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Can fishermen allocate their fishing effort in space and time on the basis of their catch rates? An example from Spermonde Archipelago, SW Sulawesi, Indonesia

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Abstract Spatial and temporal patterns in catch rates and in allocation of fishing effort were analysed for the coastal fishery in Spermonde Archipelago, Indonesia, to assess whether fishermen can optimise their strategy from catch information, or whether they fish under great uncertainty and merely minimise risks. On average 517 fishing units operated in the 2800 km^2 area, catching 21 t fish day^{-1}. Major gear categories were hook and line (59% of total effort and 5% of total catch), and lift nets (16% of total effort and 70% of total catch). The size of individual resource spaces varied with gear type and was smaller in unfavourable weather conditions. Although spatial patterns in catch rates at the scale of the whole archipelago were evident, fishermen could not differentiate between locations, as catch variance within their individual resource spaces was high relative to the contrasts in spatial patterns. The aggregated distribution of fishing effort in Spermonde must be explained by factors such as the small scale of operations, rather than fish abundance.

KEYWORDS: catch variance, coastal fishery, effort optimisation, Indonesia.

Introduction

Spatial and temporal patterns in the allocation of fishing effort are of interest to assess the impact of fishing effort on resources, and for the evaluation of management options and their consequences (Medley, Gaudian & Wells 1993). Following patterns of effort distribution, management measures regulating this effort can be confined to areas or seasons where they have the most desirable effect on the fish stocks and the least consequences for fishing communities that are engaged in non-harmful fishing activities.

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Spatial patterns are uniform, random, or aggregated (Krebs 1989; Begon, Harper & Townsend 1990; Sokal & Rohlf 1995). Most fisheries show aggregated patterns in the distribution of effort at different scales under the influence of a combination of ecological, social, cultural, economic and technical factors (Russ 1991; King 1995; Jennings & Kaiser 1998).

1. Large-scale: the distribution of fish stocks, and thus the fishery, is driven by ecological factors (Pauly 1988; Sampson 1991). Productivity varies with local differences in nutrient supply, topography and heterogeneity of habitat (Medley *et al.* 1993).
2. Medium-scale: fishing occurs in groups or in sheltered waters during rough weather conditions to minimise the risk of accidents. For the same reasons, effort is often aggregated close to population centres and in fair weather periods (Gillis, Peterman & Tyler 1993; Medley *et al.* 1993; Munro 1996). Also, cultural taboos and existing management regulations close certain areas or seasons to fishing (Gillis *et al.* 1993; Ruddle 1996).
3. Small-scale: the driving force behind a commercial fishery is the value of the fish, so fishing effort in more structured environments such as coastal shelves is likely to aggregate at locations where highly valued species, e.g. reef demersal fish, are found (Medley *et al.* 1993). Also, the distribution of fishing units is affected by geomorphological characteristics of the environment. The technical operation of, for example, a trawled net requires a habitat where the net cannot get snagged.

The simplest presentation of the spatial distribution of fishing effort is circular resource spaces, where the size of the radius is limited by the travelling distance of the fishing boats based at the island or coastal village, and varies with weather conditions (Sampson 1991). Within their individual resource spaces, effort would be allocated to suitable habitats, such that the shape of the actual resource space fished by individuals is no longer radial. In a subsistence fishery, local depletion of a species would cause fishermen to switch to catching other species within their resource space, whereas in a commercial fishery, economic forces could trigger motorisation so that fishermen can expand their search for target fish to previously unexploited waters (Jennings & Kaiser 1998). Motorisation increases the number of locations a fisherman may choose from.

In general, fishing effort will be concentrated in geographical regions with high catch-per-unit-effort (CPUE) (Gulland 1985), which is a generalisation of Hilborn & Ledbetter (1979) that a fisherman optimises the difference between the value of his catch and his operation costs, rather than his CPUE. For that purpose a fisherman can assess the probability of encountering target fish at different locations using earlier experience, which can be regarded as his personal, historical 'database' (Mangel & Clark 1983; Eales & Wilen 1986; Sampson 1991; Gillis *et al.* 1993; Medley *et al.* 1993). Exploratory fishing provides additional information and can be regarded as sampling the area, but it introduces extra costs, especially when potential fishing locations are more remote from the home port. The value of this additional information must be weighed against the extra costs (Mangel & Clark 1983). If the variability of catches is already high, fishermen might accept lower revenues rather than face extra costs and risks exploring unknown sites (Smith & McKelvey 1986).

