Fish Aqua Sci 12(2), 138-151, 2009

KOSFAS FISHERIES AND AQUATIC SCIENCES
The Korean Society of Fisheries and Aquatic Science

Variations in Species Composition, Biomass, and Density in Shrimp Trawl Bycatch Across Seasons and Tidal Phases in Southern Korean Waters: Developing a Fisheries Risk Management Approach

Chul-Woong OH*, Sung Tae KIM[1] and Jong-Hun NA[2]
Department of Marine Biology, Pukyong National University, Busan 608-737, Korea
[1]National Fisheries Research and Development institute, Busan 619-902, Korea
[2]Korea Division of Marine Production System Management, Pukyong National University, Busan 608-737, Korea

We quantitatively investigated compositions of fish and invertebrate bycatch in Korean shrimp fisheries. We sampled shrimp trawl bycatch from 48 commercial trawls over 1 year. These samples contained 108 taxa from 50 families, with 60 fish taxa contributing 51.2% of the total biomass and 48 invertebrate taxa 48.8%. However, 86.32% of the total individual organism density comprised invertebrates, while individual fishes made up the remainder. Within the bycatch, two fish species varied in population size structure by season, suggesting recruitment is seasonal in these taxa. Overall general catch characteristics (total bycatch biomass and organism density) varied significantly by season and tide, and a significant interaction effect was observed (season×tide) on total density, but not on total biomass. The data collected will be used in designing a program of long-term bycatch monitoring.

Key words: Shrimp fishery, Bycatch, Commercial trawls, Size structure, Geoje Island

Introduction

Catches in commercial fisheries landings have been in decline since the 1980s (Watson and Pauly, 2001; FAO, 2002; Worm et al., 2005), leading to growing global concerns about the state of fish resources. According to the FAO, 75% of fisheries are fully exploited, overexploited, severely depleted, or in recovery (FAO, 2002). The effect of such over-exploitation on the marine ecosystem has come under increasing scrutiny in recent years. For a sustainable harvest of marine resources, many expert fisheries groups have suggested Ecosystem-Based Fishery Management (EBFM) as a possible solution for current problems (Garcia, 1994; Lauck et al., 1998; Myers and Mertz, 1998; Darcy and Matlock, 1999; Hilborn et al., 2001; Charles, 2002; Ludwig, 2002; McAllister and Kirchner, 2002; Rosenberg, 2002; Weeks and Parker 2002; Frank et al., 2005). EBFM has the potential to account for risks inherent in managing interacting populations in uncertain and changing environments (Botsford et al., 1997; Hofmann and Powell, 1998; Pikitch et al., 2004). At the same time, impetus is growing to shift policy focus from managing species independently to con-siderations of Ecological Risk Assessment for the Effects of Fishing (ERAEF; Giddings et al., 2002; Fleeger et al., 2003; Fletcher, 2005).

In the ERAEF approach, five general ecological components are evaluated: the target species; by-product and bycatch species; threatened, endangered, and protected species; habitat; and ecological communities. Changes in the abundance of bycatch and in fishing activities can have impacts on the trophic structure of marine communities and the functioning of marine ecosystems. Fisheries bycatch has also been implicated as an important factor in the decline of many marine populations, including Pacific loggerhead *Caretta caretta* and leatherback *Dermochelys coriacea* sea turtles, North Atlantic harbor porpoise *Phocoena phocoena*, and vaquita *Phocoena sinus* in the Sea of Cortez; hence, bycatch problems are important for holistic management of resources in the marine ecosystem (Hall and Mainprize, 2005; Dichmont et al., 2007).

Shrimp trawl nets often trap more bycatch than

*Corresponding author: ohcw@pknu.ac.kr

other fishing gears. A wide range of non-targeted species is captured by these nets, including juveniles of species that would have otherwise contributed to a commercial catch of larger fish at a later time (Alverson et al., 1994; Liggins and Kennelly, 1996; Pascoe, 1997). Global bycatch in shrimp trawls in 1993 was estimated to be ca. 11.2 million tons (Alverson et al., 1994). Alverson et al. (1994) reported that in the northwestern Pacific, 97% of >4 million tons of shrimp bycatch is discarded. However, Zhou and Yimin (1996) suggest that the Chinese shrimp trawl fleet discards very little of the non-shrimp bycatch. According to Zhou and Yimin (1996), bycatch in this fleet amounts to about 1.8 million tons, all of which is used, mostly for feed in the Chinese aquaculture industry. Elsewhere in Southeast Asia, an increased industrial utilization of shrimp fishery bycatch is occurring (Chee, 1996).

Detailed information on the historic dimensions of bycatch is not available for many fisheries, and thus continued monitoring is necessary to assess trends and to measure the effectiveness of new technologies designed to minimize bycatch (Saila, 1983; Alverson et al., 1994). This information deficit and the lack of appropriate management measures are of concern to programs that are meant to take an ecosystem risk approach to shrimp trawl fishery management. The impacts of fisheries on the full spectrum of bycatch species have not been well quantified, although some studies have documented spatial and temporal changes in particular bycatch species.

Here, we present the first quantitative data on bycatch composition and temporal variation in bycatch composition among seasons and tidal phases off Geoje Island, Korea. We sought to investigate the community composition of catches, relative abundance of each bycatch species, and effects of the ERAEF approach on bycatch.

Materials and Methods

Data collection

Data were collected from commercial shrimp trawlers operating in the coastal waters off Geoje Island in the Korean South Sea between November 2000 and October 2001. The bycatches of 48 trawls were sampled opportunistically by trained crew and scientific observers from two commercial fishing vessels, viz. 12 spring samples (March to May), 8 summer samples (June to August), 15 fall samples (September to November), and 13 winter samples (December to February; Table 1). Water depth ranged from 8 to 30 m. All vessels used shrimp beam trawls (rigid beam length: 7 m), with a mesh size of 0.98× 0.98 mm. Trawl durations ranged from 20 to 90 min at speeds of 0.4 to 2.0 knots and were conducted at depths between 8 and 30 m.

The biomasses of small bycatch species were typically large, with each net catching on average ca. 18 kg per trawl (Table 1). Total catch samples were labeled, frozen onboard, and sent to the National Fisheries Research Development Institution (NFRDI) laboratories for processing.

In the laboratory, animals from each sample were identified to the lowest taxonomic level (usually species) and counted. The total mass of each taxon was recorded (precision: 0.01 g), and randomly chosen individuals of each species were measured for standard length (fishes), carapace length (Brachyura, Anomura), and mantle length (Dibranchia).

