

Abstract—Bycatch studies have largely ignored population level effects on fish species of little commercial interest. Here we analyze bycatch of the lined seahorse (*Hippocampus erectus*) in the bait-shrimp trawl fishery in Hernando Beach, Florida, providing the first fisheries data for this species. Based on catch per unit of effort (CPUE), size, sex, and reproductive status of trawled *H. erectus*, 1) approximately 72,000 seahorses were caught annually by this fleet, from a population of unknown size, 2) trawling affected population cohorts differentially because of temporal and spatial variation in CPUE and population size, and 3) a greater proportion of females than males was removed in trawling. Our findings suggest that trawling may affect seahorse populations through direct mortality, social disruption, and habitat damage. However, the lack of specific abundance or catchability estimates for *H. erectus* means that the precise impact of trawling on this fish remains uncertain. This paper focuses attention on the need for research and monitoring of small fishes that are caught incidentally in nonselective gear.

Bycatch of lined seahorses (*Hippocampus erectus*) in a Gulf of Mexico shrimp trawl fishery

Julia K. Baum

Jessica J. Meeuwig

Amanda C. J. Vincent

Project Seahorse

Department of Biology

McGill University,

1205 Dr. Penfield Ave.

Montreal, Quebec, H3A 1B1, Canada

Present address (for J. K. Baum): Department of Biology

Dalhousie University

1355 Oxford St.

Halifax, Nova Scotia, B3H 4J1, Canada

E-mail address (for J. K. Baum): baum@mathstat.dal.ca

The incidental capture of marine organisms is now recognized as a serious problem in fisheries management and marine conservation (Alverson et al., 1994; IUCN, 1996; Alverson, 1997; Jennings and Kaiser, 1998; FAO, 1999). Shrimp trawl fisheries are the single greatest source of bycatch, accounting for 35% of the world's total bycatch (Alverson et al., 1994). Bycatch research has focused on marine megafauna, seabirds, and commercially important fish species (see as examples Polacheck, 1989; Graham, 1995; Weimerskirch et al., 1997; Julian and Beeson, 1998; Pikitch et al., 1998; Galloway and Cole, 1999; Diamond et al., 2000). The conservation impacts of bycatch for noncommercial fishes and invertebrate species remain largely unstudied (but see Chan and Liew, 1986; Pettovello, 1999; Milton, 2001). The few studies that have evaluated incidental capture of these species have focused on survival rates of individuals (Hill and Wassenberg, 1990, 2000; Kaiser and Spencer, 1995; Probert et al., 1997; Mensink et al., 2000) without addressing population level effects of bycatch. However, even species that comprise only a small portion of the bycatch in a fishery may experience significant impacts of incidental harvest on their population size and structure.

Seahorses are among those species inferred to be greatly affected by nonselective fishing gear, both because intense trawling often covers seahorse

habitat and because their life history traits likely render these fishes vulnerable to overexploitation (Vincent, 1996). Most studied seahorse species are strictly monogamous (i.e. sexually and socially), meaning that removal can disrupt pairs and may reduce reproductive output (e.g. Vincent, 1995; Vincent and Sadler, 1995; Kvarnemo et al., 2000; Perante et al., 2002). Obligatory parental care by males, combined with relatively low fecundity, may reduce the potential for population recovery from overexploitation, although potentially high survival of young may also offset this apparent cost. In addition, sparse distributions and low mobility suggest that seahorses will be slow to recolonize depleted areas (Perante et al., 2002; Vincent et al.¹).

Seahorses derived from bycatch appear to be contributing greatly to the large and growing international trade in these fishes (Vincent, 1996; Vincent and Perry²). Consumer demand for seahorses—both dried for traditional medicine and curiosity trades, and, less frequently, live for the aquarium trade—is very high (Vincent, 1996). Global demand for seahorses has surpassed supply and therefore trade has increased and expanded geographically

Manuscript approved for publication 2 June 2003 by Scientific Editor.

Manuscript received 26 June 2003 at NMFS Scientific Publications Office. Fish. Bull. 101:721–731 (2003).

¹ Vincent, A. C. J., K. L. Evans, and A. D. Marsden. 2003. Home range behaviour of the monogamous Australian seahorse, *Hippocampus whitei*. Manuscript in review.

(Vincent, 1996; Vincent and Perry²), placing populations around the world under greater pressure. Much of this market demand is met from retention of incidental landings in shrimp trawls. Where no market has yet developed, incidentally caught seahorses are discarded and the survival rate for these discarded seahorses is unknown.

Trade records and anecdotal evidence from other countries indicate that the United States has imported and exported considerable numbers of both live and dried seahorses in recent years (Vincent, 1996; Vincent and Perry²). In Florida, the primary source of live seahorses in the United States (Larkin and Degner, 2001), these fishes ranked as the seventh most economically important ornamental fish group from 1990 to 1998, and seahorse landings rose 184% during this period, whereas landings of each of the more valuable fish groups declined (Adams et al., 2001). Many seahorses in the United States are probably obtained from bycatch of the shrimp trawl fisheries that operate in known seahorse habitats along the Atlantic coast of the United States.

Our objective was to document bycatch of the lined seahorse (*Hippocampus erectus*) in a live-bait shrimp trawl fishery. This fish is often retained for the aquarium trade. We quantify number, sex, size, and reproductive status of trawl-caught seahorses and examine how these parameters vary temporally and spatially. We also comment on potential conservation concerns resulting from this fishery.

Materials and methods

We focused our study on the lined seahorse (*Hippocampus erectus*) because it was caught much more often than its sympatric congeners in the Gulf of Mexico—the longsnout seahorse (*H. reidi*) and the dwarf seahorse (*H. zosterae*). *Hippocampus erectus* is a large, deep-bodied seahorse (adult height 5.5 to 18.5 cm: Lourie et al., 1999) and has a geographic range that extends from southern Canada to Argentina. Most species of seahorse have short lifespans and low fecundity: *Hippocampus erectus* lives for about four years (Lourie et al., 1999) and has broods of about 100–1500 young (Teixeira and Musick, 2000). *Hippocampus erectus* is found in shallow waters and offshore to depths of over 70 m, primarily in mangroves and seagrass beds (Vari, 1982). Like many other seahorse species, *H. erectus* is listed as Vulnerable (A2cd) by the International Union for Conservation of Nature and Natural Resources (IUCN, 2002), based on suspected declines resulting from habitat degradation and exploitation. However, as is the case for many small fishes, there is little information known about the biology of *H. erectus*, and no fishery data exist for it.

Seahorse bycatch was assessed in the live-bait shrimp trawl fishery operating from Hernando Beach, Florida (Fig. 1). The fishery, using roller beam trawls, targets pink shrimp (*Penaeus duorarum*) at night in seagrass beds and relocates seasonally in Florida. Hernando Beach was cho-

sen as our study site because it is a moderate-size fishing port with 31 licensed trawlers and is active during the summer sampling period. Boats were equipped with trawls that had a slotted roller along the bottom of the frame, and stainless steel finger bars attached vertically, 5 cm apart along the length of the frame, to limit collection of benthic substratum and other debris (Berkeley et al., 1985). Trawls were towed from each side of the vessel in four configurations: 1) one trawl per side, each measuring either 3.66 m, 4.27 m, or 4.88 m in length, or 2) two trawls per side, each measuring 3.66 m in length. Net mesh sizes were 3.18–3.81 cm and the tail bag stretched mesh size was 2.54–3.18 cm. Trawls usually lasted between 30 and 60 minutes, and fishermen made multiple successive trawls in a night. Shrimp were culled from the catch and held live onboard in aerated holding tanks. Most bycatch was discarded overboard, although some fishermen retained certain species, including seahorses, for sale as aquarium fishes.