Whether a fisherman uses acquired knowledge to stabilise, optimise or maximise his returns, the success of his fishing strategy depends on a combination of factors some of which he cannot influence (Allen & McGlade 1986; Nietschmann 1989; Sampson 1991; Hanna & Smith 1993). Crawley (1992) categorised these as extrinsic or intrinsic constraints, which are not independent. Extrinsic constraints are limitations imposed by the environment in the broad sense, such as weather conditions, the nature of fish stocks, marine tenure and management regulations. Intrinsic constraints are limitations in tolerances or abilities of fishermen or limitations imposed by his gear or boat (Ruddle 1993, 1996; Johannes 1994).

This paper describes and analyses spatial and temporal patterns in fishing effort and catch rates at a large and small scale, to assess whether fishermen can influence the success of their strategy from using catch information, or whether they fish under large uncertainties and merely minimise their risks. The large spatial scale is that of Spermonde (2800 km^2), a shelf area near the capital city of Ujung Pandang, SW Sulawesi, Indonesia, and the small spatial scale is that of a fisherman's individual resource space, down to 50 km^2. The large temporal scale is that within a year between seasons and the small temporal scale is that within months between days.

Material and methods

Study area

A rectangular part in the Spermonde Archipelago of approximately 2800 km^2 (40×70 km^2) was selected as a research area (Fig. 1). This area, situated north-west of Ujung Pandang, includes 49 of the 54 islands in Spermonde, and submerged coral reefs, sandy shallows and deep waters (Anonymous 1992). The reef area consisted of fringing reefs around the islands, the barrier reefs and the patch reefs, a total of 185 km^2 or 7% of the research area (Uljee, Engelen & White 1996). These reefs provide food, income and coastal protection to approximately 6500 fishing households that are scattered over the islands and some 25 coastal villages (Anonymous 1995; Bureau Pusat Statistik 1995a,b). Moll (1983) and Hoeksema (1990) identified four ecological zones based on the cross-shelf distribution of coral species. Delineation of these zones follows bathymetric lines parallel to the coastline and most of the 24 populated islands are situated in the two zones nearest to the mainland of SW Sulawesi. Spermonde is exposed to one rainy season during the north-west monsoon from December through April.

Sampling the fishery

The study on spatial and temporal patterns in the Spermonde fishery was conducted from January 1996 until January 1997 and included effort and catch assessment surveys. An effort assessment survey (EAS) was conducted monthly at sea to give an accurate description of the spatial and temporal patterns in fishing effort for the various gears and to estimate the total effort per gear. Four belt transect sampling routes were monitored with an 8-m research vessel with two 40-hp outboard engines. The positions of fishing activities along transects were recorded on laminated nautical charts. In total, 7569 fishing units were recorded.