Data analyses

The number of individuals and the biomass of each species from each trawl were calculated by multiplying the samples by a factor based on the sub-sample to total bycatch mass ratio (see Stobutzki et al., 2001). The catch rates of individuals (n/100 m^2) and biomass (g/100 m^2) for each species were standardized (see below) to account for different gear specifications and trawl times between vessels. We considered each trawl as an independent sample of the demersal population, since tow paths did not overlap (i.e., an assumption of no local depletion effects was made). As is often the case with trawl sampling, several potential biases are difficult or impossible to eliminate in obtaining an accurate estimate of the number or biomass of each species caught. These biases can include size- and species-specific selectivity of trawl nets and the speed of towing (Blaber et al., 1990). We consider our samples as being representative of the fleet, and our standardization procedures using measurable factors (e.g., trawl duration, trawl speed) allowed quantitative comparisons between samples in relative terms. Several ways exist to analyze multivariate data depending on specific hypotheses being tested. In this study, we were interested first in determining whether the mean biomasses and numbers of species in the overall catch differed and whether the most abundant fish and invertebrate species caught differed between spring and neap tides and among seasons. Second, we were interested in determining whether the overall assemblage structure (species composition and relative abundances and biomasses of the species) differed between neap and spring tide phases and

Table 1. Mean (±S.E.) biomass of net sampled, by fishing group, season, and time of tidal in the Geoje of Korean waters

		Trained crew							
		Spring		Summer		Autumn		Winter	
		Spring tide (6)	Neap tide (6)	Spring tide (5)	Neap tide (3)	Spring tide (7)	Neap tide (8)	Spring tide (3)	Neap tide (10)
Macrura	Mean Biomass (g/trawl)	26,856.12	13,284.55	4,426.77	19,353.99	11,243.56	15,438.77	10,422.65	14,610.61
	Standard error (S.E.)	2,517.06	1,453.35	470.21	4,638.54	1,569.71	2,212.30	1,173.59	900.16
Fishes	Mean Biomass (g/trawl)	1,558.93	2,366.96	644.86	2,358.17	1,933.05	3,011.67	136.65	8.65
	Standard error (S.E.)	245.22	418.74	41.90	270.67	172.44	471.32	12.24	1.81
Dibranchia	Mean Biomass (g/trawl)	77.25	128.15	56.63	72.92	44.16	30.23	NS	3,368.25
	Standard error (S.E.)	18.00	21.97	16.58	42.10	8.80	7.30	NS	323.36
Brachyura	Mean Biomass (g/trawl)	2,002.58	3,450.43	1,325.87	1,086.17	988.56	3,397.44	NS	154.9
	Standard error (S.E.)	326.65	704.27	337.86	363.28	271.58	525.79	NS	31.39
Anomura	Mean Biomass (g/trawl)	86.11	47.20	146.41	10.62	22.03	187.40	1,073.59	1008.46
	Standard error (S.E.)	14.97	9.05	51.57	6.13	7.59	34.78	270.54	100.7

NS: Not sampled.

Table 2. Percentage occurrence and mean catch rates of bycatch species from the Geoje of Korean waters

Bycatch group	Species	Order	% Occurrence (n=49)	Mean number (n/100 m^2)±(S.E.)	Mean biomass (g/100 m^2) ± (S.E.)
Fishes	*Conger myriaster*	Anguilliformes	61.22	53.872 (4.180)	2,301.038 (167.276)
	Lophiomus setigerus	Lophiiformes	42.86	1.943 (0.138)	347.844 (11.889)
	Caelorinchus multispinulosus	Gadiformes	42.86	13.770 (0.831)	118.293 (7.089)
	Cynoglossus semilaevis	Pleuronectiformes	36.73	0.827 (0.029)	17.503 (0.646)
	Liparis tanakai	Scorpaeiformes	32.65	1.840 (0.076)	421.940 (21.356)
	Pennahia argentata	Perciformes	32.65	0.959 (0.041)	112.045 (6.122)
	Zoarces gilli	Perçiformes	26.53	4.348 (0.253)	76.970 (4.098)
	Pseudorhombus cinnamoneus	Pleuronectiformes	24.49	1.294 (0.135)	95.486 (10.392)
	Doederleinia berycoides	Perciformes	20.41	3.339 (0.218)	55.901 (3.116)
	Parapercis sexfasciata	Perciformes	18.37	1.753 (0.160)	97.009 (8.682)
	Eopsetta grigorjewi	Pleuronectiformes	18.37	0.330 (0.020)	16.878 (0.961)
	Sillago japonica	Perciformes	16.33	0.251 (0.014)	8.499 (0.477)
	Pholis nebulosus	Perciformes	16.33	7.099 (0.752)	205.297 (18.791)
	Trichiurus lepturus	Perciformes	14.29	1.359 (0.138)	55.317 (4.857)
	Okamejei kenojei	Rajiformes	12.24	0.277 (0.024)	83.186 (9.072)
	Acrntrogobius pellidebilis	Perciformes	10.20	0.253 (0.018)	3.216 (0.223)
	Zebrias fasciatus	Pleuronectiformes	10.20	1.610 (0.130)	69.420 (5.878)
	Uranoscopus japonicus	Perciformes	10.20	0.422 (0.039)	31.333 (3.130)
	Dexistes rikuzenius	Pleuronectiformes	10.20	0.434 (0.031)	55.175 (5.204)
	Carangoides equula	Perciformes	8.16	0.159 (0.013)	4.758 (0.479)
	Platycephalus indicus	Scorpaeniformes	8.16	0.272 (0.032)	50.432 (5.346)
	Apogon lineatus	Perciformes	8.16	0.602 (0.051)	2.036 (0.161)
	Platichthys bicoloratus	Pleuronectiformes	8.16	1.664 (0.141)	150.203 (14.351)
	Psenopsis anomala	Perciformes	8.16	1.082 (0.135)	24.663 (2.462)
	Trachurus japonicus	Perciformes	6.12	0.088 (0.007)	3.114 (0.277)
Brachyura	*Charybdis bimaculata*	Decapoda	77.55	491.508 (14.887)	1,347.628 (47.050)
	Carcinoplax longimana	Decapoda	53.06	120.814 (5.711)	2,572.525 (142.584)
	Carcinoplax vestita	Decapoda	12.24	8.507 (0.611)	32.197 (2.247)
	Paradorippe granulata	Decapoda	10.20	2.003 (0.193)	10.447 (1.016)
	Portunus argentatus	Decapoda	8.16	0.380 (0.030)	0.247 (0.020)
	Pyromia tuberculata	Decapoda	6.12	1.558 (0.160)	1.072 (0.110)
Dibranchia	*Octopus minor*	Octopoda	30.61	1.834 (0.122)	146.808 (9.760)
	Loligo beka	Octopoda	8.16	0.164 (0.013)	11.186 (0.997)
	Sepia esculenta	Sepiidae	6.12	0.053 (0.004)	3.587 (0.389)
Anomura	*Oratosquilla oratoria*	Stomatopoda	42.86	12.897 (0.958)	118.540 (7.814)
	Dardanus arrosor	Decapoda	12.24	2.325 (0.159)	123.811 (12.130)

Only those with percentage of occurrence greater than 5% are included.

among seasons.

We used a univariate approach with a two-factor analysis of variance (ANOVA) to compare the mean number of individuals and biomasses of the fishes, Brachyura, Anomura, and Dibranchia between tidal phases and among seasons. Prior to ANOVA, we tested for homogeneity of variances using Bartlett's test. Where necessary, data were log transformed [$\log10(x+1)$] to produce acceptable homogeneity of variances and distribution of residuals. When ANOVA was significant, pairwise differences among means were tested using an *a posteriori* Tukey-HSD multiple comparisons test (Zar, 1984) performed with SYSTAT Version 10.0. If transformed data did not produce acceptable homogeneity of variances, differences in the variables were tested using non-parametric Kruskal-Wallis test and nonparametric multiple comparisons (Sokal and Rohlf, 1995). Kolmogorov-Smirnov tests were used to determine whether the size-frequency composition of individual bycatch species differed significantly between tidal phases (spring or neap) and among seasons. Statistical analyses were conducted using MINITAB Version 12.1 and SYSTAT Version 10.0.