Bycatch sampling and data set description

Data on seahorse bycatch in the live-bait shrimp fishery were collected on 95 fishing nights, from June to August 1998 and from June to July 1999, using three methods: 1) we sampled bycatch onboard on 50 nights; 2) we recorded seahorse bycatch data onshore on 14 nights from fishers who retained seahorses to sell; and 3) we received data from fishermen on their seahorse catches (including location, time, number of trawls, and number of seahorses per trawl) on a total of 31 nights. Onboard sampling was semistratified in that we targeted our sampling to cover all lunar and tidal phases and a variety of areas. However, we were dependent on fishermen's decisions about the time and location of tows. We also collected anecdotal information from 14 experienced fishermen about seahorse catches over time.

During onboard sampling, we recorded the number of seahorses caught, start and end time of trawl, depth and location (Loran co-ordinates) of trawl, tidal and lunar phases, and presence or absence of all bycatch species, including biogenic habitat species. *Hippocampus erectus* found in the catch were placed in a container of surface water while measurements were made. They were then released, except when fishermen chose to retain them for sale. We measured, weighed, determined the sex, and recorded the life history stage, reproductive status, and any injury for each seahorse. Measurements were taken according to Lourie et al. (1999) and included standard length, defined as the length from the tip of the snout to the opercular ridge and from the opercular ridge to straightened tail tip. Seahorses that had lost tail rings were not included in the length analysis. Unless precluded by logistic constraints, wet weights were obtained onboard by using a 60-g Pesola spring scale and onshore by using a 200-g Ohaus electronic balance. Adult males were distinguished from females and juveniles by the presence of a brood pouch. The standard length of the smallest seahorse with a brood pouch (105.3 mm) was used as the division between adults and juveniles with the assumption that males and females matured at the same size. Such an assumption may overestimate the

² Vincent, A. C. J., and A. Perry (eds.). 2003. Global trade in seahorses. Manuscript in prep.

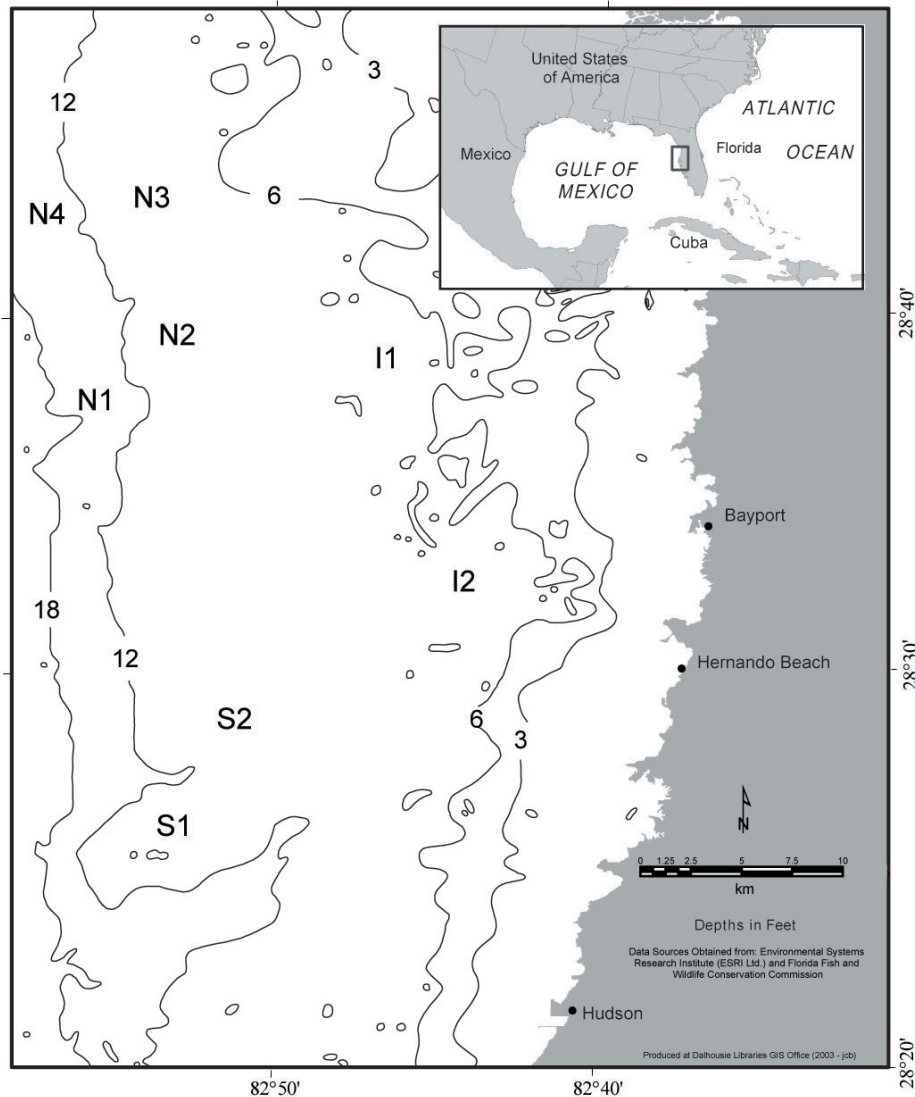


Figure 1

Map of the eastern Gulf of Mexico, showing the study site of Hernando Beach on the western coast of Florida. The shore is shaded; additional solid lines indicate depth contours in feet. Letter and number combinations (e.g. N3) represent fishing areas along the coast.

number of adult females because males that matured after that size would have been included in our analysis as females. We defined males as reproductively active if they were pregnant or had recently released young (as indicated by a loose pouch). Female reproductive state was not included in this analysis because it is difficult to determine reliably. We defined mortality to include seahorses already dead when the net was hauled and those that died onboard.

We evaluated temporal and spatial patterns in catch per unit of effort (CPUE), standard length, population structure, and reproductive status of the seahorse bycatch. Specifically, we tested 1) temporal effects of year, lunar and tidal phase, and 2) spatial effects of area and depth. In our estimates of seahorse CPUE, we used standard length instead of biomass because female weight changes with

egg hydration and male weight increases greatly when carrying embryos. Calculating CPUE per length (m) of roller beam trawl controlled for variation in gear size. The sampling unit was thus defined as the total or cumulative standard length of seahorses caught during each tow (per hour), per meter of trawl (per meter). Lunar phases were defined as continuous variables by converting lunar day to its angle, θ , based on a cycle of 29.5 days ($=360^\circ$), with new moon defined as $\theta = 0^\circ$. These angles were then converted to their cosine and sine functions for inclusion in linear regression (deBruyn and Meeuwig, 2001). Tides were semidiurnal in the Gulf of Mexico, ranging 1.3 m in tidal level in the study area. High and low tides were defined as each lasting two hours, with the remaining time classified as ebb or flood accordingly. Spatial effects were analyzed by dividing the total fishing ground into eight subareas ac-

cording to their position with respect to the depth contour and by identifying discrete geographical clusters of trawls (Fig. 1). We then compared variation among fishing areas within years for those areas with at least five observations (areas I1, I2, N1, N2, S1, S2 in 1998, and areas N1, N3 and N4 in 1999). Interannual spatial comparisons were not possible because there was little overlap in sampled areas between the two years.