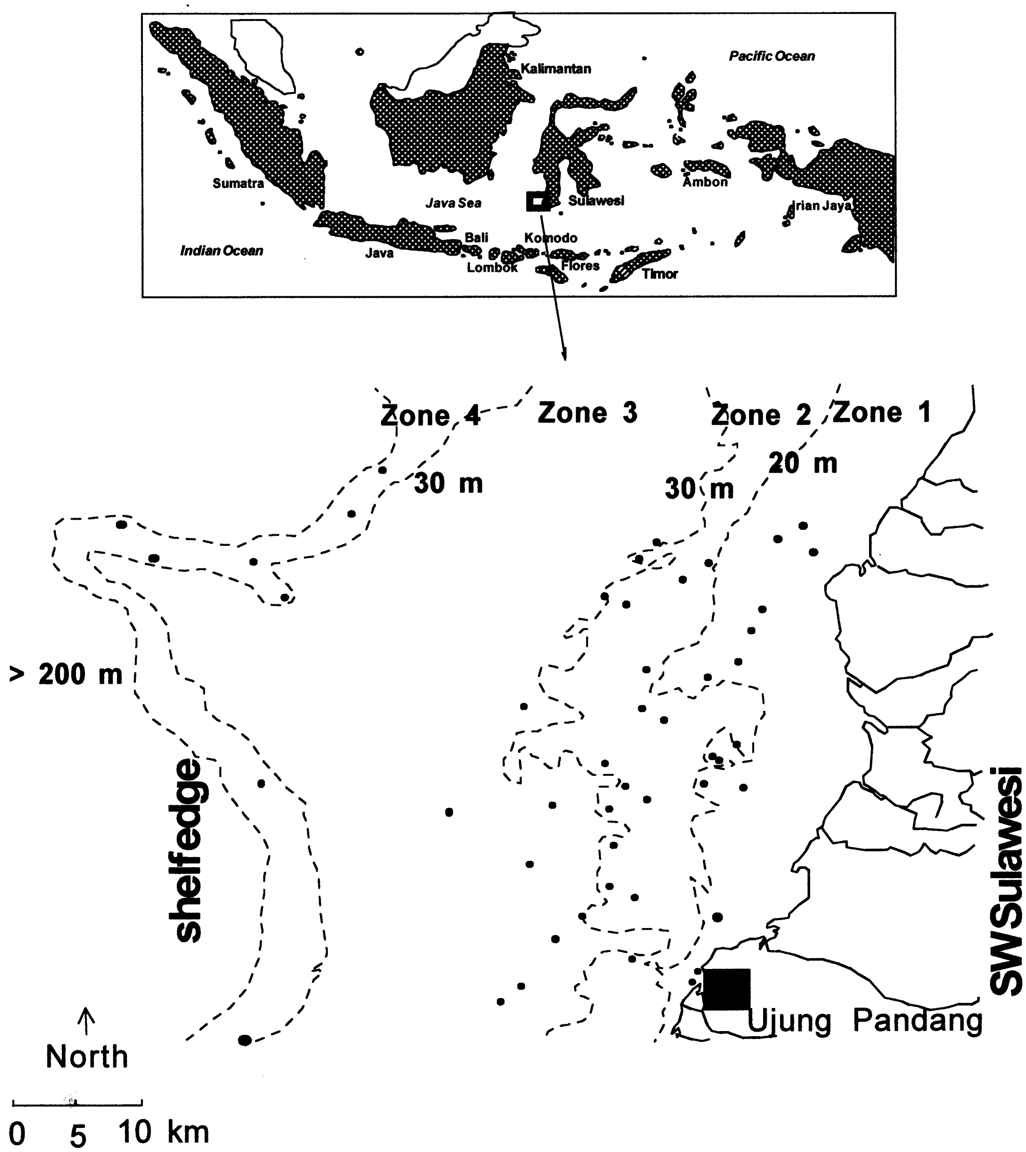

Figure 1. The study area at Spermonde Archipelago off SW Sulawesi. Indicated are four ecological zones that differ in maximum depths. Black dots represent islands and depth lines that separate the four zones are indicated. Ujung Pandang is the province capital city at the SW Sulawesi mainland.

The catch assessment surveys (CASs) were conducted at sea at two spatial scales.

1. Large-scale, within the Spermonde shelf area. A sub-sample (18%) of the boats observed during the EAS was approached and the fisherman was asked permission to record his catch (species and size composition) and to answer questions on his fishing activities. In total, 1359 boats were sampled.
2. Small-scale, within the resource space of an individual fisherman. Spatial effort allocation of six individual fishermen, each using one of the most frequently observed fishing gears, was mapped during 1 month per fisherman. Day-to-day variances in CPUE as experienced by the individual fisherman were assessed and it was evaluated whether spatial allocation of fishing effort was based on profitable catches during the previous day. For each catch the geographical location was recorded with GPS.

During the effort and catch surveys at sea the extrinsic factors, i.e. shelf zone, habitat type, water depth and weather conditions (wind, wave height, clouds and rain), were also recorded.

Data processing and analysis

Spatial and temporal patterns in fishing effort and CPUE per gear and for gears combined were analysed at the large scale of Spermonde (spatial) and per season (temporal). At the small spatial scale, patterns for six common gears were analysed within individual resource spaces and between days. In the analysis of spatial and temporal patterns in effort allocation at sea, which included non-sampled fishing units, hook and line fishermen targeting demersal fish and targeting for pelagic fish were combined.

A grid with squares of 2×2 km^2 was used as an overlay at the large scale of the entire research area. The squares were grouped in four shelf zones, four north-south latitudes and five depth ranges. Monthly average abundance of fishing units for each gear category in every square was calculated. To test whether the observed spatial distribution pattern of fishing effort deviated from random, the dispersion coefficient, being the ratio of variance and mean, was estimated. At the smaller scale of the individual resource spaces, three different grid sizes of 1×1, 2×2 and 5×5 km^2 were used. In case the dispersion coefficient was significantly higher than the expected unity, the distribution was considered aggregated (Krebs 1989).