Multivariate ordination (nonmetric multidimensional scaling: nMDS) was used to examine similarities in fish assemblage structures among seasons and between tidal phases (spring vs. neap). All multivariate analyses were carried out with the PRIMER software package (Plymouth Routines In Multivariate

Ecological Research; Version 5.2.2). Data were fourth-root transformed to reduce the influence of highly abundant taxa, and a similarity matrix was constructed using the Bray-Curtis similarity coefficient. This matrix was used in constructing two-dimensional ordinations of the multidimensional relationships between all samples. If an ordination is used in isolation to interpret differences between groups of samples separated *a priori* (i.e., seasons), potential problems can arise when the two-dimensional representation of the multidimensional relationships is poor (expressed in the ordination's "stress" value). Ordinations with stress values of ≤0.2 are useful for interpreting relationships among samples, although some caution should be exercised when values approach 0.2 (Clarke, 1993). Stress values can increase with sample size or increased variability among samples. Therefore, we used other analyses that do not rely on visual interpretation of two-dimensional ordination to explore multivariate differences between samples. Because the stress values in some of our ordinations were close to 0.2, analysis of similarities (ANOSIM) was used to test whether fish assemblages recognized *a priori* differed statistically (Clarke, 1993). This analysis involved generating 9999 random permutations of the data to calculate the probability that observed differences in the structure of bycatch assemblages could have arisen by chance. Similarity percentages (SIMPER) were then used to determine which species were responsible for differences between groups defined by ANOSIM as statistically different. The data were reordered to give a global *R*-statistic testing the null hypothesis that no significant difference existed between tidal phases or among seasons. ANOSIM *R*-values of >0.5 indicated clear differences between groups, with some degree of overlap (Clarke and Gorley, 2001).

Results

Landings

A total bycatch mass of 172 kg from 48 trawls contained 108 taxa (in 16 orders and 50 families). The target order of shrimp (Macrura) was represented by 24 species in 9 families; 60 bycatch fish species in 11 orders and 36 families, 5 species of cephalopods (Dibranchia) in 3 orders and 4 families, 11 crab species (Brachyura) in 6 families, and 8 hermit crab (Anomura) species in 2 orders and 4 families were caught. About 33.35% of taxa occurred in <5% of trawls, while 31.48% occurred in only one trawl. The contributions of fishes and invertebrates to total biomass were 51.2% and 48.8%, respectively. Numbers of individuals in the bycatch, however, was dominated by invertebrates (86.32%), with fishes making up a much smaller proportion (13.68%).

Species with >40% occurrence among trawls included 3 fish (*Conger myriaster*, *Lophiomus setigerus*, *Caelorinchus multispinulosus*), 2 brachyurans (*Charybdis bimaculata*, *Carcinoplax longimana*), and 1 anomuran (*Oratosquilla oratoria*); none of the dibranchiate species occurred at a frequency of >40% (Table 2). Among families of fish species collected in bycatch subsamples, the Pleuronectidae and Scorpaenidae were the most speciose, with 9 and 5 species, respectively. The fish family Congridae contributed most to the total bycatch mass (25.17%) and numbers of individuals (7.15%; Table 3).

Of the six families of brachyurans collected, the Goneplacidae contributed 28.49% to the total bycatch mass. Numbers of brachyuran individuals in the bycatch were dominated by the family Portunidae (65.27%; Table 3). The 4 families of anomurans contributed 2.71% of the bycatch mass. The hermit crab family Squillidae dominated in the numbers of individuals (1.71%), while the family Diogenidae had the highest proportion of mass (1.36%; Table 3). Of the 4 Dibranchia families encountered, the Octopodidae had 2 species, which contributed 1.75% of the bycatch mass. Families Ommastrephidae, Sepiolidae, and Loliginidae were each represented by a single species, which together contributed <1% to the bycatch mass (Table 3).

The standardized biomass ratio of the total bycatch (448 kg/100 m^2) to total commercial shrimp caught (2,450.2 kg/100 m^2) was 0.18:1.00.

Seasonal trends

The mean number of total bycatch species differed significantly by season ($F_{3,44}$=13.448, P<0.001). Significant pairwise differences in numbers were observed among all seasons (Tukey HSD test, P< 0.001), with the highest bycatch species richness in summer. The mean biomasses summed across bycatch species were also significantly different by season ($F_{3,44}$=22.025, P<0.001), with significant pairwise differences among all seasons (Tukey HSD test, P<0.01). The highest bycatch biomass was caught in summer.

Fish species followed patterns similar to the total bycatch. The mean numbers of fish individuals in bycatch were significantly different by season ($F_{3,44}$= 22.600, P<0.001), and significant pairwise differences were observed among all seasons (Tukey HSD

Table 3. The families caught as bycatch from shrimp trawls in the Geoje of Korean waters, showing the number of species in each and the percentage they contributed to the total number and biomass of the bycatch contributed

Family/other	Species (n)	Number of indivisuals (/100 m^2)	Number (%)	Biomass (g/100 m^2)	Biomass (%)
Total		36,927.54	100.00	448,042.55	100.00
Fishes		5,051.60	13.68	229,471.36	51.22
Congridae	1	2,639.74	7.15	112,750.88	25.17
Liparidae	1	90.14	0.24	20,675.06	4.61
Lophiidae	1	95.18	0.26	17,044.36	3.80
Pleuronectidae	9	138.35	0.37	15,242.53	3.40
Pholididae	1	347.84	0.94	10,059.55	2.25
Scorpaenidae	5	21.57	0.06	6,310.95	1.41
Coryphaenodidae	1	674.74	1.83	5,796.38	1.29
Sciaenidae	3	50.23	0.14	5,728.53	1.28
Pinguipedidae	2	86.88	0.24	4,781.45	1.07
Paralichthyidae	3	65.68	0.18	4,769.06	1.06
Rajidae	1	13.57	0.04	4,076.14	0.91
Zoarcidae	1	213.06	0.58	3,771.52	0.84
Soleidae	1	78.90	0.21	3,401.59	0.76
Acropomatidae	1	163.61	0.44	2,739.16	0.61
Tichiuridae	1	66.61	0.18	2,710.56	0.60
Platycephalidae	1	13.32	0.04	2,471.14	0.55
Uranoscopidae	1	20.69	0.06	1,535.32	0.34
Centrolophidae	1	53.01	0.14	1,208.46	0.27
Cynoglossidae	1	40.53	0.11	857.64	0.19
Stichaeidae	2	12.21	0.03	694.94	0.16
Hexagrammidae	2	1.79	<0.01	586.83	0.13
Sillaginidae	1	12.30	0.03	416.45	0.09
Carangidae	2	12.08	0.03	386.22	0.09
Gobiidae	2	48.73	0.13	343.04	0.08
Triglidae	2	2.36	0.01	324.37	0.07
Ophidiidae	2	31.95	0.09	294.69	0.07
Apogonidae	1	29.52	0.08	99.78	0.02
Leiognathidae	1	5.40	0.01	99.28	0.02
Engraulidae	2	4.27	0.01	72.01	0.02
Priacanthidae	1	1.71	<0.01	70.02	0.02
Synodontidae	1	0.55	<0.01	38.29	0.01
Stomiidae	1	10.58	0.03	32.88	0.01
Aploactinidae	1	2.31	0.01	30.59	0.01
Sparidae	1	0.99	<0.01	28.97	0.01
Clupeidae	1	0.77	<0.01	15.47	0.00
Hemitripteridae	1	0.45	<0.01	7.26	0.00
Brachyura		30,843.97	83.53	197,805.03	44.15
Cancridae	2	24.01	0.07	450.86	0.10
Dorippidae	1	98.16	0.27	511.90	0.11
Goneplacidae	2	6,336.74	17.16	127,631.36	28.49
Leucosiidae	1	10.58	0.03	63.90	0.01
Majidae	3	272.00	0.74	3,101.14	0.69
Portunidae	2	24,102.48	65.27	66,045.87	14.74
Dibranchia		105.71	0.29	8,625.46	1.93
Octopodidae	2	92.77	0.25	7,838.09	1.75
Ommastrephidae	1	8.03	0.02	548.12	0.12
Sepiolidae	1	2.59	0.01	175.76	0.04
Ommastrephidae	1	2.31	0.01	63.49	0.01
Anomura		926.26	2.51	12,140.70	2.71
Diogenidae	2	160.29	0.43	6,104.31	1.36
Galatheidae	1	24.55	0.07	4.82	0.00
Paguridae	4	109.47	0.30	223.12	0.05
Squillidae	1	631.95	1.71	5,808.45	1.30

