Energy Efficiency in Trawling Operations

M.R. Boopendranath*, V.C. George[1] and M. Shahul Hameed[2]

Abstract

Diurnal variation in trawl catches and its influence on energy efficiency of trawler operations are discussed in this paper, based on data on landings of a Japanese factory trawler which operated in the Indian waters during 1992-93. The factory vessel equipped for stern trawling had a length overall of 110 m, GT of 5460 and installed engine power of 5700 hp. Operations were conducted off the west coast of India between 31 and 278 m depth contours, using a 80.4 m high opening bottom trawl with an adjusted vertical opening of 7.60.9 m. The catch data were grouped according to the median towing hour, by the time of the day. CPUE obtained was 3713.4 kg.h^{-1} for day time operations and 1536.6 kg.h^{-1} for night-time operations. Mean daily catches were 31367 kg.day^{-1} (SE: 2743) for day time operations and 9430 kg.day^{-1} (SE: 966) for night-time operations. Fuel consumption was 0.399 and 0.982 kg fuel.kg fish^{-1}, respectively for the day and night-time operations. Total catch and catch components, such as threadfin bream, bull's eye, hair tails, trevelly, lizard fish, showed significant improvement during the day-time operations, while swarming crabs showed a significant improvement in the night-time operations. The difference in catch rates between day and night could be attributed to diurnal variation in the spatial distribution and schooling behaviour of the catch categories, their differential behaviour in the vicinity of trawl systems under varying light levels of day and night and consequent effect on the catching efficiency and size selectivity at different stages in the capture process. The results obtained in addition to its importance in the operational planning of trawling in order to realise objectives of maximising catch per unit effort and minimising fuel consumption per unit volume of fish caught, has added significance in the use of bottom trawl surveys in stock abundance estimates.

Keywords: Diurnal variation; Trawl catches; Energy efficiency

Introduction

Trawl catches are known to vary throughout the day (Woodhead, 1964; Beamish, 1966; Shepherd and Forrester, 1984; Ehrich and Groger,

* Principal Scientist, Central Institute of Fisheries Technology, Cochin
[1] Department of Aquaculture, Sacred Heart College, Thevara, Cochin
[2] School of Industrial Fisheries, Cochin University of Science and Technology, Cochin

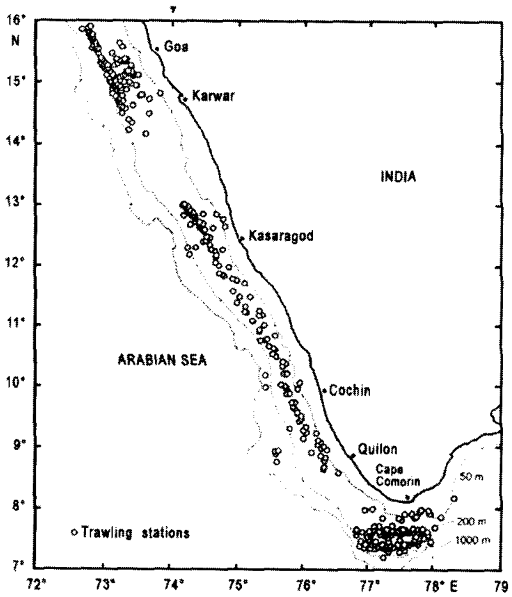
1989; Neilson and Perry, 1990; Ferno and Olsen, 1994; Francis and Williams, 1995; Freon *et. al.*, 1996; Casey and Myers, 1998; Freon and Misund, 1999; Hjellvik *et. al.*, 2002; Adlerstein and Ehrich, 2003; Axenrot *et. al.*, 2004). The differences in length distribution and species composition between day and night catches of beaked red fish were analysed by Atkinson (1989). Analysis of trawl survey results by Hylen *et. al.*, (1986) with respect to north-east Arctic cod and haddock stocks and by Godo and Wespestad (1990) on gadoids revealed a sampling problem in stock assessment surveys involving a complex set of factors including diel variation in the vertical distribution of fish. Results of a study conducted by Engas (1991) have shown diurnal variation in bottom trawl catches of cod an haddock and its influence on abundance indices. Woodhead (1964) studied the diurnal changes in trawl catches of fishes. Beamish (1966) studied the vertical migration of demersal fish in the north-west Atlantic. Shepherd and Forrester (1987) reported diurnal variation in the catchability during bottom trawl surveys off north-eastern United States. There have been no studies so far on diurnal variation in the trawl catches from the Indian Ocean region.

