mm in diameter); lines without an accompanying bar represent trawls that were not video sampled.

Trawl data collection.—Trawl samples were collected during daylight hours using two commercial stern trawlers. Sampling effort was divided approximately evenly between productive and unproductive locations to capture a range of summer flounder abundance and presumably to sample a corresponding range of habitat structure. Fishers sampled within strata using the same techniques they employed during normal fishing operations. Generally, this meant that tows were conducted perpendicular to the depth gradient and parallel to the shoreline. To avoid trawling over very large areas that could encompass multiple habitats, all trawl samples were restricted to approximately 15-min tows at constant speed of approximately 5.5 km/h. Locations were recorded continuously along the trawl paths using data logging software connected to a shipboard differential Global Positioning System (DGPS) unit. Total distance trawled was calculated from DGPS coordinates as the distance between points where the vessel reached trawling speed and where it was slowed for net retrieval. All fish captured were identified to species and enumerated after a trawl was completed, and 25 fish/species were also measured to the nearest millimeter. The mean depth of each trawl was estimated using National Geophysical Data Center bathymetric maps (NGDC 2005). A subsample of depth measurements was also made every 60 s along all trawls sampled with the video camera in Rhode Island to check concordance with the bathymetric data. These data agreed closely with the map data (mean difference = 0.9 m).

In Maryland, sampling was conducted by the 16.8-m FV *Tony and Jan* using a standard two-seam flounder trawl equipped with an 18.3-m headrope and 24.4-m footrope. The net consisted of 14-cm stretched-mesh polypropylene throughout and was equipped with chafing gear on the cod end bag. A total of 56 trawls were conducted between 16 and 31 June 2004. Twenty-six trawls were in productive locations, and 30 trawls were in unproductive locations.

In Rhode Island, sampling was conducted by the 17-m FV *Grandville Davis* using a standard two-seam flounder trawl equipped with a 15.8-m headrope and 21.3-m footrope. The net consisted of 15.2-cm stretched-mesh polypropylene throughout and was equipped with chafing gear on the cod end bag. To avoid hangs on the bottom, this net was also equipped with large, 25.4-cm rubber disks (rock hoppers) attached to the center of the lead line. Rock hoppers were not expected to bias trawling results because they were fit tightly together to form a continuous trawling surface (i.e., no leadline was visible between them) and were used consistently between productive and unproductive areas. A total of 50 trawls were conducted between 2 and 6 August 2004. Twenty-four trawls were in productive locations, and 26 trawls were in unproductive locations. Bottom water temperature, dissolved oxygen concentration, and salinity were measured at the end of each trawl using a YSI 6600 multiprobe.

Underwater video data collection.—An underwater video sled equipped with forward- and downward-facing Panasonic digital video cameras (Model GP-KR222; 768 × 494-pixel resolution) was towed between 3.7 and 5.5 km/h on the bottom along the path of fish trawls to characterize benthic habitat. To improve the visibility of images in turbid water, the sled was equipped with Perkin-Elmer video strobe lights (Model MVS-5004). The forward-facing camera was mounted 0.2 m off the bottom at an oblique angle of 20° to provide a close-up view of bottom morphology and to detect the presence of biological features from 0.5 to 2.0 m^2 in front of the sled. The downward-facing camera was mounted perpendicular to the bottom at a distance 0.15 m from the sediment surface and had a 588-cm^2 field of view. The information collected from the cameras was recorded onto digital videotape, and georeferenced data were superimposed on the video using an onboard DGPS so that habitat from specific locations along the trawl path could be identified in later analysis. The Maryland video survey was conducted from the 16-m MV *North Star* between 20 July and 24 September 2004. The Rhode Island video survey was conducted from the FV *Captain Roberts* between 4 and 8 October 2004. Video imagery was collected on 41 of 56 trawl paths in Maryland and on 46 of 50 trawl paths in Rhode Island because excessive turbidity or other logistical constraints prevented data collection along some trawls.

Benthic habitat was characterized from the underwater video by analyzing images from recorded videotape using an editing deck and high-resolution video monitor. Images were subsampled and analyzed at 2-min intervals of towing with the video sled. If video images were not visible at the 2-min interval because of poor near-bottom visibility, images from the last moment of bottom visibility and the first moment of bottom reappearance were analyzed. For analysis and archiving, 20-s video clips were captured around the sampled videotape times using iMovie version 3.0.3 (Apple Computer, Inc.). Each video image from the forward camera sampled 2–4 m^2 of substrate depending on turbidity, and each image from the downward camera sampled 0.25 m^2. For each image, the substrate was classified for the presence or absence of physical and biological characteristics related to bottom relief, substrate particle size, biogenic structures, and shell hash (Table 1), similar to the classification described by Diaz et al. (2003). All fish and megafauna observed in the images were also identified to the lowest possible taxon.