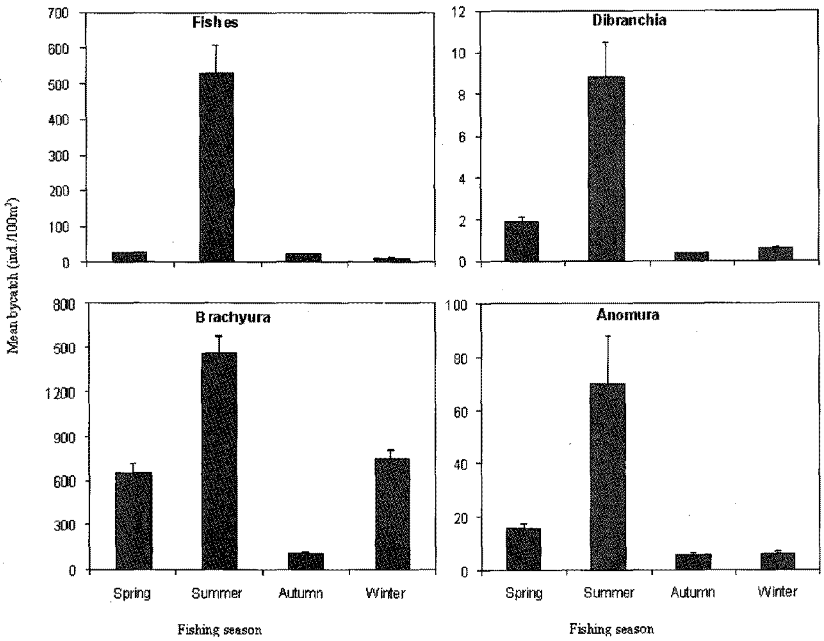

Fig. 1. Mean number (n /100m^2) ($\pm$S.E.) for fish, dibranchi, brachyuran and anomura bycatch between seasons.

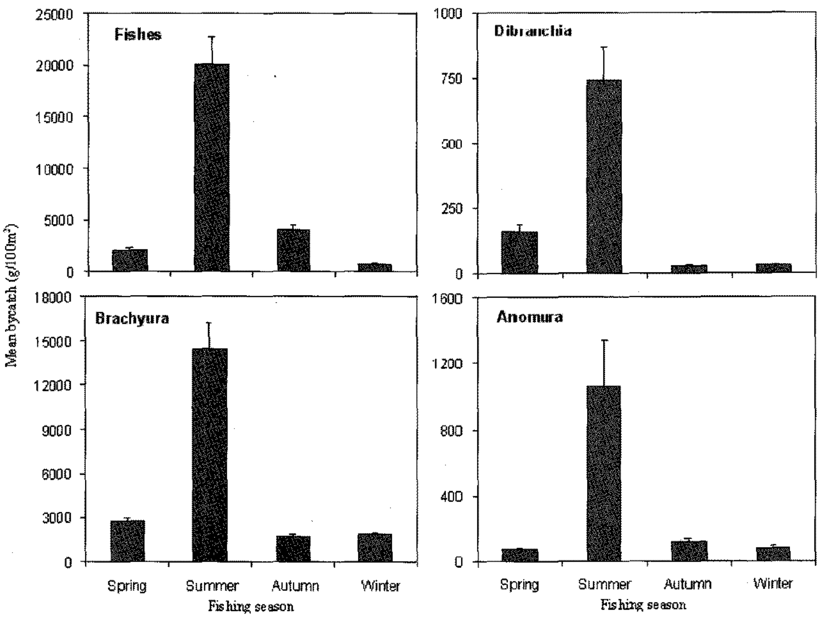

Fig. 2. Mean biomass(g /100m^2) ($\pm$S.E.) for fish, dibranchi, brachyuran and anomura bycatch between seasons.

test, $P<0.001$), with the highest number of bycatch individuals in summer (Fig. 1). The mean fish biomass varied significantly by season ($F_{3,44}=22.025$, $P<0.001$) and significant pairwise fish biomass differences were observed among all seasons (Tukey HSD test, $P<0.01$), with the highest bycatch biomass in summer (Fig. 2).

The mean (±SE) numbers of Dibranchia in bycatch were 1.89 (±0.21) individuals per 100 m^2 in spring, 8.82 (±1.63) in summer, 0.34 (±0.04) in fall, and 0.57 (±0.07) in winter. However, these differences among seasons were not significant (H=3.72, d.f.=3, $P>0.2$; Fig. 1). The mean Dibranchia bycatch biomass was 161.50 g (±23.51) per 100 m^2 in spring, 739.02 (±128.70) in summer, 27.16 (±3.14) in fall, and 28.30 (±3.55) in winter, and again, these seasonal values were not significantly different ($F_{3,44}=1.132$, $P>0.3$; Fig. 2).

The mean numbers of Brachyura in bycatch were significantly different among seasons (H=16.29, d.f.=3, $P<0.01$), with 647.68 (±65.56) individuals per 100 m^2 in spring, 1464.87 (±111.23) in summer, 108.32 (±6.22) in fall, and 742.56 (±57.15) in winter. Mean numbers were not significantly different in pairwise comparisons among spring, fall, and winter ($P>0.05$), but summer values were significantly higher than those of other seasons ($P<0.01$; Fig. 1). Mean Brachyura bycatch biomasses were 161.50 g (±23.51) per 100 m^2 in spring, 739.02 (±128.70) in summer, 27.16 (±3.14) in fall, and 28.30 (±3.55) in winter; these values were not significantly different. The mean biomasses of brachyuran bycatch were significantly different by season (H=14.44, d.f.=3, $P<0.01$). Summer biomass values were significantly higher than those of the other seasons ($P<0.01$), which were not significantly different from one another ($P>0.05$).

Hermit crab (Anomura) bycatch trends tracked those of Dibranchia. Neither the mean numbers of hermit crabs in bycatch ($F_{3,44}=1.930$, $P>0.1$; Fig. 1) nor the mean hermit crab biomass were significantly different among seasons ($F_{3,44}=1.231$, $P>0.3$; Fig. 2).

Seasonal variation in the size structure of bycatch samples was investigated using length-frequency distributions of each species. Brachyura, Anomura, and Dibranchia, however, had small sample sizes and could not be analyzed in this manner.