Materials and Methods

Data on trawl catches obtained during 4 cruises of a Japanese factory trawler which operated in the Indian waters during 1992-93, were utilised for this study. The factory vessel equipped for stern trawling has a length overall of 110 m, GRT of 5460 and an installed engine horse power of 5700 hp at 300 rpm. The vessel is a commercial deep sea stern trawler with onboard facilities for processing of *surimi* (washed and stabilised fish mince), fish fillets and fish meal.

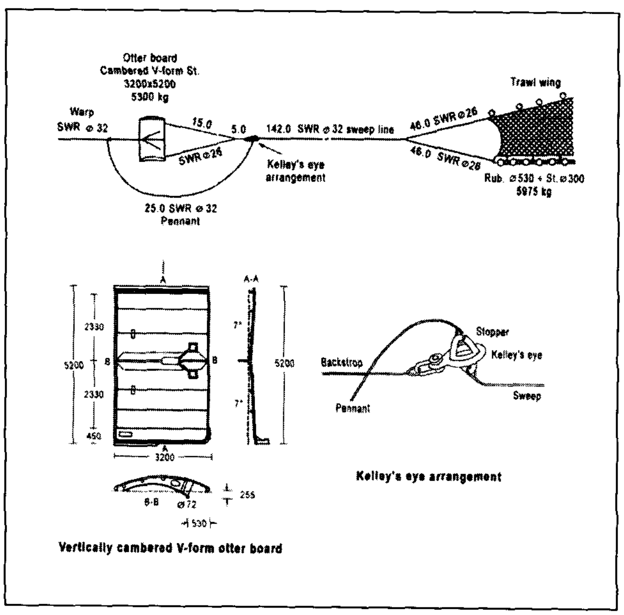
Operations were conducted off south-west coast of India, between latitudes 16° and 7° N (Fig. 1). The depth of operations ranged from 30 to 360 m, with 68% of the observations falling between 50 and 140 m depth contours. A Japanese bottom trawl of 80.4 m head line length rigged with bobbin gear for rough bottom conditions, were used for the operations. Details of rigging are given Fig. 2. Bobbin gear consisted of 530 mm dia rubber and 300 mm dia steel bobbin weighing 5975 kg in the air. Average tow duration during the period of operations was 2.7 h and mean towing speed measured using Doppler log was 4.0 0.6 kn.

Fig. 1



Trawling stations

Fig. 2



Rigging details of 80.4 m Japanese bottom trawl

Trawl geometry was estimated from data obtained from Net recorder (Furuno Electric Co., Japan) with sensors for measuring vertical opening and Otter graph (Kaiyo Denki, Japan) with sensors for depth and horizontal opening between the otter boards. The gear was so rigged as to attain a vertical opening of 10 m and it assumed ellipsoidal mouth configuration by providing wing-end strops and adjusting floatation, to suit the tropical demersal shoal characteristics.

Catch data were grouped according to the time of the day and night using the median towing hour (calculated as the hour of starting the tow plus half the tow duration). Hauls taken between local sunrise and sunset were classified as day-time hauls and those made after sunset and before sunrise as night-time hauls. The difference in catch per unit effort (catch per hour) with respect to different species groups and total catch, between day and night-time hauls were analysed using Student t test after logarithmic transformation of the data (Motte & Iitaka, 1975). In addition to total catch, the species groups analysed were threadfin bream (*Nemipterus* spp.), bull's eye (*Priacanthus* spp.), lizard fish (*Saurida* pp.), hairtails (*Trichiurus* spp.) trevally (*Caranx* spp.), perches (*Epinephelus* spp., *Lutjanus* spp. *Lethrinus* spp.), swarming crabs (*Charybdis* spp.), cephalopods (squids and cuttlefishes) and miscellaneous fish. Catches were obtained for 8 h trawling period for day and night, as 8 hours are conveniently available for towing in 12 h period of day or night allowing for time spent for shooting, hauling and ground shifting, etc. Normalised catch data were used to estimate the percentage split between day and night operations, of the total catch and catch components.

Fuel consumption per kg of fish landed was estimated from the catch data and fuel expended for 12 h duration of the day or night. Daily fuel consumption per kg of fish landed were subjected to Student t test after logarithmic transformation of data, to determine if there is any significant difference between day and night fuel consumption per unit volume of the fish landed.

Results

Average vertical opening of the trawl mouth was 7.60.9 m. Mean horizontal opening between otter boards was determined to be 116.74.7 m. Horizontal opening between wing-ends was estimated to be 34 m which is 44 % of the head line length of the trawl. Area of the trawl mouth for the assumed ellipsoidal shape of the trawl mouth was estimated to be 209 m^2 and the volume of seawater filtered per trawling hour at 4.0 kn towing speed was estimated to be 1504636 m^3.