Statistical analysis

We based CPUE estimates on all trawls ($n=445$). Statistical analyses evaluating temporal and spatial variation in seahorse bycatch included only those trawls with nonzero seahorse observations ($n=205$). The analysis required the data or their residuals to be normal; this was achieved by inverse hyperbolic sine transformations following exclusion of zeros (Zar, 1996). It should be noted that by excluding zeros we overestimated seahorse CPUE and we lost information about areas where seahorses were absent or rare. Our analyses should be interpreted as applying to locations where and times when seahorses were found in sufficient numbers as to be caught.

We examined the data using ANOVA, ANCOVA, linear regression and chi-square analyses (Zar, 1996; SYSTAT, version 7.0, SPSS Inc., Chicago, IL). All two-way and three-way ANOVAs included tests for interactions. We used a general linear model because the data were unbalanced. Interactions were removed from the model if they were found to be nonsignificant. Models were then rerun, followed by pairwise Tukey tests to indicate where significant differences occurred (Zar, 1996; SYSTAT, version 7). We report results for the final ANOVA only. The Yates correction was applied to 2×2 chi-squares (Zar, 1996). All significance levels were set to reject H_0 at $P < 0.05$ and all means are reported with standard errors.

Results

Bait shrimp fishermen trawled from 11 to 24 km offshore, between 1.8 and 6.4 m deep water (mean = 3.76 ± 0.87 m). Fishermen typically left port between 17:00 and 19:00 and spent 5.8 ± 0.23 h actively trawling per night ($n=50$ nights). Trawls lasted 40.2 ± 11.4 min ($n=445$) on average, and fishermen usually set 8 to 9 trawls per night. Distance trawled could not be estimated because we were unable to track trawler trajectories continuously and because they changed direction during the tows. The benthic habitat was composed primarily of seagrass (*Thalassia testudinum*) but also included algae, coral, and sponge. Bycatch included at least 118 species of fishes, invertebrates, and marine flora.

Catch per unit of effort

Hippocampus erectus was the only seahorse species commonly caught in this fishery. Almost half of the trawls (46%)

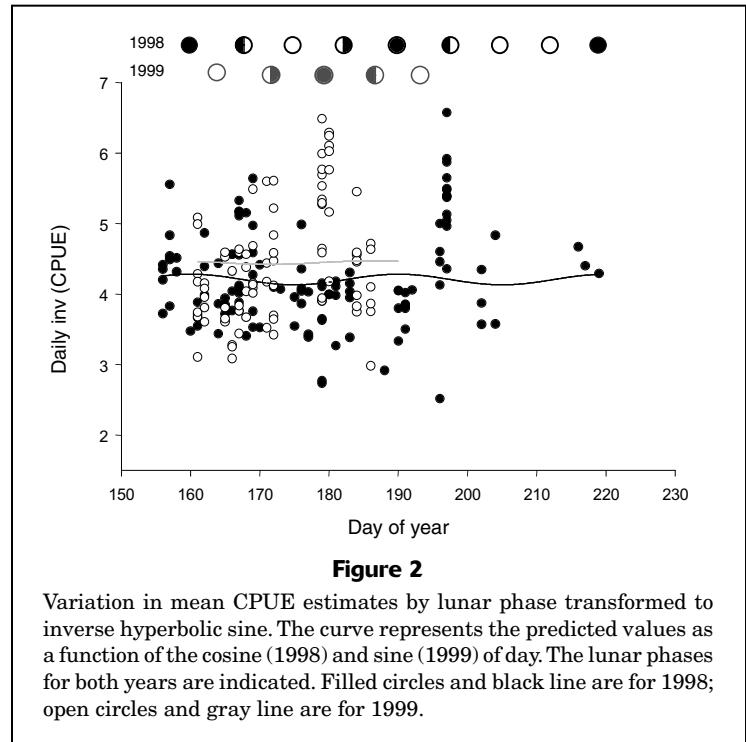


Figure 2
Variation in mean CPUE estimates by lunar phase transformed to inverse hyperbolic sine. The curve represents the predicted values as a function of the cosine (1998) and sine (1999) of day. The lunar phases for both years are indicated. Filled circles and black line are for 1998; open circles and gray line are for 1999.

caught *H. erectus*, and the number per trawl ranged from 0 to 16, whereas no *H. reidi* and only two of the much smaller species, *H. zosterae*, were caught. In total, 916 *H. erectus* were caught during the 95 documented fishing boat nights of the two fishing seasons, resulting in an overall mean of 9.64 seahorses per fishing boat night. Mean CPUE for *H. erectus* was 24.25 ± 2.15 mm/(h × m), about one and a half seahorses per hour per boat. If only trawls with seahorses were included, CPUE was 52.52 ± 3.80 mm/(h × m), or about three seahorses per hour per boat ($n=205$). Very high CPUE was recorded on three nights: 16 July 1998 (mean CPUE = 122.0 ± 22.5 mm/(h × m), $n=12$ trawls), 28 June 1999 (mean CPUE = 118.1 ± 24 mm/(h × m), $n=12$ trawls) and 30 June 1999 (mean CPUE = 154.9 ± 36.6 mm/(h × m), $n=8$ trawls). Bycatch is characterized by a high number of low catches and infrequent large catches. Because the large catches more likely reflect the spatial-temporal distribution characteristics of fish stocks rather than outliers of the data (Ortiz et al. 2000), we analyzed the entire dataset and then tested the robustness of our models by excluding these three nights in order to assess their influence on the CPUE patterns.

CPUE of nonzero trawls varied between years and with lunar phase (Table 1), but not with tidal phase ($P=0.15$). Trawls captured significantly more seahorses in 1999 than in 1998 ($P < 0.0005$). The effect of lunar phase varied between years: CPUE was highest on the lunar third quarter in 1998, but only weakly significant and had slightly higher CPUE on the full moon in 1999 (Fig. 2). The temporal variation in CPUE was largely driven by the three high CPUE nights, but the effect persisted when these were excluded (Table 1).

Table 1

General linear model of effects of year, lunar phase, and area on the CPUE (mm/(h×m) for nonzero *H. erectus* bycatch trawls in the Hernando Beach bait-shrimp trawl fishery.