Thus, data were inadequate for assessing seasonal variation in size structure in these taxa. For the two dominant fish, *Conger myriaster* and *Caelorinchus multispinulosus*, we were able to make size structure comparisons across seasons. Seasonal size distributions of *C. myriaster* are presented in Fig. 3. A total of 189 specimens was included: 40 individuals in spring, 44 in summer, 98 in fall, and 7 in winter. A Kolomogorov-Smirnov two-sample test revealed that size-frequency distributions were not significantly different in pairwise comparisons among seasons (Table 4a). Size structure of *C. multispinulosus* is presented in Fig. 3. A total of 290 specimens was included: 18 individuals in spring, 144 in summer, 82 in fall, and 46 in winter. A Kolomogorov-Smironov two-sample test revealed no significant difference in size-frequency distributions among seasons (Table 4b).

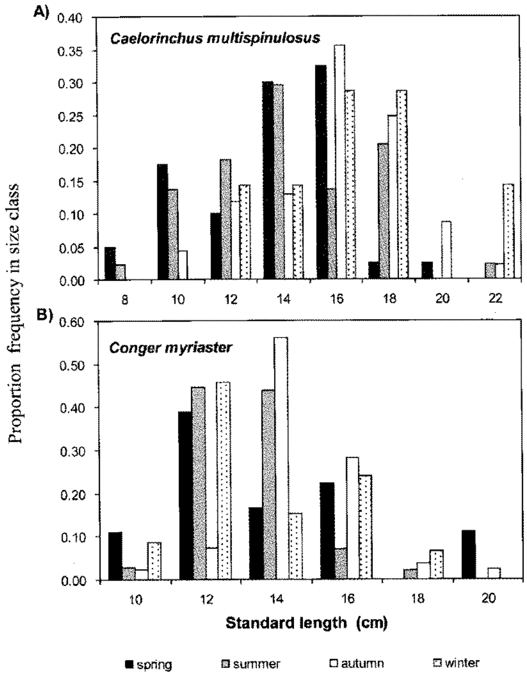

Fig. 3. Percentage length-frequency distribution of the two most abundance species caught in fishing seasons. All measurements are standard length (SL).

MDS ordinations showed clear seasonal differences in the shrimp trawl bycatch assemblage in both numbers of individuals and biomass (Figs. 4, 5). ANOSIM further supported the MDS results, showing significant differences among seasons in the numbers of bycatch individuals (R=0.227, P=0.0001) and biomass (R=0.259, R=0.0001). SIMPER showed that the average similarity (major species) was 28.48 (*Charybdis bimaculata*, *Carcinoplax longimana*) in spring, 37.15 (*C. bimaculata*, *C. longimana*, *C. myriaster*, and *C. multispinulosus*) in summer, 25.73 (*C. bimaculata*, *C. longimana*, *C. multispinulosus*, and *C. myriaster*) in fall, and 32.31 in winter (*C. bimaculata*). Among brachyurans, *C. bimaculata* had the highest bycatch rates through all sampling seasons.

Tidal trends

The mean numbers of total bycatch individuals and

Table 4. Kolomogorov-Smironov two-sample test for frequency distribution of size between pairwise seasons. Parenthesis that d_{max} (Maximum differences) values. a) *Conger myriaster*; b) *Caelorinchus multispinulosus*

a)	Spring	Summer	Autumn	Winter
Spring				
Summer	P>0.9 (0.250)			
Autumn	P>0.9 (0.125)	P>0.5 (0.375)		
Winter	P>0.9 (0.250)	P>0.9 (0.250)	P>0.5 (0.375)	
b)	**Spring**	**Summer**	**Autumn**	**Winter**
Spring				
Summer	P>0.3 (0.500)			
Autumn	P>0.3 (0.500)	P>0.7 (0.333)		
Winter	P>0.7 (0.333)	P>0.7 (0.333)	P>0.7 (0.333)	

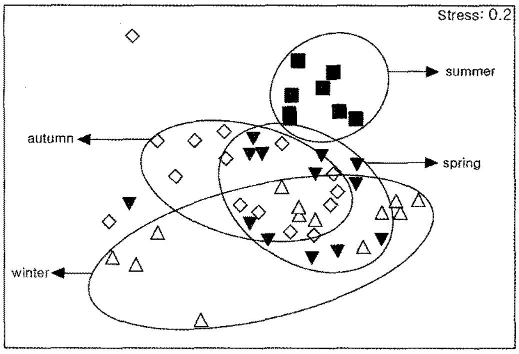

Fig. 4. Non-metric MDS ordination plots showing seasonal comparisons of bycatch species composition based on the numbers.

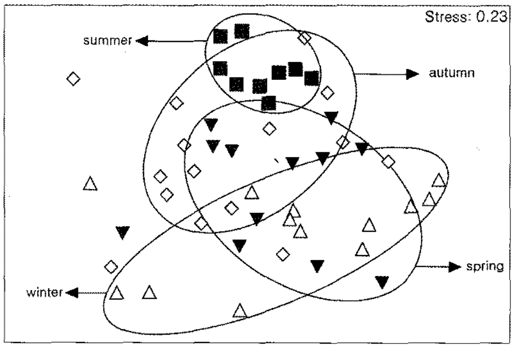

Fig. 5. Non-metric MDS ordination plots showing seasonal comparisons of bycatch species composition based on biomass.

mean total biomass did not differ significantly between tidal phases ($F_{1,46}$=1.684, $P>0.05$ and $F_{1,46}$= 0.112, $P>0.05$, respectively). For the fish component, no significant differences were detected between spring and neap tides in either the mean number of individuals (H=1.80, d.f.=1, $P>0.1$) or biomass (H=1.80, d.f.=1, $P>0.4$). Neither the mean number of invertebrate species (Dibranchia: H=1.88, d.f.=1, $P>0.1$; Brachyura: $F_{1,46}$=1.157, $P>0.2$; Anomura: $F_{1,46}$=0.287, $P>0.5$) nor the mean biomass of invertebrate species differed significantly between spring and neap tides (Dibranchia: $F_{1,46}$=1.624, $P>0.2$; Brachyura: $F_{1,46}$=0.925, $P>0.3$; Anomura: $F_{1,46}$=0.002, $P>0.9$).

Tidal variations in the size-frequency structure of samples in bycatch were investigated using length-frequency distributions of each species. Tidal size-frequency distributions of *Conger myriaster* and *Caelorinchus multispinulosus* are presented in Fig. 6. A Kolomogorov-Smirnov two-sample test revealed that frequencies were not significantly different bet-

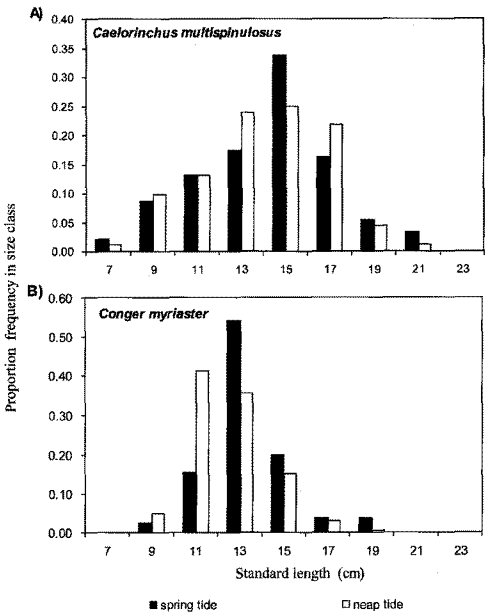

Fig. 6. Percentage length-frequency distribution of the two most abundance species caught in fishing tides. All measurements are standard length (SL).

ween tidal phases.