Total landing during the four cruises conducted off the south-west coast of India was 3528.5 tonnes. 466 hauls were taken with a total duration of 1254.1 hours. Of this, 2697.6 t was landed during 280 hauls taken during the day-time from sunrise to sunset, expending 726.5 h. and 811.0 t was landed during 186 hauls taken in the night hours from sunset to sunrise, expending a total of 527.7 h. Variations in catch volume, catch rate and percentage composition of the day-time and night- time, and day and night hauls during the period of observations are given in Table 1.

Table 1

Species groups	Day-time Hauls			Night-time Hauls			Day and Night Hauls		
	Total catch, kg	CPUE, $kg.h^{-1}$	%	Total catch, kg	CPUE, $kg.h^{-1}$	%	Total catch, kg	CPUE, $kg.h^{-1}$	%
Threadfin bream	1573077	2165.43	58.31	467527	886.03	57.65	2040604	1627.12	58.16
Bulls eye	106766	146.97	3.96	15638	29.64	1.93	122404	97.60	3.49
Lizard fish	87981	121.11	3.26	23113	43.80	2.85	111094	88.58	3.17
Hairtails	78420	107.95	2.91	496	0.93	0.06	78916	62.93	2.25
Trevally	73393	101.02	2.72	805	1.53	0.10	74198	59.16	2.11
Perches	45331	62.40	1.68	15699	29.75	1.94	61030	48.66	1.74
Swarming crabs	17252	23.75	0.64	43573	82.52	5.57	60825	48.50	1.73
Scad	28854	39.72	1.07	2894	5.49	0.36	31748	25.32	0.91
Cephalopods	22116	30.42	0.82	8935	16.93	1.10	31051	24.76	0.89
Horse mackerel	2694	3.71	0.10	0	0.00	0.00	2694	2.15	0.08
Barracuda	1065	1.47	0.04	0	0.00	0.00	1065	0.85	0.03
Miscellaneous catch	660651	909.42	24.49	232270	440.18	28.64	892921	711.99	25.45
Total catch	**2697600**	**3713.40**	**100.00**	**810950**	**1536.88**	**100.00**	**3508550**	**2797.62**	**100.00**

Variation in catch volume, catch rate and percentage composition of day-time, night- time and day and night hauls

The overall catch per hour during the period of operations was 3713.4 $kg.h^{-1}$ during the day-time operations and 1536.8 $kg.h^{-1}$ during the night time operations, and daily catch was 31367.4 kg.day^{-1} (SE: 2743.0) for day-time operations and 9429.7 kg.day^{-1} (SE: 965.6) for night-time operations. Estimates of catches normalised for 8 h trawling period, were 29707 kg and 12295 kg, respectively, for day and night operations and the total for the entire day was 42002 kg. Estimates of normalised catch rates for important catch components such as threadfin bream, bulls eye, lizard fish, hairtails, trevally, perches, swarming crabs, cephalopods, scad, horse mackerel, barracuda and miscellaneous catch for both day and night operations are presented in Table 2 and percentage split between normalised day and night catches is given Fig. 3.

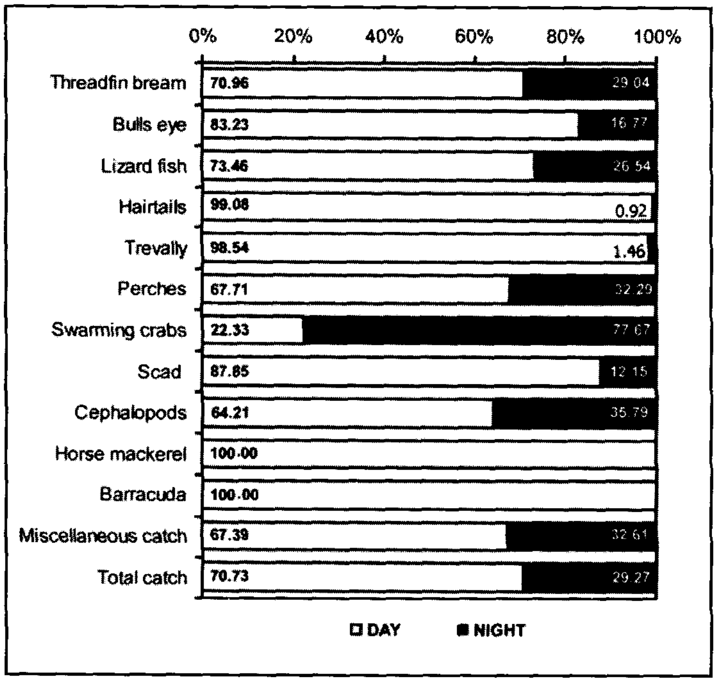
Table 2

Catch categories	Day-time catch kg	Night-time catch kg
Threadfin bream	17323	7088
Bulls eye	1176	237
Lizard fish	969	350
Hairtails	864	8
Trevally	808	12
Perches	499	238
Swarming crabs	190	661
Scad	318	44
Cephalopods	244	136
Horse mackerel	30	0
Barracuda	12	0
Miscellaneous catch	7275	3521
Total catch	**29707**	**12295**

Comparison of catches normalised for 8 h trawling period and percentage split of total catch and component groups between day-time and night-time catches.