Statistical analysis.—The number of summer flounder captured per trawl was standardized to CPUE, defined as the number of fish captured per 1,000 m of trawl distance. The data were transformed to $\log_e$(CPUE + 1) before analysis to reduce or eliminate the dependence between mean CPUE and variance. For each study area, the success of participating fishers at predicting productive versus unproductive summer flounder locations was evaluated using a two-sample *t*-test in which $\log_e$(CPUE + 1) was the response variable and trawl designation (productive or unproductive) was the explanatory variable. The size distribution of summer flounder captured in each tow was compared by 5-cm length-class using a Kolmogorov–Smirnov test (Conover 1971). No statistical analyses were performed to link fish observations on underwater video with microhabitat observations because only seven summer flounder were encountered in the 1,030 video image frames analyzed, and all were observed in the same habitat (sand).

We modeled the relationship between summer flounder CPUE in trawls and measured habitat variables by fitting a set of generalized linear models

TABLE 1.—Habitat characteristics of the benthic substrate measured by underwater video imagery at points along trawl paths used to determine summer flounder abundance in Maryland and Rhode Island. All variables had a binary response (e.g., yes or no) except those indicated as requiring counts.

Variable type	Variable or subvariable	Description
Physical	Bedforms	Were bedforms present? If yes, then subvariables were measured.
	Bedform size	Was the local bedform relief $>$ 30 cm in wavelength?[a]
	Bedform shape	Was the local bedform asymmetric?[a]
	Bedform ripples	Were bedform ripples present?[a]
	Bedform sharpness	Was the bedform crest sharp?[a]
	Sediment	Did the sample consist entirely of coarse sand or finer sediment ($\leq$1 mm)?[b]
Biological and biogenic	Shell hash (5%)	Was $>$ 5% of the area occupied by shell fragments?[a]
	Shell hash (25%)	Was >25% of the area occupied by shell fragments?
	Whole shells	Were whole shells present?[a]
	Tubes	Number of tubes present (*Diopatra*, etc.)
	Burrows	Number of burrows present
	Biogenics	Number of burrows, tubes, feeding pits, or other sessile fauna present

[a] These variables were tested but do not appear in the final model results because their Akaike weights were less than 0.01, indicating a lack of support.

[b] Substrate particle sizes were initially categorized as silt or clay, fine sand, medium sand, coarse sand (<1 mm), granule (1–4 mm), pebble (4–64 mm), or cobble (64–256 mm), but categories were aggregated to create a binary variable because most samples (81%) consisted entirely of sand, and larger particles occurred only rarely.

and using a model selection procedure to determine which habitat variables were the best predictors of summer flounder abundance. Although multiple points were sampled along a trawl path using the underwater video, summer flounder were captured at unknown positions during the trawl. This allowed for only a single CPUE response for each trawl. Therefore, habitat variables measured at individual points along a trawl path were consolidated into a single mean or proportion for the trawl. Variables were reduced by taking the proportion of individual samples for variables that were binary or the mean for variables that were counts (Table 1). For example, if 10 points were sampled along a trawl path and 8 of these were observed to have bedforms (uneven topography resulting from movement of sediment by current), then the bedform predictor variable had a value of 0.8 for that trawl.

The proportions or means of habitat variables associated with trawls were tested for relations with summer flounder abundance by fitting a set of generalized linear models with $\log_e(\mathrm{CPUE} + 1)$ as the dependent variable and one or more habitat variables as predictors. We evaluated the relative weight of evidence for each model using Akaike's information criterion corrected for small sample bias (AIC_c; Hurvich and Tsai 1989; Burnham and Anderson 2002). The AIC_c evaluates the weight of evidence for each model relative to other models in the set. Rankings are based on model fits as measured by the log-likelihood and penalized for complexity as measured by the number of parameters estimated. The relative evidence for a model can be summarized by its Akaike weight (w_i), a proportion summing to 1.0 over all models in the set. Model-averaged means and associated 95% confidence intervals (CIs) were calculated for all habitat predictors in a set of models to judge their unconditional effect sizes; estimates of the effect of each habitat predictor on summer flounder abundance were averages that were weighted by the relative amount of support for each model. The weighted estimates were therefore more likely to reflect the true magnitude of underlying effects than would estimates conditional on a single model (Burnham and Anderson 2002).