MDS ordinations did not demonstrate clear separations by tidal phase in the shrimp trawl bycatch species assemblage of either the numbers of individuals or biomass (Figs. 7, 8). However, ANOSIM showed significant differences among seasons for the numbers of individuals ($R=0.227$, $P<0.001$) and biomass ($R=0.259$, $P<0.001$), and SIMPER revealed significant differences between spring and neap tide in the numbers of individuals ($R=0.078$, $P<0.05$) and biomass ($R=0.098$, $P<0.01$). SIMPER showed that three species contributed 81.92% to the dissimilarity among bycatch assemblages: *Charybdis bimaculata* (55.65%), *Carcinoplax longimana* (20.89%), and *Conger myriaster* (5.38%).

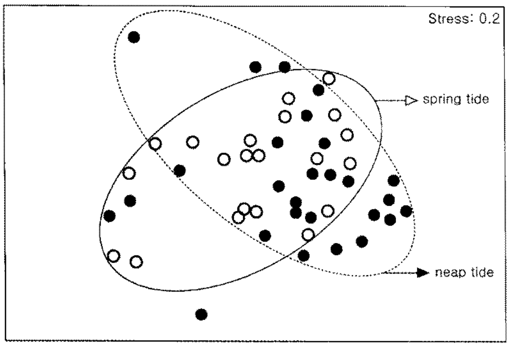

Fig. 7. Non-metric MDS ordination plots showing tidal comparisons of bycatch species composition based on the numbers.

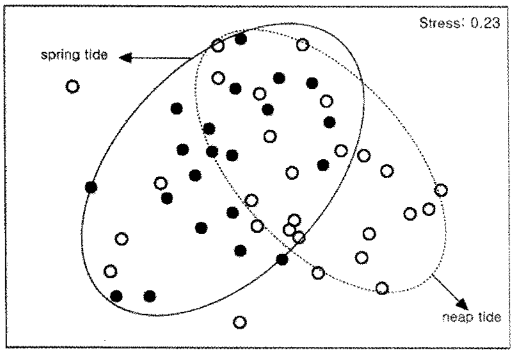

Fig. 8. Non-metric MDS ordination plots showing tidal comparisons of bycatch species composition based on the biomass.

Two-way crossed (season × tidal phase) trends

A two-way ANOVA revealed significant main effects of season and tidal phase ($P<0.01$) on the mean total numbers of individuals, but not on the mean total biomass ($P>0.05$). The mean numbers of fish were not significantly different among seasons or between tides (two-way ANOVA, $P>0.05$); fish biomass variances were not homogeneous (Bartlett's test, $P<0.01$), so these data were tested using non-parametric tests. The Kruskal-Wallis test and non-parametric multiple comparisons indicated significantly different mean biomasses between seasons and tides ($H=23.94$, d.f.$=7$, $P<0.01$). The mean number and biomass of Dibranchia bycatch were not significantly different between seasons and tides ($P>0.1$). However, the mean numbers and biomasses of Brachyura bycatch were significantly different between seasons and tides (two-way ANOVA, $P<0.01$). The mean numbers and biomasses of Anomura bycatch were not significantly different between seasons and tides ($P>0.1$; Figs. 9, 10).

Two-way crossed analysis of ANOSIM revealed significant differences between seasons and tides for the number of individuals (averaged across all tidal groups: $R=0.422$, $P=0.001$, averaged across all season groups: $R=0.428$, $P=0.001$) and biomass (averaged across all tidal groups: $R=0.432$, $P<0.01$, averaged across all season groups: $R=0.411$, $P<0.01$).

Discussion

This study area is known to serve as a spawning and nursery ground for commercial fishes. It is influenced by the warm Tsushima Current, which originates in the Korean South Sea, and by the Kuroshio Current (to the south), which is warmer still and has higher salinity (Yamada et al., 1986; Kim et al., 2003). The depth ranges from 30 to 90 m, with silty sediments on the seabed providing highly suitable habitats for *Palaemon gravieri*, *Crangon hakodatei*, and *Trachypenaeus curvirostris*, all of which are exploited commercially by Korean beam trawlers. Individuals are kept alive for use as fish bait, and this shrimp fishery inevitably includes a wide range of bycatch species, most of which are discarded into the sea.

The annual bycatch to commercial shrimp ratio is 0.18:1.00 for this fishery. Slavin (1982) showed that the shrimp trawl fishery bycatch to shrimp biomass ratio is 5:1 in temperate waters and 10:1 in tropical waters, ratios much higher than those we found. Reasons for the discrepancy may include fish abundance, fishing strategy, water depth, sediment type, energy level, and biological community characteristics. Although bycatch amounted to only 18% of the total catch mass, most of the bycatch consisted of

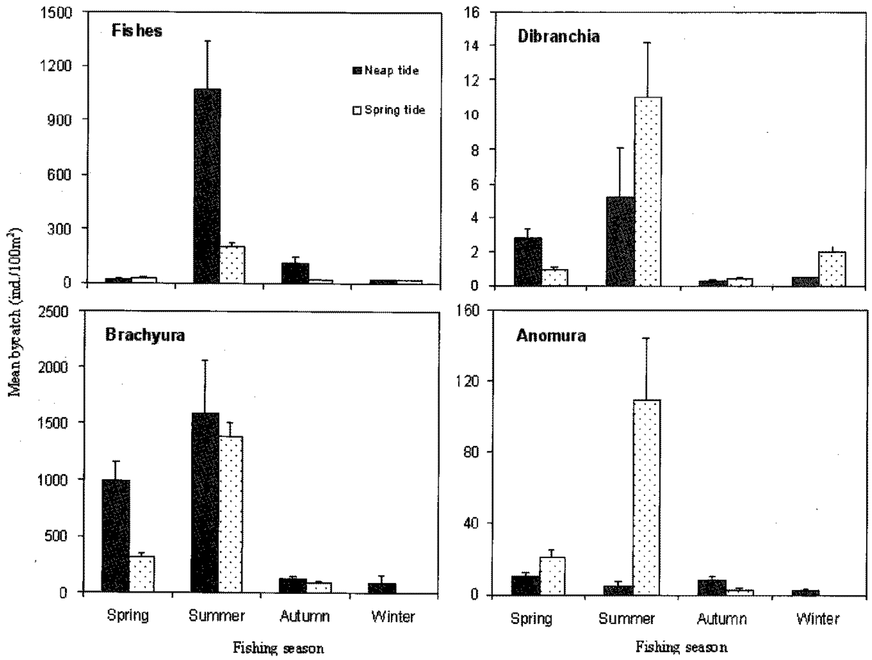

Fig. 9. Mean number (n /100 m^2) (±S.E.) for fish, dibranchi, brachyuran and anomura bycatch between seasons and tides.