The total fuel consumption for the period of operation was 2,060 tonnes which is equally split between day and night operations. Estimates of the fuel consumed per unit of fish production were

Fig. 3



Percentage split between normalised day and night catches

estimated from the catches during the period of operations. These were 0.399, 0.982 and 0.568 kg fuel.kg fish-1, respectively for day, night and combined period of operations (Table 3).

Table 3

	Day	Night	Day & Night
Total catch normalised for 8 h effort per day for 86 days, kg	2554802	1057370	3612172
Total fuel consumption for 86 days, kg	1029934	1029934	2059872
Fuel consumption, kg fuel kg fish^{-1}	**0.403**	**0.974**	**0.570**

Fuel consumption per unit volume of fish caught during day, night, and day and night hauls

Discussion

Trawl operations were carried out continuously during the 24 h period within a depth strata 30 -360 m, with the 95 % of the operations falling within 180 m depth contour, between latitudes 16° and 7° N, off south-west coast of India. During the period of operations, the vessel spent on an average 16.2 % time for sailing and ground shifting, 6.5 % for shooting operations, 57.9 % for towing the gear, 7.9 % for hauling and the balance for performing miscellaneous functions.

The catch data showed large diurnal differences in the volume of total catch and catch components and in the catch composition.

Catch per unit effort (CPUE) in terms of total catch was 3,713.4 and 1,536.9 $kg.h^{-1}$, respectively for day and night operations (Table 1). The percentage improvement in CPUE realised during the day-time was over 140 % compared to night operations. The difference in daily catch rates between day and night was found to be statistically highly significant ($p<0.01$; df: 86). Percentage split of the normal landings between day and night were 70.7 and 29.3 % respectively (Fig. 3).

Threadfin bream (*Nemipterus* spp.) of the family Nemipteridae represented the most abundant catch component during day and night operations, contributing 58.31 and 57.65 %, respectively. It formed 58.16 % of the combined landings of day and night, during the period of operations. Threadfin bream seems the most abundant demersal fish resource and its potential yield off the west coast of India, beyond 50 m depth in the continental shelf and slope, has been estimated to be 96200 tonnes which forms about 20 % of the total potential of demersal resources from this zone (Sudarsan, *et. al.*, 1990). CPUE for threadfin bream catches were 2,165.4 and 886.0 $kg.h^{-1}$, respectively for day and night hauls (Table 1). Percentage split of the normal landings of threadfin bream between day and night were 71.0 and 29.0 %, respectively, representing an improvement of 144 % over night catches (Fig. 3). The difference in the landings of threadfin bream between day and night was statistically highly significant ($p<0.01$; df: 80).

Bull's eye (*Priacanthus* spp.) which ranked second in terms of abundance in the total landings (3.49%) contributed 3.96 % of the day-time landings and 1.93% of the night catches. Estimated potential yield of bull's eye from the west coast of India beyond 50 m depth is 43700 tonnes which forms about 9 % of the total potential demersal yield from this area (Sudarsan, *et. al.*, 1990). CPUE was 146.97 and 29.64 $kg.h^{-1}$, respectively for the day and night hauls, showing a near five-fold increase during the day-time as compared to night landings. The day-night split of the normal landings was 83.23 and 16.77 % respectively (Fig. 3). The difference in daily catch rates between day and night was found to be highly significant ($p<0.01$; df: 24).

Lizard fish (*Saurida* spp.) contributed 3.26 % to the day-time catches, 2.85 % to the night catches and 3.17 % of the total landings. Potential yield of the lizard fish off west coast of India beyond 50 m was estimated to be 18,800 tonnes and forms about 4 % of the potential demersal resource from this zone (Sudarsan, *et. al.*, 1990). The CPUE of lizard fish were 121.11 and 43.80 $kg.h^{-1}$, respectively for day and night hauls, showing an improvement of over 170 % over the night landings. The split between day and night in the total normal landings was 73.46 and 26.54 %, respectively (Fig. 3). However, the difference between daily day and night landings of the lizard fish was not found to be statistically significant (($p>0.05$; df: 16).