We developed a set of models to link habitat variables to EFH interactively because there were a large number of variables and possible interactions, and the analysis emphasized power to detect relationships rather than minimizing type II error (i.e., incorrectly rejecting the null hypothesis). First, models were individually fitted with an intercept for each variable listed in Table 1. The bedform variable was fitted with an intercept alone, and then four additional models were fitted in which the hierarchical bedform descriptive variables (bedform size, shape, and sharpness) were nested within the bedform variable. A limited number of higher-order models were fitted using variables that held a w_i of 10% or greater for the set of runs on individual variables. In practice, only the sediment and burrows variables had a w_i value greater than 10%, so two additional models were run: (1) a model with sediment, burrows, and an intercept; and (2) a model with sediment, burrows, an intercept, and a sediment × burrows interaction. Because the interactive approach taken may have led to overfitting of models

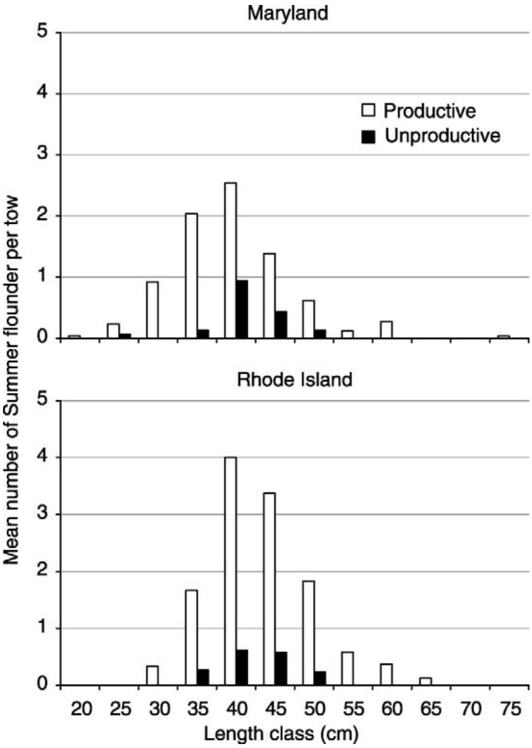

FIGURE 3.—Mean number of summer flounder (total catch = 615) per 5-cm length-class captured in trawls conducted at locations designated by commercial fishers as being productive or unproductive for this species in Maryland (upper panel; $N = 56$ trawls) and Rhode Island (lower panel; $N = 50$ trawls) .

and overestimates of precision (as reflected in 95% CIs), we considered models obtained from this procedure to be preliminary and subject to further investigation using additional data. However, this approach was consistent with the idea that the survey was designed to identify habitat–CPUE correlations that would require additional experimental work to verify causal relationships (Stephens et al. 2005).

The effects of water characteristics on summer flounder abundance were tested using single analyses of variance with $\log_e$(CPUE + 1) as the dependent variable and temperature, dissolved oxygen, and salinity as predictors. These variables were not included in the main analysis because they were incidentally measured only once at the end of each trawl, as described above.

Results

Fishers in both Maryland and Rhode Island were effective at identifying productive and unproductive locations within the study areas, as indicated by summer flounder capture rates (Figures 1B, 2B). In Maryland, the mean summer flounder catch was about 6.5 times greater in productive locations (7.9 fish/1,000 m) than in unproductive locations (1.2 fish/1,000 m). The mean difference of 1.22 log-transformed units was statistically significant ($\log_e$[CPUE + 1]: 95% CI = 0.89–1.54; $t = 7.55$; df = 53; $P \leq 0.001$). In Rhode Island, mean summer flounder catch was about 4.7 times greater in productive locations (6.3 fish/1,000 m) than in unproductive locations (1.3 fish/1,000 m). The mean difference of 1.35 log-transformed units was also statistically significant ($\log_e$[CPUE + 1]: 95% CI = 0.98–1.73; $t = 7.35$; df = 44; $P \leq 0.001$). For each size-class of summer flounder, catch was greater in productive locations than in unproductive locations, but the distribution of sizes was generally similar between location types (Maryland: $D = 0.63$, $P = 0.09$, $N = 56$ tows; Rhode Island: $D = 0.57$, $P = 0.20$, $N = 50$ tows; total summer flounder catch = 615 fish). An exception was that relatively large (>55-cm) summer flounder were only captured in productive locations in both Maryland and Rhode Island (Figure 3). Several other species also were captured more frequently in productive locations than in unproductive locations, or vice versa (Table A.1).

Relative summer flounder abundance as measured by the CPUE was generally related to mean depth of trawls. Most tows with high summer flounder catch rates occurred in depths of 10–20 m (Figures 1C, 2C), but both high and low catches occurred within that range. In Maryland, depths of 10–20 m were generally located at the bottom of troughs between shoals and represented some of the deepest habitat available. In Rhode Island, most of the substrate in the 10–20-m depth range was located near the shoreline, and much of the study area consisted of deeper water. Fishers correctly identified most of the unproductive locations in both states even when trawls were located in the 10–20-m depth range. In Maryland, such trawls occurred in the easternmost unproductive location (Figure 1A–C). In Rhode Island, such trawls occurred in the two southernmost unproductive locations (Figure 2A–C) near Block Island.