Source	CPUE by trawl			CPUE by trawl (excluding CPUE of three highest nights)		
	<i>n</i>	<i>F</i>	<i>P</i>	<i>n</i>	<i>F</i>	<i>P</i>
Year	205	15.2	<0.0005	173	3.9	0.049
Lunar phase	205			173		
cos(θ)		19.1	<0.0005		4.1	0.045
sin(θ)		8.9	0.003			
1998 areas (I1, I2, N1, N2, S1, S2)	116	7.4	<0.0005	105	2.3	0.037
1999 areas (N1, N2, N3, N4)	87	8.3	<0.0005	68	0.3	0.85

In both years, there were significant differences in nonzero CPUE trawls among sites. In 1998, CPUE was significantly higher in S2 than in I2, N1, N2 and S1 (Fig. 3A, Table 1). In 1999, CPUE was significantly higher in area N1 than in areas N3 and N4 (Fig. 3B, Table 1). However, both of these spatial patterns, like the lunar patterns, were driven primarily by the high CPUE nights. Removing the three outliers left a significant difference in CPUE by area in 1998 only (Table 1). CPUE did not vary with depth of the fishing ground ($P=0.67$).

Size of seahorses

Mean standard length of adults (standard length ≥ 105.3 mm) was 139.5 ± 21.7 mm ($n=465$, range 105.3–202 mm) and mean weight was 11.6 ± 5.5 g ($n=232$, range 3–31 g). *Hippocampus erectus* was sexually dimorphic: males had a brood pouch and were significantly longer than females ($n=465$, $P<0.0005$, Table 2), and had a greater weight to standard length ratio, although this latter difference was relatively weak ($P=0.04$). Juveniles (standard length <105.3 mm) had a mean standard length of 83.3 ± 16.7 mm ($n=65$, range 41.4–105 mm) and a mean weight of 2.4 ± 1.0 g ($n=38$, range 0.9–4.0 g).

In adults, standard length varied by year ($n=425$, $F=7.1$, $P=0.008$) and by lunar phase ($n=425$, $\cos(\theta):F=5.4$, $P=0.02$, $\sin(\theta):F=7.7$, $P=0.006$). Mean standard length was greater in 1998 than in 1999 and highest on the new moon. In 1998 significantly larger adult seahorses were caught in areas I2 and S2 than in I1 and S1 ($n=229$, $F=13.7$, $P<0.0005$; Fig. 4). There was no effect of area in 1999 ($n=212$, $F=1.9$, $P=0.14$). Standard length was not related to depth or tide.

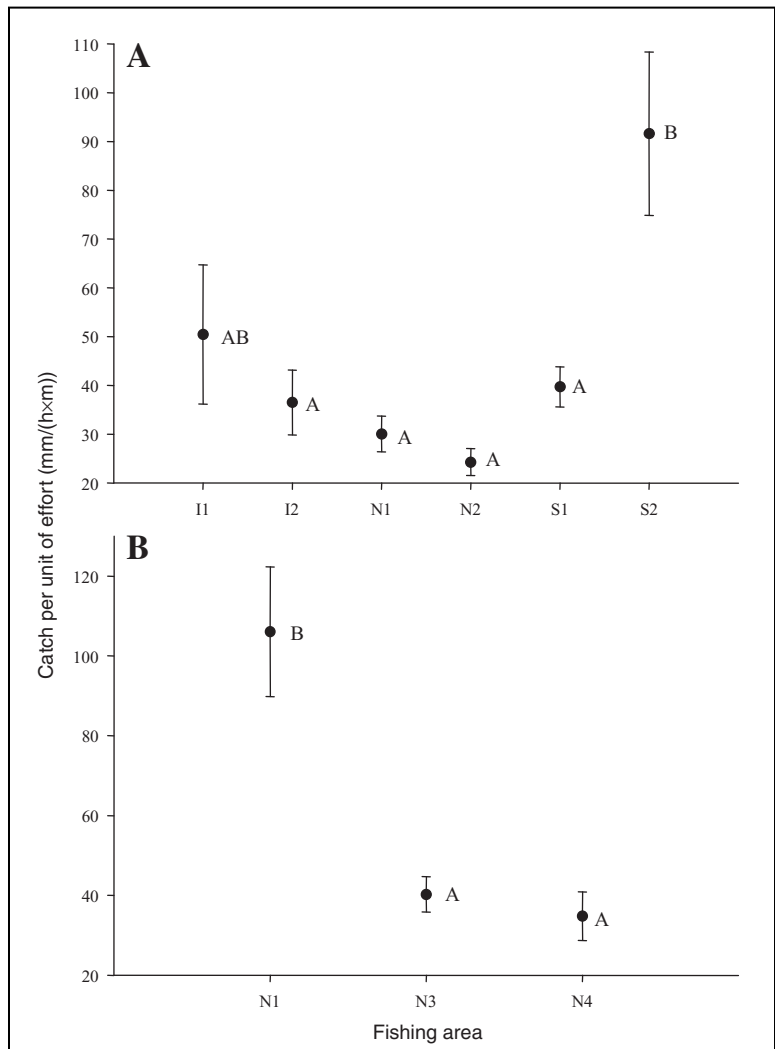
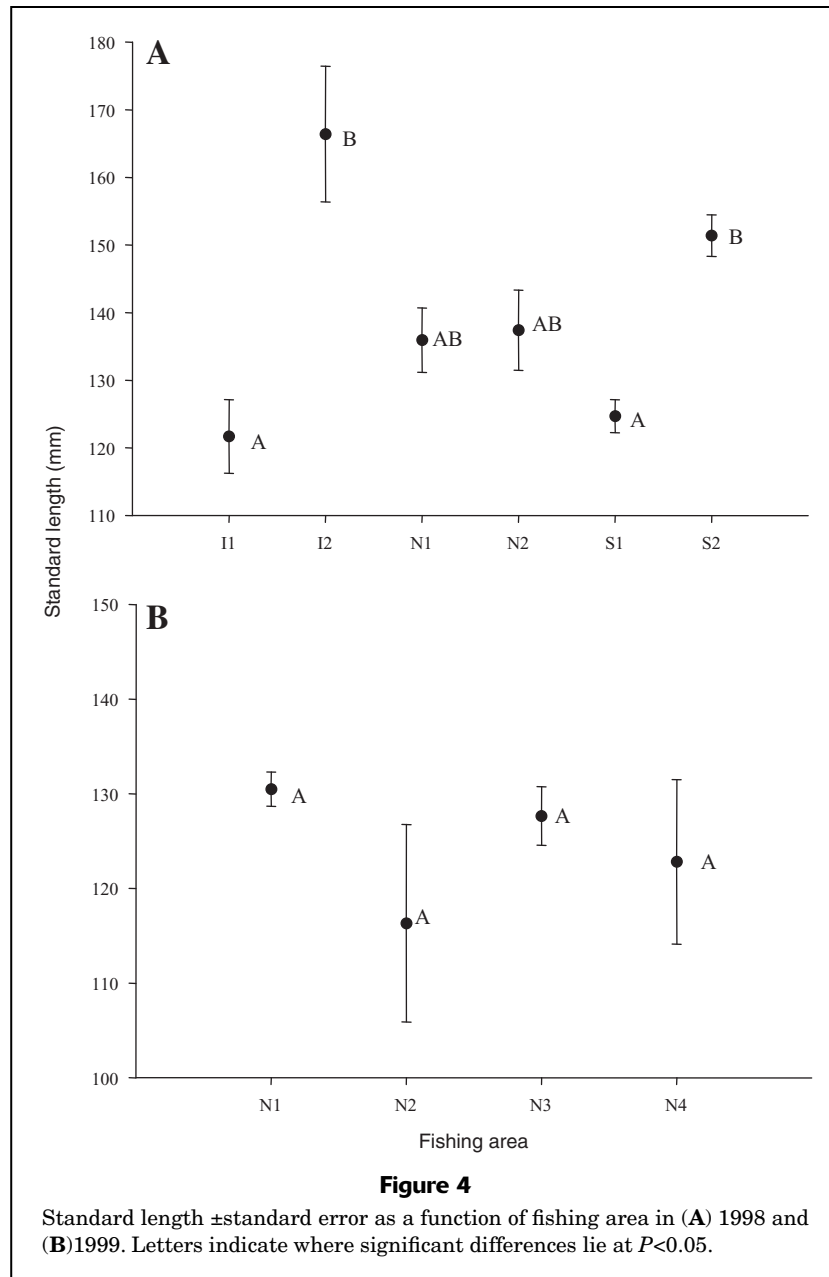


Figure 3

Catch per unit of effort (\pm standard error) as a function of fishing area in (A) 1998 and (B) 1999. Letters indicate where significant differences lie at $P<0.05$.