Hairtails (*Trichiurus* spp.) or ribbon fishes contributed 2.91 % to the day-time catch while it contributed only 0.06% in the night catches and ranked fourth in the overall landings (2.25%) (Table 1). The potential yield of hairtails from the west coast of India beyond 50 m depth was estimated to be 22100 tonnes which forms about 4.5 % of the potential demersal yield from this area (Sudarsan, *et. al.*, 1990). The CPUE obtained were 107.95 and 0.93 $kg.h^{-1}$, respectively for day and night operations, showing a pronounced difference in the catchability according to the time of the day. The percentage split between day and night in the normal landings was 99.08 and 0.92, respectively (Fig. 3). The difference in catch rates was statistically highly significant ($p<0.01$; df: 16).

Trevally (*Caranx* spp.) formed 2.72 % in the day-time catch and 1.53 % in the night landings (Table 1). Estimated potential yield of trevally from the west coast of India, beyond 50 m depth is 11600 tonnes which forms 2.4 % of the potential demersal yield from this zone (Sudarsan, *et. al.*, 1990). The CPUE were 101.02 and 1.53 $kg.h^{-1}$, respectively for day and night period of operations. Percentage split of the normalised landings between day and night were 98.54 and 1.46 %, showing a highly pronounced difference between the two periods of operations (Fig. 4). The difference in the daily landings between day and night was found to be statistically significant ($p<0.05$; df: 6).

Perches consisting mainly of groupers (*Epinephelus* spp.), snappers (*Lutjanus* spp.) and sea breams (*Lethrinus* spp.) contributed 1.68, 1.94 and 1.74 %, respectively of the day, night and total landings (Table 1). Perches are estimated to have a potential yield of 11100 tonnes and forms 2.3 % of the potential demersal fishery resources off west coast of India beyond 50 m depth (Sudarsan, *et. al.*, 1990). The CPUE realised was 62.40 and 29.75 $kg.h^{-1}$, respectively for the day and night operations. Day-time operations contributed 67.71 % of the normalised catches of these species while night hauls contributed 32.29 % (Fig. 4). Percentage improvement in the landings during day-time was 110 % compared to night hauls. However, the difference in the daily catch rates between day and night was not found to be statistically significant ($p>0.05$; df: 26).

Swarming crabs (*Charybdis* spp.) contributed 0.64, 5.37 and 1.73 % respectively to the day, night and total landings (Table 1). The CPUE were 23.75 an 82.52 $kg.h^{-1}$, respectively for the day and night hauls. Percentage split of the normalised landings of the species between day and night were 22.33 and 77.67 % (Fig. 4), respectively, showing a pronounced improvement of 248 % in the night, compared to day-time operations. The difference in catch rates between night and day was found to be statistically highly significant ($p<0.01$; df: 10). Swarming crabs which form extensive swarms are considered to be an undesirable by-catch in the trawl landings.

Cephalopods consisting of squids (*Loligo* spp., *Sepioteuthis* spp.) and cuttlefishes (*Sepia* spp.) contributed 0.82, 1.10 and 0.88 % of the day, night and total landings, respectively (Table 1). Squids and cuttlefishes are estimated to have a potential yield of 19500 tonnes off the west coast of India, beyond 50 m depth contour and forms about 4 % of the potential demersal resources of this zone (Sudarsan, *et. al.*, 1990). The CPUE realised was 30.42 and 16.93, respectively for day and night hauls with a corresponding percentage split of 64.21 and

35.79 in the normalised landings (Fig. 4). Day-time operations showed an improvement of 79 % over the night-time hauls. However, the difference in catch rates was not found to be statistically significant ($p>0.05$; df: 32).

Scad (*Decapterus* spp.) contributed 1.07, 0.36 and 0.91 % of the day, night and total landings (Table 1). Potential yield of scad off west coast of India beyond 50 m depth is estimated to be 11500 tonnes which forms about 2.3 % of the potential demersal yield form this zone (Sudarsan, *et. al.*, 1990). The CPUE realised were 39.72 and 5.49 $kg.h^{-1}$, respectively for day and night operations, indicating a seven-fold increase in the catch rates during day-time hauls. The percentage split in the normalised landings between day and night were 87.25 and 12.15 %, respectively (Fig. 4). The difference in catch rates was found to be statistically highly significant ($p<0.01$; df: 14).

Horse mackerel (*Megalaspis* spp.) and barracuda (*Sphyraena* spp.) contributed 0.10 and 0.04 % of the day-time landings while they were unrepresented in the night hauls. Their CPUE for day-time hauls were 3.71 and 1.47 $kg.h^{-1}$, respectively (Table 1).

Miscellaneous catch consisting of the rest of the species groups represented 24.49, 28.64 and 25.45% in the day, night and total landings (Table 1). The CPUE for the miscellaneous catch were 909.42 and 440.18 $kg.h^{-1}$, respectively for day and night operations. Percentage split between day and night of the normalised landings of this group were 67.39 and 32.61, respectively, showing a two-fold increase in the volume of day-time landings (Fig. 4). The difference in the catch rates of the miscellaneous catch between and day and night, was found to be statistically significant ($p<0.05$; df: 84).