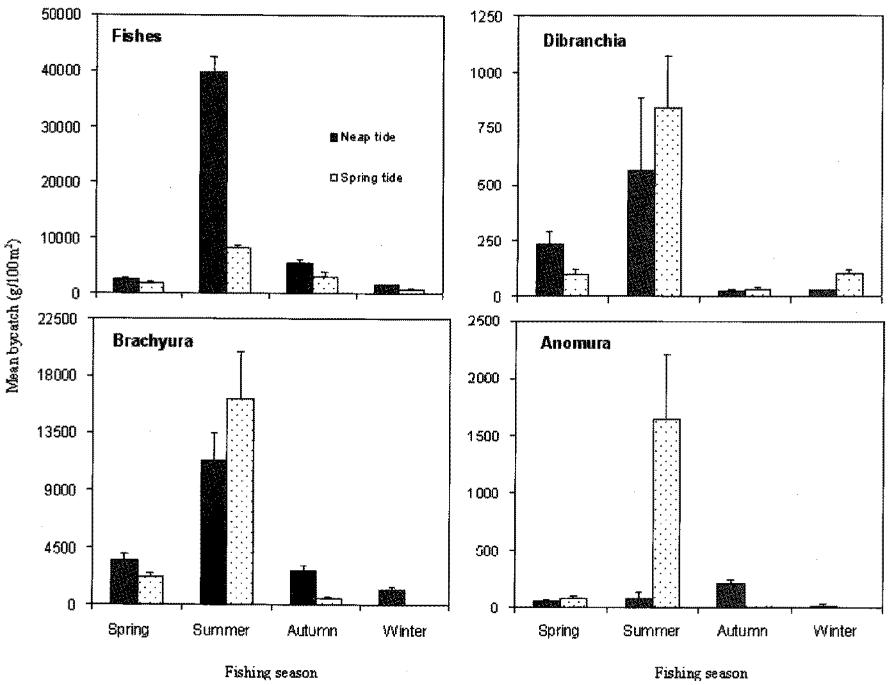

Fig. 10. Mean biomass(g /100 m^2) (±S.E.) for fish, dibranchi, brachyuran and anomura bycatch between seasons and tides.

undersized commercial species. This dominance of fishes in bycatch appears to be characteristic of shrimp trawl fisheries.

The size-frequency structures of some bycatch species in the study area varied significantly among seasons. The two abundant fish species had a higher proportion of smaller individuals during summer than in spring, suggesting that recruitment and migration are seasonal.

The Geoje shrimp fishery catches a significantly larger biomass and abundance of bycatch during summer than in other seasons. Several other tropical prawn trawl studies have also reported temporal variation in bycatch assemblages (Rainer and Munro, 1982; Wright, 1988; Blaber et al., 1990; Gallaway and Cole, 1999; Tonks et al., 2008). In inshore waters of the Geoje region, seasonal variations in temperature and salinity may contribute to variation in faunal assemblage structure. Biotic factors such as seasonality of reproduction and recruitment can also be important. In our study, *Conger myriaster*, *Lophiomus setigerus*, *Carcinoplax longimana*, and *Charybdis bimaculata* accounted for the main differences in biomass among seasons.

The density and biomass changes in invertebrate bycatch show that the shrimp trawl fishery has an important effect on the benthic community structure. Selective trawl harvesting among species may alter benthic faunal composition. In general, the organisms most affected by trawling include epibenthic species of mollusks, echinoderms, crustaceans, sponges, hydrozoans, bryozoans, and fish (e.g., Caddy, 1973; de Groot, 1984; Rumohr and Krost, 1991; Bergman and Hup, 1992; Eleftheriou and Robertson, 1992; Kaiser and Spencer 1994; Graham, 1995; Auster et al., 1996; Collie et al., 1997; Jennings and Kaiser, 1998). Many studies have shown that bycatch and discards can alter the character of species assemblages (Wassenberg and Hill, 1987; Hudson and Furnes, 1988; Blaber and Wassenberg, 1989). Such shifts have the potential to alter prey/predator relationships, increase food for scavengers, and modify the ecosystem structure and function in the benthos (Alverson et al., 1994). Because of these massive effects, biological information and long-term catch data on individual bycatch species should be collected and analyzed before formulating fisheries management measures.

References

Alverson, D.L., M.H. Freeburg, S.A. Murawski and J.G. Pope. 1994. A Global Assessment of Fisheries Bycatch and Discards. FAO Fisheries Technical Paper 339, Food and Agriculture Organization, Rome.

Annala, J.H. 1991. Factors influencing fecundity and population egg production of *Jasus* species. In: Wenner, A., Kuris, A. (Eds.), Crustacean Issues 7. Crustacean Egg Production. A.A. Balkema, Rotterdam, The Netherlands, pp. 301-315.

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 Marine (Northwest Atlantic): implications for conservation of fish population. Rev. Fish Sci., 4, 185-202.

Bergman, M.J.N. and M. Hup. 1992. Direct effects of beam trawling on marcrofauna in a sandy sediment in the southern North Sea. ICES J. Mar. Sci., 49, 5-11.

Blaber, J.M., D.T. Brewer, J.P. Salini and J. Kerr. 1990. Biomasses, catch and abundances of demersal fishes, particularly predators of prawns, in a tropical bay in the Gulf of Carpentaria. Aust. Mar. Biol., 107, 397-408.

Blaber, S.J.M. and T.J. Wassenberg. 1989. Feeding ecology of the piscivorous birds *Phalacrocorax varius*, *P. melanoleucos* and *Sterna bergii* in Moreton Bay, Australia: diets and dependence on the trawler discards. Mar. Biol., 101, 1-10.

Botsford, Louis W., Juan Carlos Castilla, Charles H. Peterson. 1997. The Management of Fisheries and Marine Ecosystems. Science, 277, 509-515.

Caddy, J.F. 1973. Underwater observations on tracks of dredges and trawls and some effects of dredging on a scallop ground. J. Fish Res. Board Can., 30, 173-180.

Charles, A.T. 2002. The precautionary approach and 'burden of proof' challenges in fishery management. Bull. Mar. Sci., 70, 683-694.

Clarke, K.R. 1993. Non-parametric multivariate analyses of changes in community structure. Aust. J. Ecol., 18, 117-143.

Clarke, K.R. and R.N. Gorley. 2001. PRIMER v5: User manual/Tutorial PRIMER-E Ltd., Plymouth, UK.

Collie, J.S., G.A. Escanero and P.C. Valentine. 1997. Effects of bottom fishing on the benthic megafauna of Georges Bank. Mar. Ecol. Prog. Ser., 155, 159-172.

Darcy, G.H. and G.C. Matlock. 1999. Application of the precautionary approach in the national standard guidelines for conservation and management of fisheries in the United States. ICES J. Mar. Sci., 56, 589-853.

de Groot, S.J. 1984. The impact of bottom trawling on benthic fauna of the North Sea. Ocean Manage., 9, 177-190.

Dichmont, C., N. Loneragan, D. Brewer and I. Poiner. 2007. Partnerships towards sustainable use of

Australia's Northern Prawn Fishery. In: T.R. Mc-Clanahan & J.C. Castilla (Eds.), *Fisheries Management: Progress towards sustainability*. Blackwell Publishing Ltd, Oxford, UK, 207-230.

Chee, P.E. 1996. A review of the bycatch and discards in the fisheries of Southeast Asia - In Report on the Technical Consultation on Reduction of Wastage in Fisheries. (Clucas, I.J. and D. James - Eds.) Tokyo, Japan, 28 October - 1 November 1996. FAO Fisheries Report. No 547 supplement. Rome, FAO, 1996.

Eleftheriou, G.B. and R.O. Miller. 1992. The effects of experimental scallop dredging on the fauna and physical environment of a shallow sandy community. Neth. J. Sea Res., 30, 289-299.

FAO, 2002. The State of the World's Fisheries and Aquaculture. Food and Agriculture Organization of the United Nations, Rome.