Population structure

We assessed population structure in terms of size cohorts, life history stages, sex ratio (males/total) and reproductive status. Standard-length frequency histograms suggested that the 1998 bycatch was composed of three year classes but the largest of these was not evident in 1999 (Fig. 5). Of 530 seahorses measured, 87.7% were considered to be adults. The ratio of juveniles to adults did not differ by year ($P > 0.10$) or tidal phase ($P > 0.90$). However, significantly more juveniles were caught during the first quarter than during other lunar phases (Table 3). Fishing area had a significant effect on size class, with the highest numbers of juveniles caught in N2 and N3 (Table 3).

The sex ratio (males as fraction of total) of 0.42 differed significantly from a 1:1 ratio ($\chi^2 = 19.56$, $df = 1$, $P < 0.001$). The sex ratio did not vary temporally or spatially (Table 3), but it did vary as a function of size class. There were proportionally more males in the larger size class (≥ 150 mm, 0.61) than in the smaller size class (< 150 mm, 0.30) ($\chi^2 = 14.95$, $df = 1$, $P < 0.005$).

About 25% of the male seahorses captured in 1998 were considered to be reproductively active, whereas fewer than 1% were reproductively active in 1999. Indeed, male reproductive activity was higher in 1998 than 1999 even after controlling for smaller male size in 1999 (Table 3). The proportion of reproductively active males did not vary with lunar or tidal phase but did vary significantly with area

Table 2

Descriptive statistics (sample size [*n*], mean, standard deviation [SD], minimum [min] and maximum [max]) for standard length and weight of female (F) and male (M) seahorses. *P* values and sample sizes (*n*) indicate results of *t*-tests evaluating sexual dimorphism in SL and weight.

	Sex	<i>n</i>	mean	SD	min	max
Standard length (mm)	M	201	146.1	21.9	105.3	200.5
	F	264	134.4	20.1	105.3	202.0
Weight (g)	M	105	12.5	5.0	6.0	27.0
	F	140	11.0	5.8	3.0	31.0

Table 3

Contingency tables on effects of year, lunar phase, and area on population structure of seahorses in the bycatch of the Hernando Beach bait shrimp trawl fishery. Yates corrections were applied to 2x2 contingency tables.

Source	Juveniles:Adults			Sex ratio			Reproductive state		
	df	χ^2	<i>P</i>	df	χ^2	<i>P</i>	df	χ^2	<i>P</i>
Year	1	2.46	>0.10	1	0.15	>0.50	1	27.89	<0.001
Lunar phase	3	11.00	<0.025	3	3.69	>0.25	3	7.80	>0.05
Area	3	8.84	<0.05	7	13.3	>0.05	2	21.64	<0.001

(Table 3); almost half of the reproductively active males were found in one area (S2), and 83% of them were caught on one of the three nights with very high CPUE (16 July 1998).

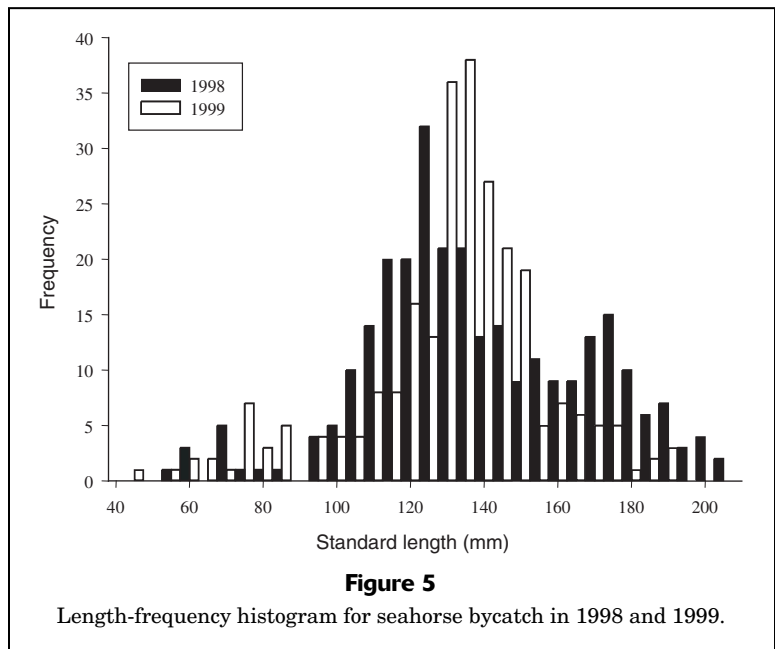
Mortality and injury

Fewer than 1% of seahorses died during tows or sorting, but 4.7% (*n*=28 of 588 seahorses) lost tail rings. The mean loss was 22 of the usual 36 tail rings (Lourie et al., 1999), or 61% of the tail (range=8–31 rings lost). Approximately 14% of the losses (*n*=4 of 588 seahorses) appeared to be the result of new wounds, probably caused by the focal trawl. There was no effect of year (*P*=0.25), sex (*P*=0.75), or reproductive status (*P*=0.75) on incidence of seahorse injury. Postrelease mortality is unknown.

Discussion

Direct effects of the trawl fishery on seahorse mortality

We estimate that this fleet catches almost 72,000 seahorses incidentally per annum, based on the mean CPUE and given that 31 boats fished approximately 240 nights per year. Most seahorses were returned to the wild in the Hernando Beach fishery, but this may not be the case in other live-bait shrimp trawl fleets in Florida (Vincent, pers.



obs.). We could not determine the potential fishing-induced mortality for the Hernandez Beach *H. erectus* population, even when all trawled seahorses were retained, because seahorse catchability in roller beam trawl gear is unknown and no studies have estimated *H. erectus* density in the wild. Focal behavioral studies on congeners similar in

size to *H. erectus* have found varied densities: *H. comes*, an exploited species associated with coral reefs in the tropics, had localized densities of 0.019/m² in a marine protected area, and much less elsewhere (Perante et al., 2002), and an unexploited species, *H. whitei*, had localized densities of 0.088–0.215/m² in a study area, and no seahorses were found over large adjacent areas (Vincent et al.¹). Our study also suggests very patchy distributions of *H. erectus* (54% of the trawls had no seahorses at all and the number of seahorses per trawl set ranged from 0 to 16).