The energy consumed per unit of fish production increased from 0.403 kg $fuel.kg\ fish^{-1}$ realised during day-time operations to 0.974 kg fuel.kg $fish^{-1}$ during the night-time operations (Table 3). The percentage increase in fuel consumption per unit volume of fish caught was 142 % higher during night-time compared to day-time trawling. The difference in fuel consumption per unit volume of fish caught calculated in terms of normalised landings, was found to be statistically highly significant ($p<0.01$; df: 86). Results indicated a strong case for significant improvement in trawler landings and reduction in fuel requirement in capture process, with consequent increase in profitability, by maximising the fishing operations during day-time.

The degree of success of trawling operations is influenced generally by three factors, viz. (i) spatial distribution of fish in relation to fishing gear; (ii) behaviour of fish in the vicinity of fishing gear and (iii) intrinsic selection properties of the fishing gear system itself (Parrish, *et. al.*, 1964; Doubleday and Rivard, 1981; Hylen, *et. al.*, 1986; Engas, 1994). Diurnal differences in the catch and catch composition are reported by Woodhead (1984), Beamish (1966), Shepherd and Forrester (1987), Ehrich and Groger (1989), Walsh (1988; 1989) and others. Diurnal changes in catch rates is generally assumed to reflect changes in the availability of the resource to the trawl system, in terms of its spatial distribution and shoaling behaviour which may vary according to the time of the day. Fish behaviour in the vicinity of trawl system might also change according to the time of the day and visibility (Glass and Wardle, 1989). Studies by Engas and Godo (1986) and Engas (1991) in the Barents Sea have reported higher catch rate for cod and haddock during day-time. They also observed diurnal differences in the species and size composition, obtaining a higher haddock-cod ratio and increase in small haddock during day-time hauls. Though not specifically studied here, diurnal changes in the length classes is also to be expected as indicated by studies elsewhere (Engas and Godo, 1986; Engas, 1991; Hylen, *et. al.*, 1986; Godo and Wespestad, 1990).

In the vicinity of the trawl system, fish are exposed to a number of stimuli both visual and auditory in nature, generated by the vessel; otter boards; sand-mud clouds produced by the otter boards, sweeps and ground rig; the net and it peripheral components. Even though many fish can detect sound and react to it, it is vision that cause fish to react in a firm and precise manner to an object (Wardle and He, 1996) Vision of fish is affected by light levels, colour of the objects and the background. Glass and Wardle (1989) demonstrated that mackerel ceased schooling at light levels below 10^{-6} lux. In high light level conditions in the day time, fish showed ordered patterns of behaviour in the vicinity of the trawl mouth and in the night, at light level lower than the threshold, these ordered patterns of behaviour were seen to have disappeared.

Vision could thus be considered to be the most important sense involved during day time trawling, up to depths where light penetration is above threshold level for eliciting response behaviour from the fish. The otter boards are the first conspicuous part of the trawl system sensed by the fish visually as the gear approaches (Korotkov, 1984; Wardle, 1986). The appearance of the otter boards depends on the type of the seabed, light level and the background. Fish avoid the approaching otter boards by swimming around it. The visible range is known to determine the reaction distance to otter boards (Wardle, 1986). Fish between the otter boards are guided by the sweeps and sand-mud clouds generated by the otter boards, sweeps and ground gear components, towards the centre of the approaching trawl (Main and Sangster, 1981a; 1981b). The sweep angle, which is the angle between sweeps and towing direction, is known to influence the herding and sweep angles above 20° are shown to significantly reduce the catching ability for cod and haddock (Strange, 1984). Korotkov (1984) reported that highly visible sand-mud clouds in alignment with the sweeps provide a strong herding effect. Fish herded in to the vicinity trawl mouth by otter boards, sweeps and sand-mud clouds are known to behave differentially as it approaches the trawl mouth. Fish turn to swim in the same direction of the tow at the mouth of the trawl just before the ground gear, until they are exhausted and fall back into the trawl bag (Hemmings, 1969; Wardle, 1986; Glass and Wardle, 1969; Engas, 1994). Different species show different behaviour response in the net mouth area of trawl (Main and Sangster, 1981a; 1981b)

The capture efficiency of trawls may thus vary considerably according to the time of the day, since the reaction distance, fish orientation and escape behaviour change with the light level available at the depth of operation, at various stages of capture process. In addition, differences in species and size selectivity may take place due to variation in the response behaviour between different species and size classes. Generally herding effect is reduced at low light levels causing a reduction in the effective swept area in front of trawl mouth.