Fleeger, J.W., K.R. Carman and R.M. Nisbet. 2003. Indirect effects of contaminants in aquatic ecosystems. Sci. Total Environ., 317, 207-233.

Fletcher, W.J. 2005. The application of qualitative risk assessment methodology to prioritize issues for fisheries management. ICES J. Mar. Sci., 62, 1576-1587.

Frank, K.T., B. Petrie, J.S. Choi and W.C. Leggett. 2005 Trophic cascades in a formerly cod-dominated ecosystem. Science, 308, 1621-1623.

Gallaway, B.J. and J.G. Cole. 1999. Reduction of Juvenile Red Snapper Bycatch in the U.S. Gulf of Mexico Trawl Fishery. N. Am. J. Fish. Manage., 19, 342-355.

Garcia, S.M. 1994. The precautionary principle: its implications in capture fisheries management. Ocean and Coastal Management, 22, 99-125.

Giddings, B., B. Hopwood and G. O'Brian. 2002. Environment, economy and society: fitting them together into sustainable development. Sustainable Development, 10, 187-196.

Graham, M. 1955. Effects of trawling on animals of the sea-bed. Deep Sea Res (Suppl)., 3, 1-6.

Hall, S.J. and B.M. Mainprize. 2005. Managing by-catch and discards: how much progress are we making and how can we do better? Fish Fish., 6, 134-155.

Hilborn, R., J.J. Maguire, A.M. Parma and A.A. Rosenberg. 2001. The Precautionary Approach and risk management: can they increase the probability of successes in fishery management? Can. J. of Fish. and Aquatic Sci., 58, 99-107.

Hofmann, E.E. and T.M. Powell. 1998. Environmental Variability Effects on Marine Fisheries: Four Case Histories. Ecological Applications, 8, S23-S32.

Hudson, A.V. and R.W. Furness. 1988. Utilization of discarded fish by scavenging seabirds behind white-fish trawlers in Shetland. J. Zool., London. Vil., 215, 151-166.

Jennings, S. and M.J. Kaiser. 1998. The effects of fishing on marine ecosystems. Adv. Mar. Biol., 34, 201-352.

Kaiser, M.J. and B.E. Spencer. 1995. Survival of bycatch from a beam trawl. Mar. Ecol. Prog. Ser., 126, 31-38.

Kim, J.N., J.H. Choi, Y.J. Im, K.H. Choi and K.D. Cho. 2003. Seasonal variation in abundance and species composition of fishes collected by a beam trawl around Naro-do, Korea. J. Kor. Fish. Soc., 36, 378-388.

Lauck, T., C.W. Clark, M. Mangel and G.R. Munro. 1998. Implementing the recautionary principle in fisheries management through marine reserves. Ecol. Appl., 8, 572-578.

Liggins, G.W., S.J. Kennelly and M.K. Broadhurst. 1996. Observer-based survey of by-catch from prawn trawling in Botany Bay and Port Jackson, New South Wales. Mar. Freshwater Res., 47, 877-888.

Ludwig, D. 2002. A Quantitative Precautionary Approach. Bull. Mar. Sci., 70, 485-497.

McAllister, M. and C. Kirchner. 2002. Accounting for Structural Uncertainty to Facilitate Precautionary Fishery Management: Illustration with Namibian Orange Roughy. Bull. Mar. Sci., 70, 499-540

Myers, R.A. and G. Mertz. 1998. The limits of exploitation: a precautionary approach. Ecol. Appl., 8, 165-169.

Pascoe, S. 1997. Bycatch management and the economics of discarding. FAO Fisheries Technical Paper no.370. Rome: FAO.

Pikitch, E. K., C. Santora, E.A. Babcock, A. Bakun, R. Bonfil, D.O. Conover, P. Dayton, P. Doukakis, D. Fluharty, B. Heneman, E.D. Houde, J. Link, P.A. Livingston, M. Mangel, M.K. McAllister, J. Pope, and K.J. Sainsbury. 2004. ECOLOGY: Ecosystem-Based Fishery Management. Science, 305, 346-347.

Rainer, S.F. and I.S.R. Munro. 1982. Demersal fish and cephalopod communities of an unexploited coastal area in the northern Australia. Aust. J. Mar. Freshw., 33, 1039-1055.

Rosenberg, A.A. 2002. The Precautionary Approach in Application from a Manager's Perspective. Bull. Mar. Sci., 70, 577-588.

Rumohr, H. and P. Krost. 1991. Experimental evidence of damage to benthos by bottom trawling with special reference to *Arctica islandica*. Meeresforsch, 33, 340-345.

Saila, S.B. 1983. Importance and assessment of discards in commercial fisheries. FAO Fisheries Circular No. 765, 62.

Slavin, J.W. 1982. Utilization of the shrimp bycatch. In: Fish by-catch-Bonus from the sea. Report of a Technical Consultation on the Shrimp By-catch

Utilization held in Georgetown, Guyana, October 27-30, 1981. IDRC, Ottawa, Canada, 21-28.
Sokal R.R. and F.J. Rohlf. 1995. Biometry. The principles and practice of statistics in biological research. 3rd eds. San Francisco: W.H. Freeman & Company.
Stobutzki, I.C., M.J. Miller, P. Jones and J.P. Salini. 2001. Bycatch diversity and variation in a tropical Australian penaeid fishery; the implications for monitoring. Fish. Res., 53, 283-301.
Tonks, M.L., S.P. Griffiths, D.S. Heales, D.T. Brewer and Q. Dell. 2008. Species composition and temporal variation of prawn trawl bycatch in the Joseph Bonaparte Gulf, northwestern Australia. Fish. Res., 89, 276-293.
Wassenberg, T.J. and B.J. Hill. 1987. Feeding by the sand crab *Portunus pelagicus* on the material discarded from prawn trawlers in Moreton Bay, Australia. Mari. Biol., 95, 387-393.
Watson, R. and D. Pauly. 2001. Systematic distortion in world fisheries catch trends. Nature, 424, 534-536.
Weeks, H. and Parker, S. 2002. Scientific and Management Uncertainty Create Competing Precautionary Needs for Fishery Managers. Fisheries, 27, 25-7.
Worm, B., M. Sandow, O. Andreas, H.K. Lotze and R. Myers. 2005. A Title Global Patterns of Predator Diversity in the Open Oceans - Science (Washington) [Science (Wash.)]. Vol. 309, No. 5739, 1365-1369.
Wright, J.M. 1988. Seasonal and spatial differences in the fish assemblages of the non-estuarine Sulaibikhat Bay, Kuwait. Mar. Biol., 100, 13-20.
Yamada, U., M. Tagawa, S. Kishida and K. Honjo. 1986. Fishes of the East China Sea and the Yellow sea. Seikai Regional Fisheries Research Laboratory, Nagasaki, 1-288.
Zar, J.H. 1984. Biostatistical Analysis, second ed. Prentice-Hall International, Inc, 718 pp.
Zhou, Y. and Y. Yimin. 1996. Estimation of discards and bycatch in Chinese fisheries - In Report on the Technical Consultation on Reduction of Wastage in Fisheries. (Clucas, I.J. and D. James - Eds.) Tokyo, Japan, 28 October - 1 November 1996. FAO Fisheries Report. No. 547 supplement. Rome, FAO, 1996.

(Received 2 April 2009; Revised 28 May 2009; Accepted 12 June 2009)