The bottom substrate sampled with underwater video was relatively heterogeneous in both states and was dominated by sediment that was less than or equal to 1 mm in diameter (Figures 1D, 2D). Consequently, the benthic habitat was similar between productive and unproductive locations. For example, 75% (SE = 2%) of the total trawls in productive locations in Maryland occurred over fine sand with no shells or cobbles, as compared with 83% (SE = 3%) of trawls in unproductive locations. In Rhode Island, 82% (SE = 3%) of the trawls in productive locations were on fine sand, and 81% (SE = 3%) of trawls in unproductive

TABLE 2.—Models used to compare summer flounder abundance (log-transformed catch per unit effort) along trawl paths with habitat variables measured using underwater video imagery in Maryland and Rhode Island. All models included an intercept. The value of the maximized log-likelihood function (log L), number of parameters (k) estimated in the model (including the intercept and mean square error), Akaike's information criterion corrected for small sample size (AIC_c), difference (Δ_i) between the model with the lowest AIC_c and the given model, and Akaike weight (w_i), indicating support for each model relative to the other models, are given.

Model	Log L	k	AIC_c	Δ_i	w_i
All variables listed + intercept (no interactions)	−97.023	9	214.545	0.000	0.422
Sediment[a] + burrows	−103.431	4	215.382	0.837	0.278
Sediment + burrows + sediment × burrows	−102.938	5	216.666	2.121	0.146
Sediment	−105.245	3	216.798	2.253	0.137
Burrows	−108.027	3	222.347	7.802	0.009
Tubes	−108.916	3	224.124	9.578	0.004
Biogenic structure[b]	−109.436	3	225.165	10.620	0.002
Bedforms	−109.485	3	225.262	10.716	0.002
Shell hash (25–75%)[c]	−109.506	3	225.304	10.759	0.002
Intercept only	−137.527	2	279.170	64.624	<0.001
Study site (Maryland or Rhode Island; block)	−137.431	3	281.098	66.553	<0.001

[a] Proportion of samples that were completely composed of course sand or finer sediment ($\leq$1 mm).

[b] Biogenic structure was the presence of burrows, tubes, or other sessile life forms.

[c] Proportion of samples where shell hash covered 25–75% of the area.

locations were on fine sand. The 95% CIs for differences in the proportion of sandy habitat in productive versus unproductive locations overlapped zero, and thus the hypothesis of equal amount of sandy habitat between the locations could not be rejected at the 0.05 level (Schenker and Gentleman 2001). We observed a total of seven summer flounder in both study areas in the video samples. All were located in substrate composed of 100% fine sand, and there were no other fish or megafauna in the areas where these seven fish were observed.

Benthic habitat variables measured using the underwater video yielded poor predictions of summer flounder CPUE. Summer flounder catch was best predicted by a model that included two variables: (1) proportion of samples that were composed completely of sand and (2) mean number of burrows per sample (Table 2). Two other models were plausible, as indicated by w_i of about 0.25. The first included the same variables as the best model plus an interaction term. The second consisted of sediment only (and an intercept). However, even for the best model, the adjusted R^2 was only 0.02, indicating that the model had almost no predictive ability. Furthermore, 95% CIs for all model-averaged parameter estimates were nearly centered on zero (Table 3), indicating that no benthic substrate factor included in our analysis consistently explained CPUE of summer flounder in trawls.

No significant relations existed between $\log_e$(CPUE) and temperature ($P = 0.442$; range = 12.1–19.3°C), dissolved oxygen ($P = 0.743$; range = 3.2–8.6 mg/L), or salinity ($P = 0.601$; range = 32.3–40.4‰; $N = 106$ for all measurements).

Discussion

In our study, fishers correctly discriminated between locations of high and low fishing productivity, indicating the existence of localized areas with distinct physical attributes that attract summer flounder predictably through some direct or indirect means. This result has implications for both the management of summer flounder and the use of fishers' knowledge for EFH-related research.

For management, this result suggests that if one or more important features of the habitat in these locations can be identified, the areas can be protected and possibly manipulated to benefit summer flounder. Abundance was not related to features of the substrate

TABLE 3.—Model-averaged estimates of effect size and approximate 95% confidence limits for variables measured by underwater video imagery and used to predict summer flounder abundance along trawl paths in Maryland and Rhode Island (study sites). All confidence intervals intersected zero (i.e., no effect), indicating that all variables were poor predictors of abundance. Estimates were calculated using all models in Table 2 and included a zero for each variable that was absent from a particular model (Burnham and Anderson 2002).