Conclusions

In the present study, total catch and catch components such as threadfin bream, bulls eye, hairtails, trevally, scad, lizard fish, perches, cephalopods and miscellaneous catch showed a pronounced improvement during day-time operations. On the other hand the crustacean component, *viz.* swarming crab, showed a significant improvement in the night operations. In the light of discussions in the preceding paragraphs, the difference in catch rates between day and night, could be attributed to diurnal variation in the spatial distribution and schooling behaviour of the catch categories, their differential behaviour in the vicinity of the trawl gear system under varying light levels of the day and night and the consequent effect on the catching efficiency, and species and size selectivity at different stages in the capture process.

In addition to its importance in the operational planning of trawling operations to realise objectives of improving trawl selectivity, maximising catch per unit effort and minimising fuel consumption per unit volume of fish caught, the results obtained in this study has added significance in the use of bottom trawl surveys in stock abundance estimates and biological investigations. When trawl catches are used to monitor abundance indices or for conversion of acoustic abundance to absolute abundance estimates, the basic assumption is that each trawl sample provides a representative estimate of the density of species and length classes of the particular depth stratum. It is clear from the diurnal variation observed in the catch volume and composition of catch during this study, that this assumption is not met. Hence, it is necessary to take into account the diurnal differences in estimating abundance indices and data derived from day and night need to be given equal weight, while interpreting trawl survey results, to arrive at realistic stock abundance estimates.

References

Adlerstein, S. and Ehrich, S., 2003. Patterns in diel variation of cod catches in North Sea bottom trawl surveys, *Fish. Res.* **63(2)**, pp. 169-178.

Atkinson, D.B., 1989. Diel movements of beaked red fish and the implications of these for stratified random trawl estimates of biomass and abundance, *N. Am. J. Manage.* **9**, pp. 163-170.

Axenrot, T., Didrikas, T., Danielsson, C., and Hansson, S. 2004. Diel patterns in pelagic fish behaviour and distribution observed from a stationary, bottom-mounted, and upward-facing transducer. *ICES J. Mar. Sci.*, **61**, pp. 1100-1104.

Beamish, F.W.H., 1966. Vertical migration by demersal fish in the north-west Atlantic, *J. Fish. Res. Bd.* Canada. **23**. pp. 109-139.

Casey, J. M. and Myers, R.M., 1998. Diel variation in trawl catchability: is it as clear as day and night? *Can. J. Fish. Aquat. Sci.* **55**, pp. 2329-2340.

Doubleday, W.G. and Rivard, D., 1981. Bottom trawl surveys, Can. Spec. Publ. *Fish. Aquat. Sci.* **58**, 273 pp.

Ehrich, S. and Groger, J., 1989. Diurnal variation in the catchability of several fish species in the North Sea, *ICES C.M.* 1989/B. **35**, pp. 1-10.

Engas, A. and Godo, O.R., 1986. Influence of trawl geometry and vertical distribution of fish on sampling with bottom trawl, *J. Northwest. Atl. Fish. Sci.* **7**, pp. 35-42.

Engas, A. and Ona, E., 1991. Day and night fish distribution pattern in the net mouth area of the Norwegian bottom sampling trawl, Rapp.P.-V. *Reun. Cons. Int. Explor. Mer.*, **189**, pp. 123-127.

Engas, A., 1991. *The Effects of Trawl Performance and Fish Behaviour on the Catching Efficiency of Sampling Trawls*, Ph.D. Thesis, University of Bergen, Bergen, 169 pp.

Engas, A., 1994. The effects of trawl performance and fish behaviour on catching efficiency of demersal sampling trawls, In: Ferno, A. and Olsen, S. (Eds.) *Marine Fish Behaviour in Capture and Abundance Estimation*, Fishing News Books, Osney Mead, Oxford., pp. 45-68.

Fabi, G., and Sala, A. 2002. An assessment of biomass and diel activity of fish at an artificial reef (Adriatic Sea) using a stationary hydroacoustic technique. *ICES J. Mar. Sci.* **59**, pp. 411-420.

Ferno, A. and Olsen, S. (Eds). 1994. *Marine Fish Behaviour in Capture and Abundance Estimation*. Fishing News Books, Oxford, 221 pp.

Francis, M. P. and Williams, M.W., 1995. Diel variation in trawl catch rates of *Pagrus auratus* (Sparidae), *Fish. Res.* **24**, pp. 301-310.

Freon, P., and Misund, O.A. 1999. *Dynamics of Pelagic Fish Distribution and Behaviour: Effects on Fisheries and Stock Assessment.* Fishing News Books, Blackwell Science Ltd, Oxford. 348 pp.