Although variation in CPUE may reflect differential catchability by habitat, we suggest that in areas where seahorses were caught, temporal rather than spatial effects drove CPUE. It is difficult to make conclusions about variation in CPUE because data were unbalanced, in that the areas trawled differed between years and among lunar phases. However, analysis of variance on a subset of data for three sites (N1, N2, N3) on three lunar phases (1st quarter, full moon, 3rd quarter) for which we had data in both years ($n=149$ trawls), indicated that there was a strong effect of year, a weaker effect of lunar phase, and no effect of site. These results suggest that CPUE was mainly affected by temporal variation. Lunar patterns in CPUE as a result of fish behavior and ecology are common (e.g. Parrish, 1999). This would be consistent with observations for other species of seahorses: *H. comes* in the Philippines (Vincent et al.³) and *H. spinosissimus* and *H. trimaculatus* in Vietnam (Meeuwig et al.⁴) exhibited patterns in CPUE with respect to lunar phase, although these species were also distributed in patches in space.

Data from this study suggest that the *H. erectus* population was spatially structured. In 1999, the mean size of incidentally caught adult seahorses decreased, reflecting the absence of the largest size class of males and an increase in smaller females that year (Fig. 5). We attribute this difference to spatial structuring: the shallower areas (I2, S2) where the largest male and female seahorses were caught in 1998 were not fished during the 1999 sampling season. Most of the seahorse bycatch were adult *H. erectus*; the dearth of juvenile *H. erectus* (and dwarf seahorses, *H. zosterae*) in the trawls reflects low catchability or retention due to mesh size. Similar proportions of juvenile seahorses were caught over the two sampling seasons. The ratio of juveniles to adults appears to be temporally influenced (proportionally more juveniles were caught on new moons), but this variation probably also reflects spatial structuring because these trawls occurred primarily in deeper offshore areas (N2, N3) that were fished almost exclusively during this lunar phase. Perhaps *H. erectus* undergoes ontogenetic movement, between juvenile and adult life history stages, and adults maintain site fidelity. Spatial size structuring probably also occurs in other seahorse species, for the entire population and for adults alone (*H. comes*, Meeuwig⁵;

H. guttulatus, Curtis⁶). A better understanding of the spatial structuring of populations could allow for spatial control of fishing effort to minimize bycatch.

We found a consistent, female-biased sex ratio in the catch across the two years of our study, with only 42% males. This bias may reflect the sex ratio of the *H. erectus* population: a similar sex ratio (40% males) was found in a population of *H. erectus* in Chesapeake Bay, Virginia (Teixeira and Musick, 2000). Female-biased sex ratios have also been found in *H. zosterae* (33% males) when sampled by pushnet (Strawn, 1958), and in *H. abdominalis* studied underwater in Australia (Martin-Smith⁷). Many other wild populations of seahorses studied underwater, however, have documented equal numbers of males and females (*H. breviceps*: *H. comes*: Moreau and Vincent⁸; Perante et al., 1998; *H. reidi*: Dauwe, 1993; *H. whitei*: Vincent and Sadler, 1995). Sexual dimorphism in *H. erectus* was too slight to explain different catchability of the two sexes and would, in any case, have favored the capture of males. The disproportionate catch of females could have arisen from spatial segregation by sex; the greater catches of reproductively active males in shallower areas suggests that males may spend most of their time inshore of the trawled area. We also cannot discount the possibility that some seahorses classified as females may have been immature males, and the sex ratio in the population could in fact be 1:1.

The proportion of reproductively active seahorses in the bycatch was lower than expected, particularly in 1999. Our study occurred during summer, within the breeding season for the congeneric and sympatric *H. zosterae* in Florida (February to October; Strawn, 1958), and for *H. erectus* in Chesapeake Bay (May to October; Teixeira and Musick, 2000; Vincent, personal obs.). Males of all studied seahorse species were reproductively active almost continuously throughout the breeding season (Dauwe, 1993; Nijhoff, 1993; Vincent and Sadler, 1995; Perante et al., 2002), often remating the same day that they release their young (Vincent and Sadler, 1995). In our study, trawling may have occurred outside the primary breeding areas for male *H. erectus*, but catches of reproductively nonactive adult males during the breeding season also suggest that repeated trawling may have disrupted breeding in the population. A further indication of possible spatial structuring in the population (by reproductive status and size) is that almost half of the reproductively active males caught in 1998 were found in S2, the shallowest area; this area was not sampled in 1999 when few reproductively active males were found. Such spatial structuring offers the possibility of trawling outside the breeding area.

³ Vincent, A. C. J., J. J. Meeuwig, M. G. Pajaro, and N. C. Perante. Seahorse catches in the central Philippines: characteristics and conservation implications. Manuscript in prep.

⁴ Meeuwig, J. J., D. H. Hoang, T. S. Ky, S. D. Job, and A. C. J. Vincent. Bycatch landings of seahorses in central Vietnam. Manuscript in prep.

⁵ Meeuwig, J. J. Life history parameters of the exploited seahorse *Hippocampus comes*: a length based analysis. Manuscript in prep.

⁶ Curtis, J. 2002. Unpubl. data. Project Seahorse, Fisheries Center, The University of British Columbia, 2204 Main Mall, Vancouver, BC, V6T 1Z4, Canada.

⁷ Martin-Smith, K. 2002. Unpubl. data. Project Seahorse, Fisheries Center, The University of British Columbia, 2204 Main Mall, Vancouver, BC, V6T 1Z4, Canada.

⁸ Moreau, M.-A., and A. C. J. Vincent. 2000. Unpubl. data. Project Seahorse, Fisheries Center, The University of British Columbia, 2204 Main Mall, Vancouver, BC, V6T 1Z4, Canada.

Indirect effects of the trawl fishery on mortality

Direct immediate mortality from trawling and culling was rather low, probably in part because trawl sets were of very short duration in this live-bait fishery. More importantly, most *H. erectus* caught in the Hernando Beach fishery were returned to sea, rather than retained as in some other Florida trawl fisheries (Vincent, pers. obs.). Indirect impacts of the fishery may, however, be considerable.

Seahorses caught in trawls may experience high postrelease mortality. A study in the live-bait shrimp trawl fishery in Tampa Bay, Florida (Meyer et al., 1999), found that only one of four of the congeneric dwarf seahorse (*H. zosterae*) caught as bycatch were alive in the holding tank of seawater 36 hours after collection (Meyer⁹). Such tows lasted only 5 minutes (Meyer et al., 1999); therefore trawl-induced mortality could be greater in the Hernando Beach fishery (with trawls of 30–50 minutes), although *H. erectus* are larger and perhaps more robust than *H. zosterae*. Like other discarded bycatch, seahorses may also be subject to intense predation upon release. Predation on discarded fish has been observed on prawn trawlers in Australia (Hill and Wassenberg, 1990) and within the bait shrimp fishery of Tampa Bay (Meyer et al., 1999). Captains of bait-shrimp boats concurred that this is commonplace in the Hernando Beach fishery, and we frequently observed bottlenosed dolphins (*Tursiops truncatus*) and schools of ladyfish (*Elops saurus*) swimming alongside the boats, feeding on discarded bycatch.