Variable	Mean effect size estimate	95% confidence limits	
		Lower	Upper
Sediment	−0.112	−1.380	1.156
Burrows	−0.016	−0.679	0.647
Tubes	−0.009	−0.560	0.542
Biogenic structure	0.012	−0.525	0.549
Bedforms	0.071	−1.123	1.264
Shell hash (25–75%)	0.040	−1.070	1.150
Study site (block)	0.058	−0.992	1.107

measured in this study. We hypothesized that such a relation might exist because this species is strongly associated with the benthic zone and thus is likely to prefer measurable habitat characteristics of the substrate. However, the benthic habitat requirements of adult fish generally become less specific as they mature and migrate (Sullivan et al. 2000). Juvenile fish frequently require specific meso- and microscale habitats (Sullivan et al. 2000), and their abundance has been linked to benthic habitat variables using remote sensing techniques similar to those described here (Diaz et al. 2003). In contrast, the distribution of larger adult fish often is related to hydrographic conditions, spatial dynamics of the population, and community interactions (Stoner 2003). The distribution of summer flounder was probably controlled by one or more of these unmeasured factors in our study. The distribution of other species with respect to productive and unproductive summer flounder fishing grounds (Table A.1) suggests that habitat could affect summer flounder indirectly through biological interactions such as predation and competition. The homogeneity of the substrate in both study sites also indicates that summer flounder distribution was affected by localized features other than bottom substrate. Sand overwhelmingly predominated in both productive and unproductive locations and thus could not have caused the observed differences in fishing productivity.

The result that summer flounder were located in fine sand agrees with published literature linking flatfish in general (Gibson 1997), and juvenile summer flounder in particular (reviewed by Packer and Hoff 1999), to sandy, soft-bottom habitats. Likewise, all seven summer flounder observed directly by underwater video in our study occupied fine sand. However, we cannot rule out the possibility that summer flounder captured in trawls occupied small areas with different substrates. This is because other types of habitat were probably available to summer flounder somewhere within the length of each tow, even if a particular habitat did not predominate in our video samples. Such information is lost by coupling trawl data with video observations. Lathrop et al. (2006) noted a similar problem in coupling bottom trawl surveys conducted by NOAA with seafloor mapping of the New York Bight based on sidescan sonar and direct sampling of the sediment. They did not find significant associations between catch rates of adult summer flounder or adult silver hakes *Merluccius bilinearis* and bottom sediment type; however, because trawl tows were long (3 nautical miles) and precise fish locations were unknown, Lathrop et al. (2006) could not preclude the possibility that such associations existed.

The small fish sample size obtained when using remote sensing methods is a common problem, so remote-sensing data often are paired with trawling to increase the number of fish observations, as was done here (Auster et al. 1995). Our results demonstrate that coupling methods with different spatial resolutions may represent a trade-off between obtaining a sufficient sample size and sufficient measurement precision. This could be a problem if summer flounder selected patchy features of the substrate that were spatially rare. For example, Lascara (1981; cited in Packer and Hoff 1999) found that summer flounder selected sandy substrates adjacent to patches of eelgrass *Zostera marina*, presumably for concealment in the sand but also for easy ambush of prey located in the eelgrass. If these types of features occurred so rarely that they were not detected in video samples, we could not have identified them.

Depth was the best predictor of summer flounder distribution in our study. Most summer flounder were captured between 10 and 20 m (Figures 1C, 2C). This result agrees closely with data reported elsewhere in New England and the Middle Atlantic Bight. Most adult summer flounder captured in fishery-independent surveys between 1963 and 1997 were in 10–20-m depths during summer (Packer et al. 1999). Summer flounder may select this range of depths because water temperatures are most appropriate for feeding (Packer and Hoff 1999), although temperatures measured at the end of trawls did not explain fish distribution well in this study. Summer flounder are commonly captured on the continental shelf and in estuaries (juveniles and adults) during summer but migrate offshore into much deeper water during winter and spring (Packer and Hoff 1999; Packer et al. 1999). Participating fishers in our study also stated that they would not have fished within the study areas during winter because few summer flounder are present. Anthropogenic activities that are not destructive to features that are used by summer flounder during summer could probably be conducted during winter or spring in the nearshore productive zone without greatly affecting adult stocks. The seasonality of summer flounder nearshore abundance also underscores the fact that several habitats may have to be managed to protect a species throughout its migratory period and in all life stages (Langton et al. 1996; Stoner 2003).