Freon, P., Gerlotto, F., and Soria, M. 1996. Diel variability of school structure with special reference to transition periods. *ICES Journal of Marine Science.* **53**. pp. 459-464.

Glass, C.W. and Wardle, C.S., 1989. Comparison of the reaction of fish to a trawl gear, at high and low light intensities, *Fish. Res.* **7(3)**. pp. 249-266.

Godo, O.R. and Wespestad, V., 1990. Monitoring changes in abundance of gadoids with varying availability to the applied survey techniques. In: Godo, O.R. (1990) *Factors Affecting Accuracy and Precision in Abundance Estimates of Gadoids from Scientific Trawl Surveys*, Ph.D. Thesis, Institute of Fisheries and marine Biology, University of Bergen, Norway. pp. 139-169.

Hemmings, C.C., 1969. Observations on the behaviour of fish during capture by Danish seine net, and their relation to herding by trawl bridles, In: Ben Tuvia, A. and Dickson, W. (Eds.) Proc. FAO Conference on Fish Behaviour in Relation to Fishing Techniques and Tactics, Bergen, Norway, 19-27 October 1967, *FAO Fish. Rep.* **62(3)**. pp. 645-655.

Hjellvik, V., Godø, O.R.and Tjøstheim, D., 2002. Diurnal variation in bottom trawl survey catches: does it pay to adjust? *Can. J. Fish. Aquat. Sci.*. **59(1)**. pp. 33-48.

Hylen, A., Nakken, O. and Sunnana, K., 1986. The use of acoustics and bottom trawl surveys in the assessment of north-east Arctic cod and haddock stocks. In: Alton, M. (Ed.) *A Workshop on Comparative Biology, Assessment and Management of Gadoids from North Pacific and Atlantic Oceans*, Seattle, Washington, USA., pp. 473-498.

Korotkov, V.K., 1984. Fish behaviour in a catching zone and influence of bottom trawl rig elements on selectivity, *Coun. Meet. Int. Coun. Explor Sea, C.M.* 1984/B. **15**. pp.1-14.

Main, J. and Sangster, G.I., 1981a. A study of the sand clouds produced by the trawl board and their possible effect on fish capture, *Scott. Fish. Res. Rep.* **20**. pp. 1-20.

Main, J. and Sangster, G.I., 1981b. A study of the fish capture process in a bottom trawl by direct observations from an underwater vehicle, *Scott. Fish. Res. Rep.* **23**. pp. 1-23.

Neilson, J. D., and Perry, R. I. 1990. Diel vertical migrations of marine fish: an obligate or facultative process? *Advances in Marine Biology*, **26**. pp. 115-167.

Parrish, B.B., Blaxter, J.H.S. and Hall, W.B., 1964. Diurnal variation in size and composition of trawl catches, *Cons. Explor. Mer.* **155**. pp. 27-34.

Shepherd, J.G. and Forrester, J., 1987. Diurnal variation in the catchability during bottom trawl surveys off north-eastern United States. *ICES C.M.* 1987/B. **44**. pp. 1-15.

Strange, E.S., 1984. Review of fishing trials with Granton and Saro deep sea trawl gear 1963-1967, *Scottish Fisheries Working Paper*. **8(84)**. pp. 1-60.

Sudarsan, D., John, M.E. and Somavanshi, V.S., 1990. Marine fishery resources potential in the Indian Exclusive Economic Zone - an update, *Bull. Fish. Surv. India*, December 1990, Fishery Survey of India, Bombay, pp.1-27.

Walsh S.J., 1989. Diel influences on fish escapement beneath a ground fish survey trawl, *Coun. Meet. int. Coun. Explor. Sea, C.M.* 1989/B:21, pp.1-22.

Walsh, S.J.,1988. Diel variability in trawl catches of juveniles and adult yellow tail flounder on the Grand banks and the effect on resource assessment, *N. Am. J. Fish Mange.* **8**. pp. 373-381.

Wardle, C.S. and He, P., 1996. Fish behaviour near trawls - recent advances, In: *Proc. Workshop on Cooperation Research in Asian Fishing*

Technology, March 1996, **2**. National Research Institute of Fisheries Engineering, Fisheries Agency, Hasaki, Ibaraki Pref., Japan, pp. 35-44.

Wardle, C.S.,1986. Fish behaviour and fishing gear, In: Pitcher, T.J. (Ed.) *The Behaviour of Teleost Fishes*, Croom Helm Ltd., London and Sidney, pp. 463-595.

Woodhead, P.M.J., 1964. Diurnal changes in trawl catches of fishes, *Rapp. P.-v. Reun. Cons. int. Explor. Mer.* **155**. pp. 35-44.