Trawling may significantly disrupt seahorse populations, particularly if they are spatially structured, as the present study suggests. The disproportionate removal of females could reduce mating opportunities, especially if *H. erectus* is monogamous, as are most studied seahorse species (e.g. Vincent, 1995; Vincent and Sadler, 1995; Kvarnemo et al., 2000; Perante et al., 2002). Trawling, on account of repeated intrusion onto breeding grounds, could also disrupt courtship and negatively affect reproduction. In heavily exploited areas of the fishery where fishermen repeatedly trawl productive areas, seahorses may face cumulative stress. For example, tail injuries are likely a serious wound for seahorses, given that their tails are essential to grasp holdfasts and may play a key role in mating competition, as they do with *Hippocampus fuscus* (Vincent, 1994).

Benthic habitat degradation is another potential indirect effect of live-bait shrimp trawling on seahorses. Bottom-fishing gear can reduce habitat complexity by removing emergent epifauna, smoothing sedimentary bedforms and by removing structure-forming species such as corals and sponges (Hutchings, 1990; Auster et al., 1996; Auster and Langton, 1999; Thrush and Dayton, 2002). Roller beam trawls also affect habitat complexity by redistributing macroalgae and seagrass (Meyer et al., 1999). We estimated that seagrasses comprised between 50% and 80% of the volume of the catch for each trawling operation. Although roller beam trawls are assumed to have low impact on seagrass habitat (Tabb and Kenny, 1969; Meyer et al., 1999), the effects of long-term re-

petitive trawling have not been tested, and it is possible that species composition and abundance, including that of *H. erectus*, have been adversely affected (Watling and Norse, 1998).

Summary

Despite the relatively low direct mortality of seahorse per boat, the live-bait trawl fishery has the potential to affect seahorse populations, both directly and indirectly. The key question is whether the level of exploitation, and subsequent impacts, represents a conservation concern. Our evidence is inconclusive. Perhaps only the skewed sex ratio and low proportion of reproductively active males suggest a potential problem. However, fishermen have consistently reported that seahorse catch per boat has declined greatly over the past two decades in this area. Effects of trawling are also almost certainly greater in food shrimp trawl fisheries, which trawl with much larger gear for longer periods, and obtain substantially more bycatch, with higher mortality. Our analysis should thus be seen as a first step in identifying areas for which more information is needed, specifically estimating abundance and fishing mortality, and understanding spatial structuring in *H. erectus*.

This paper focuses attention on the need for research on and monitoring of small fishes that may be affected by non-selective fishing gear. Management responses to minimize bycatch have focused primarily on seabirds, sea turtles, and commercially important finfishes, but trawl fisheries may also have significant impacts on the many small marine organisms obtained as bycatch, even if they comprise only a small proportion of the bycatch. Bycatch excluder devices are unlikely to be effective in reducing incidental catches of these species. Temporal variation in CPUE and spatial population structuring, as observed in our present study for *H. erectus*, suggest that time-area closures may be a pragmatic solution for reducing incidental catch.

Acknowledgments

This paper is a contribution from Project Seahorse. We thank Jana Schulz for her assistance with fieldwork, Daniel and Patricia Mohr for their support during fieldwork, James Boxall for preparing the map, A. DeBruyn, L. Crowder, M. Kaiser, and an anonymous reviewer for providing helpful comments on an earlier draft of this manuscript. This study would not have been possible without the cooperation and support of many of the shrimp boat captains and crew in Hernando Beach. This research was funded through an NSERC summer undergraduate award to JKB, support from the Community Fund (UK) and Guylian Chocolates Belgium for JJM, and an NSERC operating grant to ACJV.

Literature cited

- Adams, C., S. Larkin, and D. Lee.
2001. Volume and value of marine ornamentals collected in Florida, 1990–98. *Aquar. Sci. Conserv.* 3(1–3):25–36.

⁹ Meyer, D. 1999. Personal commun. NOAA Center for Coastal Fisheries and Habitat Research, Beaufort Laboratory, 101 Pivers Island Road, Beaufort, NC 28516.