The expertise of fishers has often been underutilized in designing and interpreting fisheries studies (Pederson and Hall-Arber 1999; Ames 2001) but is increasingly being called upon to develop and carry out all aspects of research on managed species (Haggan et al. 2001; National Research Council 2004). This study demonstrates that fishers are particularly qualified to assist in designing surveys to capture fish across a gradient of abundances, not only because they are able to efficiently stratify study areas but also because their knowledge is partly the product of repeated historical sampling. Because of this repeatability, the evidence is stronger that observed differences in abundance are the result of habitat features rather than patchiness in distribution or sampling variation. We are more confident that the observed spatial patterns of fish capture are consistent with a long-term historical pattern than we would have been if trawling locations had been selected at random.

One limitation of the study is that only two fishers were used, and the extent to which their performance can be generalized is unknown. The fishers depended on the fishery for livelihood, and each had over 20 years of experience in fishery participation. Their success at predicting productive fishing locations indicates that this level of knowledge and experience was appropriate for the study. However, we cannot assess how representative they are of fishers in general or how much experience is required to obtain their level of proficiency. Fisheries in both states were limited to a small number of vessels that actively fished in the same places during the season, and fishers frequently contacted each other regarding harvest and location of summer flounder (H.W.S., personal observation). Fishers may have brought a collective knowledge of the fleet to the study, in addition to their personal knowledge of summer flounder distribution.

Fishers identified productive locations for summer flounder that had appropriate depths and one or more unmeasured factors in this study. In Maryland, fishers target summer flounder in troughs between shoals during the summer (J. Eustler, commercial fisherman, personal communication). However, similar ridge-and-swale habitat was rare in the Rhode Island study site. This result demonstrates that fishers identify habitat characteristics that are proxies for other variables rather than features that affect distribution directly. The presence of troughs is therefore not required by summer flounder but probably coincides with other factors that attract them. In Rhode Island, fishers targeted locations in the preferred depth range except for the location around Block Island, which was predicted and observed to be unproductive. This result demonstrates that appropriate depth alone did not attract summer flounder; one or more unmeasured factors also affected their distribution. As consequence of their focus on productivity at specific locations, fishers may be able to provide more information related to EFH than they are explicitly asked for. For example, distributions of the windowpane and other species were similar to those of adult summer flounder in this study (Table A.1), suggesting that habitat features attracting summer flounder during the summer may also be important for a larger community.

Previous literature has reported that fishers are able to identify relatively large areas or general features where fishing is productive (e.g., Bergmann et al. 2005), but we are unaware of other studies in which fishers have delineated productive fishing grounds with such specificity. Although our analysis of the substrate yielded a negative result, these small locations provide a manageable opportunity to identify possible characteristics of EFH using this type of observational study. More importantly, such locations could be used to test causal links between EFH characteristics and vital rates of managed species. Obtaining this type of information from fishers may be the only way to efficiently study EFH requirements for the large number of managed species that each have potentially different needs among life stages, seasons, regions, and migrational periods.

Acknowledgments

This project was funded by the Cooperative Research Partners Initiative of the NOAA–Fisheries Northeast Regional Office under Contract EA133F-03-CN-0048. We thank Jeff Eustler of the FV *Tony and Jan* and Christopher Brown and Dean West of the FV *Granville Davis* and their crews for providing expert knowledge of summer flounder distribution and assistance with collecting fish. We are grateful to Captain Dean from North Star Marine for his cooperation and assistance with collection of underwater imagery in Maryland and to Michael Marchetti and the crew of the FV *Captain Roberts* for assisting with the collection of underwater imagery in Rhode Island. We also thank April Valliere of the Rhode Island Division of Fish and Wildlife, Jamestown, for her assistance in planning data collection, and two anonymous reviewers for constructive comments that improved this manuscript.

References

Ames, T. 2001. Putting fishermen's knowledge to work: the promise and pitfalls. Pages 184–188 *in* N. Haggan, C. Brignall, and L. Wood, editors. Putting fishers' knowledge to work. University of British Columbia, Vancouver.

Auster, P. J., R. J. Malatesta, and S. C. LaRosa. 1995. Patterns of microhabitat utilization by mobile megafauna on the southern New England (USA) continental shelf and slope. Marine Ecology Progress Series 127:77–85.

Bergmann, M., H. Hinz, R. E. Blyth, M. J. Kaiser, S. I. Rogers, and M. J. Armstrong. 2005. Combining scientific and fishers' knowledge to identify possible groundfish essential fish habitats. Pages 265–276 *in* P. W. Barnes and J. P. Thomas, editors. Benthic habitats and the effects of fishing. American Fisheries Society, Symposium 41, Bethesda, Maryland.

Burnham, K. P., and D. R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach, 2nd edition. Springer-Verlag, New York.