- Alverson, D. L.
1997. Global assessment of fisheries bycatch and discards: a summary overview. *In* Global trends: fisheries management (E. K. Pikitch, D. D. Huppert, and M. P. Sissenwine, eds.), 115–125 p. Am. Fish. Soc. Symp., Vol. 20.
- Alverson, D. L., M. H. Freeberg, S. A. Murawski, and J. G. Pope.
1994. A global assessment of fisheries bycatch and discards, 233 p. FAO Fish. Biol. Tech. Pap. 339. FAO, Rome.
- Auster, P. J., and R. W. Langton.
1999. The effects of fishing on fish habitat. *In* Fish habitat: essential fish habitat (EFH) and rehabilitation (L. Benaka, ed.), p. 150–187. Am. Fish. Soc. Rep. 22.
- Auster, P. J., R. J. Malatesta, R. W. Langton, L. Watling, P. C. Valentine, C. L. S. Donaldson, E. W. Langton, A. N. Shepard, and I. G. Babb.
1996. The impacts of mobile fishing gear on seafloor habitats in the Gulf of Maine (Northwest Atlantic): implications for conservation of fish populations. *Rev. Fish. Sci.* 4:185–202.
- Berkeley, S. A., D. W. Pybas, and W. L. Campos.
1985. Bait shrimp fishery of Biscayne Bay, 16 p. Fla. Sea Grant Ext. Prog. Tech. Pap. 40. Florida Sea Grant, Gainesville, FL.
- Chan, E. H., and H. C. Liew.
1986. Characteristics of an exploited tropical shallow-water demersal fish community in Malaysia. *In* Proceedings of the first Asian fisheries forum (J. L. Maclean, L. B. Dizon, and L. V. Hosillows, eds.), p. 349–352. Asian Fisheries Society, Manila, Philippines.
- Dauwe, B.
1993. Ecology of the seahorse *Hippocampus reidi* on the Bonaire coral reef (N.A.): habitat, reproduction and community interaction. M.S. thesis, 65 p. Rijksuniversiteit, Groningen, Netherlands.
- deBruyn, A. M. H., and J. J. Meeuwig.
2001. Detecting lunar cycles in marine ecology: periodic regression versus categorical ANOVA. *Mar. Ecol. Prog. Ser.* 214:307–310.
- Diamond, S. L., L. G. Cowell, and L. B. Crowder.
2000. Population effects of shrimp trawl bycatch on Atlantic croaker. *Can. J. Fish. Aquat. Sci.* 57(10):2010–2021.
- FAO (Food and Agriculture Organization of the United Nations).
1999. The state of world fisheries and aquaculture 1998, 112 p. FAO, Rome.
- Galloway, B. J., and J. G. Cole.
1999. Reduction of juvenile red snapper bycatch in the Gulf of Mexico shrimp trawl fishery. *N. Am. J. Fish. Manag.* 19(2):342–355.
- Graham, G. L.
1995. Finfish bycatch from the Southeastern shrimp fishery. *In* Solving bycatch: considerations for today and tomorrow, p. 115–119. Univ. Alaska Sea Grant College Program Report 96-03, Fairbanks, AK.
- Hill, B. J., and T. J. Wassenberg.
1990. Fate of discards from prawn trawlers in Torres Strait. *Aust. J. Mar. Freshw. Res.* 41:53–64.
2000. The probable fate of discards from prawn trawlers fishing near coral reefs. A study in the northern Great Barrier Reef, Australia. *Fish. Res.* 48(3):277–286.
- Hutchings, P.
1990. Review of the effects of trawling on macrobenthic epifaunal communities. *Aust. J. Mar. Freshw. Res.* 41:111–120.
- IUCN (International Union for Conservation of Nature and Natural Resources).
1996. World Conservation Congress, 1st session. Resolutions and recommendations. 1.16 Fisheries by-catch; Montreal, Canada, 14–23 October 1996. IUCN, Gland, Switzerland.
2002. 2002 IUCN red list of threatened species. IUCN, Gland, Switzerland and Cambridge, UK. <http://www.redlist.org/> [Accessed 21 January 2003].
- Jennings, S., and M. J. Kaiser.
1998. The effects of fishing on marine ecosystems. *Adv. Mar. Biol.* 34:201–352.
- Julian, F., and M. Beeson.
1998. Estimates of marine mammal, turtle and seabird mortality for two California gillnet fisheries: 1990–1995. *Fish. Bull.* 96:271–284.
- Kaiser, M. J., and B. E. Spencer.
1995. Survival of by-catch from a beam trawl. *Mar. Ecol. Prog. Ser.* 126:31–38.
- Kvarnemo, C., G. I. Moore, A. G. Jones, W. S. Nelson, and J. C. Avise.
2000. Monogamous pair bonds and mate switching in the Western Australian seahorse *Hippocampus subelongatus*. *J. Evol. Biol.* 13:882–888.
- Larkin, S. L., and R. L. Degner.
2001. The U.S. wholesale market for marine ornamentals. *Aquar. Sci. Conserv.* 3(1):13–24.
- Lourie, S. A., A. C. J. Vincent, and H. J. Hall.
1999. Seahorses: an identification guide to the world's species and their conservation, 214 p. Project Seahorse, London, UK.
- Mensink, B. P., C. V. Fischer, G. C. Cadee, M. Fonds, C. C. Ten Hallers-Tjabbes, and J. P. Boon.
2000. Shell damage and mortality in the common whelk *Buccinum undatum* caused by beam trawl fishery. *J. Sea Res.* 43(1):53–64.
- Meyer, D. L., M. S. Fonseca, P. L. Murphey, R. H. McMichael, Jr., M. M. Byerly, M. W. LaCroix, P. E. Witfield, and G. W. Thayer.
1999. Effects of live-bait shrimp trawling on seagrass beds and fish bycatch in Tampa Bay, Florida. *Fish. Bull.* 97:193–199.
- Milton, D.
2001. Assessing the susceptibility to fishing of populations of rare trawl bycatch: sea snakes caught by Australia's northern prawn fishery. *Biol. Conserv.* 101:281–290.
- Nijhoff, M.
1993. Reproductive cycle of the seahorse *Hippocampus reidi* on the Bonaire coral reef. M.S. thesis, 49 p. Rijksuniversiteit, Groningen, Netherlands.
- Ortiz, M., C. M. Legault, and N. M. Ehrhardt.
2000. An alternative method for estimating bycatch from the U.S. shrimp trawl fishery in the Gulf of Mexico, 1972–1995. *Fish. Bull.* 98:583–599.
- Parrish, J. K.
1999. Using behavior and ecology to exploit schooling fishes. *Environ. Biol. Fishes* 55:157–181.
- Perante, N. C., M. G. Pajaro, J. J. Meeuwig, and A. C. J. Vincent.
2002. Biology of *Hippocampus comes* in the central Philippines. *J. Fish Biol.* 60(4):821–837.
- Perante, N. C., A. C. J. Vincent, and M. G. Pajaro.
1998. Demographics of *Hippocampus comes* seahorses in Bohol, central Philippines. *In* Proceedings of the third international conference on the Marine Biology of the South China Sea; Hong Kong 1996, p. 439–448. Hong Kong Univ. Press, Hong Kong.
- Pettovello, A. D.
1999. By-catch in the Patagonian red shrimp (*Pleoticus muelleri*) fishery. *Mar. Freshw. Res.* 50:123–127.
- Pikitch, E. K., J. R. Wallace, E. A. Babcock, D. L. Erickson, M. Saelens, and G. Oddsson.
1998. Pacific halibut bycatch in the Washington, Oregon, and

- California groundfish and shrimp trawl fisheries. *N. Am. J. Fish. Manag.* 18:569–586.
- Polacheck, T.
1989. Harbour porpoises and the gillnet fishery: Incidental takes spur population studies. *Oceanus* 32:63–70.
- Probert, P. K., D. G. McKnight, and S. L. Grove.
1997. Benthic invertebrate bycatch from a deep-water trawl fishery, Chatham Rise, New Zealand. *Aquatic conservation: marine and freshwater ecosystems* 7(1):27–40.
- Strawn, K.
1958. Life history of the pygmy seahorse, *Hippocampus zosterae* Jordan and Gilbert, at Cedar Key, Florida. *Copeia* 1958:16–22.
- Tabb, D. C., and N. Kenny.
1969. A brief history of Florida's live bait shrimp fishery with description of fishing gear and methods. *FAO Fish. Rep.* 57:1119–1134.
- Teixeira, R. L., and J. A. Musick.
2000. Reproduction and food habits of the lined seahorse, *Hippocampus erectus* (Teleostei: Syngnathidae) of Chesapeake Bay, Virginia. *Rev. Bras. Biol.* 61(1):79–90.
- Thrush, S., and P. K. Dayton.
2002. Disturbance to marine benthic habitats by trawling and dredging: implications for marine benthic biodiversity. *Ann. Rev. Ecol. Syst.* 33:449–473.
- Vari, R. P.
1982. Fishes of the western North Atlantic, subfamily Hippocampinae. The seahorses, p. 173–189. *Sears Foundation for Marine Research Memoir*, vol. 1, Yale Univ., New Haven, CT.
- Vincent, A. C. J.
1994. Operational sex ratios in seahorses. *Behaviour* 128:153–167.
1995. A role for daily greetings in maintaining seahorse pair bonds. *Anim. Behav.* 49:258–260.
1996. The international trade in seahorses, vii + 163 p. *TRAFFIC International*, Cambridge, UK.
- Vincent, A. C. J., and L. M. Sadler.
1995. Faithful pair bonds in wild seahorses, *Hippocampus whitei*. *Anim. Behav.* 50:1557–1569.
- Watling, L., and E. A. Norse.
1998. Disturbance of the seabed by mobile fishing gear: a comparison to forest clear cutting. *Conserv. Biol.* 12(6):1180–1197.
- Weimerskirch, H., N. Brothers, and P. Jouventin.
1997. Population dynamics of wandering albatross *Diomedea exulans* and Amsterdam albatross *D. amsterdamensis* in the Indian Ocean and their relationships with long-line fisheries; conservation implications. *Biol. Conserv.* 79:257–270.
- Zar, J. H.
1996. *Biostatistical analysis*, 3rd ed., 662 p. Prentice Hall, Upper Saddle River, NJ.