Coen, L. D., M. W. Luckenbach, and D. L. Breitburg. 1999. The role of oyster reefs as essential fish habitat: a review of current knowledge and some new perspectives. Pages 421–437 *in* L. R. Benaka, editor. Fish habitat: essential fish habitat and rehabilitation. American Fisheries Society, Symposium 22, Bethesda, Maryland.

Conover, W. J. 1971. Practical nonparametric statistics. Wiley, New York.

Diaz, R. J., G. R. Cutter, Jr., and K. W. Able. 2003. The importance of physical and biogenic structure to juvenile fishes on the shallow inner continental shelf. Estuaries 26:12–20.

Gibson, R. N. 1997. Behaviour and the distribution of flatfishes. Journal of Sea Research 37:241–256.

Haggan, N., C. Brignall, and L. Wood, editors. 2001. Putting fishers' knowledge to work. University of British Columbia, Vancouver. Available: www.fisheries.ubc.ca. (October 2005).

Hurvich, C. M., and C. L. Tsai. 1989. Regression and time series model selection in small samples. Biometrika 76:297–307.

Kraus, R. T., and J. A. Musick. 2001. A brief interpretation of summer flounder, *Paralichthys dentatus*, movements and stock structure with new tagging data on juveniles. U.S. National Marine Fisheries Service Marine Fisheries Review 6(3):1–6.

Langton, R. W., R. S. Steneck, V. Gotceitas, F. Juanes, and P. Lawton. 1996. The interface between fisheries research and habitat management. North American Journal of Fisheries Management 16:1–7.

Lascara, J. 1981. Fish predator–prey interactions in areas of eelgrass (*Zostera marina*). Master's thesis. College of William and Mary, Williamsburg, Virginia.

Lathrop, R. G., M. Cole, N. Senyk, and B. Butman. 2006. Seafloor habitat mapping of the New York Bight incorporating sidescan sonar data. Estuarine, Coastal and Shelf Science 68:221–230.

Magnuson–Stevens Fishery Conservation and Management Act. 1996. U.S. Code, volume 16, sections 1801–1812.

National Research Council. 2004. Cooperative research in the National Marine Fisheries Service. National Academy Press, Washington, D.C.

NGDC (National Geophysical Data Center). 2005. Coastal relief model: volume 1, U.S. northeast Atlantic coast; and volume 2, U.S. southeast Atlantic coast. CD-ROM. NGDC, Boulder, Colorado.

Packer, D. B., S. J. Griesbach, P. L. Berrien, C. A. Zetlin, D. L. Johnson, and W. W. Morse. 1999. Summer flounder, *Paralichthys dentatus*, life history and habitat characteristics. NOAA Technical Memorandum NMFS-NE-151.

Packer, D. B., and T. Hoff. 1999. Life history, habitat parameters, and essential habitat of mid-Atlantic summer flounder. Pages 76–92 *in* L. R. Benaka, editor. Fish habitat: essential fish habitat and rehabilitation. American Fisheries Society, Symposium 22, Bethesda, Maryland.

Pederson, J., and M. Hall-Arber. 1999. Fish habitat: a focus on New England fishermen's perspectives. Pages 150–177 *in* L. R. Benaka, editor. Fish habitat: essential fish habitat and rehabilitation. American Fisheries Society, Symposium 22, Bethesda, Maryland.

Reid, R. N., F. P. Almeida, and C. A. Zetlin. 1999. Fishery-independent surveys, data sources, and methods. NOAA Technical Memorandum NMFS-NE-122.

Schenker, N., and J. F. Gentleman. 2001. On judging the significance of differences by examining the overlap between confidence intervals. American Statistician 55:182–186.

Stephens, P. A., S. W. Buskirk, G. D. Hayward, and C. M. DelRio. 2005. Information theory and hypothesis testing: a call for pluralism. Journal of Applied Ecology 42:4–12.

Stoner, A. W. 2003. What constitutes essential nursery habitat for a marine species? A case study of habitat form and function for queen conch. Marine Ecology Progress Series 257:275–289.

Sullivan, M. C., R. K. Cowen, K. W. Able, and M. P. Fahay. 2000. Spatial scaling of recruitment in four continental shelf fishes. Marine Ecology Progress Series 207:141–154.

Appendix: Catch of All Species in Trawls Targeting Summer Flounder

TABLE A.1.—Mean catch per unit effort (CPUE; number/1,000 m) for each fish and invertebrate species captured in trawl surveys used to estimate summer flounder abundance, Maryland (MD) and Rhode Island (RI). Catch rates are reported for productive and unproductive summer flounder fishing areas, as predicted by commercial fishers.

Species	CPUE area		Proportion of catch in productive areas	Number captured	
	Productive	Unproductive		MD	RI
Atlantic torpedo *Torpedo nobiliana*	0.03	0.00	1.00	0	3
Crevalle jack *Caranx hippos*	0.01	0.00	1.00	0	1
Lookdown *Selene vomer*	0.01	0.00	1.00	0	1
Blueback herring *Alosa aestivalis*	0.15	0.00	1.00	0	11
American shad *Alosa sapidissima*	0.01	0.00	1.00	0	1
Atlantic herring *Clupea harengus*	0.13	0.00	1.00	0	10

TABLE A.1.—Continued.

Species	CPUE area		Proportion of catch in productive areas	Number captured	
	Productive	Unproductive		MD	RI
Fourspot flounder *Paralichthys oblongus*	0.10	0.00	1.00	0	7
Weakfish *Cynoscion regalis*	0.88	0.00	1.00	57	0
Northern kingfish *Menticirrhus saxatilis*	0.42	0.00	1.00	27	0
Dusky shark *Carcharhinus obscurus*	0.01	0.00	1.00	1	0
Smallmouth flounder *Etropus microstomus*	0.04	0.00	1.00	3	0
Sand tiger *Carcharias taurus*	0.01	0.00	1.00	1	0
Smooth butterfly ray *Gymnura micrura*	0.01	0.00	1.00	1	0
Butterfish *Peprilus triacanthus*	70.02	0.53	0.99	33	5,889
Spotted hake *Urophycis regia*	1.00	0.04	0.96	66	4
Horseshoe crab *Limulus polyphemus*	6.50	0.34	0.95	419	28
Moon snails *Polinices* spp.	0.17	0.01	0.92	3	11
Channeled whelk *Busycotypus canaliculatus*	1.99	0.18	0.92	76	79
Southern stingray *Dasyatis americana*	1.01	0.14	0.88	79	0
Windowpane *Scophthalmus aquosus*	1.54	0.27	0.85	65	70
Summer flounder *Paralichthys dentatus*	6.94	1.21	0.85	266	349
Atlantic rock crab *Cancer irroratus*	1.95	0.39	0.83	58	125
American lobster *Homarus americanus*	0.18	0.04	0.83	0	17
Portly spider crab *Libinia emarginata*	9.19	2.06	0.82	361	459
Tautog *Tautoga onitis*	1.01	0.32	0.76	0	106
Knobbed whelk *Busycon carica*	12.51	4.36	0.74	1,144	0
Squids *Cephalopoda* spp.	13.46	6.15	0.69	99	1,580
Winter skate *Leucoraja ocellata*	7.26	4.28	0.63	56	879
Right-handed hermit crabs *Paguridae* spp.	0.54	0.32	0.63	51	14
Starfishes Class Asteroidea	1.67	1.07	0.61	180	14
Winter flounder *Pseudopleuronectes americanus*	0.29	0.20	0.59	0	39
Striped searobin *Prionotus evolans*	1.08	0.75	0.59	77	64
Blue crab *Callinectes sapidus*	0.15	0.12	0.56	17	1
Atlantic angel shark *Squatina dumeril*	0.15	0.12	0.55	19	0
Bullnose ray *Myliobatis freminvillei*	1.28	1.12	0.53	166	0
Atlantic mackerel *Scomber scombrus*	0.53	0.48	0.53	0	86
Clearnose skate *Raja eglanteria*	74.79	76.81	0.49	10,703	4
Black sea bass *Centropristis striata*	0.25	0.39	0.39	3	50
Bluefish *Pomatomus saltatrix*	0.22	0.72	0.23	0	80
Scup *Stenotomus chrysops*	3.01	13.74	0.18	80	1,252
Roughtail stingray *Dasyatis centroura*	0.01	0.04	0.17	4	0
Northern stargazer *Astroscopus guttatus*	0.01	0.06	0.12	5	0
Striped bass *Morone saxatilis*	0.09	1.26	0.07	0	117
Little skate *Leucoraja erinacea*	0.06	0.95	0.06	0	92
Smooth dogfish *Mustelus canis*	0.40	6.68	0.06	38	546
Lady crab *Ovalipes ocellatus*	0.24	4.21	0.05	317	7
Blue runner *Caranx crysos*	0.30	5.98	0.05	0	573
Spiny dogfish *Squalus acanthias*	0.15	9.67	0.02	1	761
Northern searobin *Prionotus carolinus*	0.00	0.05	0.00	3	1
Gray triggerfish *Balistes capriscus*	0.00	0.03	0.00	2	0
Atlantic menhaden *Brevoortia tyrannus*	0.00	0.01	0.00	1	0
Northern pipefish *Syngnathus fuscus*	0.00	0.01	0.00	1	0
Northern puffer *Sphoeroides maculatus*	0.00	0.03	0.00	2	0
Coarsehand lady crab *Ovalipes stephensoni*	0.00	0.04	0.00	3	0