Monthly estimates of effort per gear category (number of fishing units day^{-1}) per square were subjected to statistical analysis using generalised linear modelling and ANOVA. Since the proportion of squares containing zero number of units per sampling day amounts to well over 50%, the abundance data were first transformed in a presence–absence variable. This binomial distributed response variable was analysed using logistic regression with a logit link function. The response variable was calculated as the ratio of number of events and number of trials, resulting in a proportion of squares where at least one fishing unit was observed. The linear predictor, $g(m)$, was determined using the following model:

$$g(m)_{ijklmn} = \mu + zone_i + latitude_j + habitat_k + depth_l + season_m + \varepsilon_{ijklmn} \quad (1)$$

where μ = overall mean, zone = effect of zone i (1–4), latitude = effect of latitude j (1–4), habitat = effect of habitat k (1–4), depth = effect of depth l (1–5), season = effect of season m (1–2), and ε_{ijklmn} = error. Latitudes were defined as areas perpendicular to the coast line with a width in a north-south direction of approximately 20 km starting at coordinate S 4°33′ and ending at S 5°13′. Five depth categories (0–10, 10–20, 20–30, 30–40, and > 40 m) and four habitat categories (coral reef, sandy reef, sea grass bed, open water) were defined.

The model was implemented using the GENMOD procedure of the SAS software (SAS 1990). In case of significant effects, the 95% confidence limits of the predicted values were calculated and compared to test for significant differences between main group means. Effects of zone, latitude, depth and season on effort abundance were estimated using ANOVA, excluding the zero observations. Effort abundance data were $\log_{10}$-transformed to meet the conditions for parametric analysis of variance. The model used was:

$$Y_{ijklm} = \mu + zone_i + latitude_j + depth_k + season_l + \varepsilon_{ijklm} \quad (2)$$

where Y_{ijklm} is the dependent variable ($\log_{10}$) effort abundance. Residuals were tested for normality and 95% confidence limits were estimated to compare main group means in case of significant effects.

To study whether the observed patterns in effort allocation resulted from intrinsic or extrinsic constraints that limited a fisherman's choice of fishing locations, variance in distributions of distances travelled from origin to fishing location was analysed. Distances travelled to reach a fishing location were estimated by applying Pythagoras's rule to the coordinates of the fishing location and the village of origin. The model used was similar to (2) but included the variable 'boat type' and four class variables that described weather conditions (wind, wave height, cloud cover and type of rain) rather than season.

The catches, which were sampled at different times of the day, were corrected to a fixed fishing period of 6 h. For different gears an exponential relation between sampled total catch at the moment of sampling and fishing duration until then was fitted: $C_t = \alpha t^{\gamma}$, where C_t equals the actual catch at the moment of sampling (0.1 kg), α is a coefficient, t the fishing duration ($\frac{1}{4}$ h) and γ the exponent. $C_6 = C_t(6/t)^{\alpha}$, where C_6 is the estimated catch after 6 h fishing, which is considered as an unbiased estimate for CPUE (kg day^{-1}) for a particular gear type. From the EAS, the average duration of a trip was estimated at 6 h. Fishermen on lift net and purse seine boats were interviewed to obtain information on their CPUE because they fished at night. CPUE estimates for each gear category were $\log_{10}$-transformed and subjected to ANOVA with zone, latitude, depth and season as independent class variables. The standard deviation ($s\log_{10}CPUE$) in the residuals, calculated as the square root of the model mean square error, indicated the uncertainty or day-to-day variance in CPUE for each gear. Per 2×2 km^2, values of CPUE were correlated with the mean number of fishing units using Pearson's correlation coefficient (Sokal & Rohlf 1995).

The distance of a fishing location on a particular day to the location on the previous day was related to CPUE on that previous day to analyse the possible effect of CPUE on the allocation of fishing effort within the individual resource space. If this distance decreased with increasing CPUE, the fisherman had apparently reacted on a high CPUE at a particular location by allocating his next day fishing activity near that location again. Whether such a strategy is effective was evaluated by looking for significant auto-correlation ($P < 0.05$) in the time series of daily catches with a time-step of 1 day. To study whether a larger risk was rewarded by larger CPUE, average CPUE was compared between fishermen that fished near the edge of their resource space and fishermen that fished at the average distance from their village. This comparison was made for both hook and line and lift net fishermen.

Results

Large-scale distribution of fishing effort in space and time

The fishing fleet in Spermonde was very diverse and operated some 22 different gear types from 10 different boat types. The total number of boats at the islands and coastal villages was estimated at 6266 units, 68% of which were 4-m long wooden canoes. Most fishing operations were carried out near the islands in the south-east of Spermonde and near the mainland of south-west Sulawesi. Total effort was dispersed over a larger area during the fair weather season, lasting from May to November, than during the rainy season. Mean daily effort was 517 units for the total research area, the majority were hook and line fishermen that operated from 4-m long canoes. The second most important gear contributing to total fishing effort was lift net operated from 10 to 20-m long motorised boats. Together these two gears contributed nearly 75% to total fishing effort applied.

The average total fishing density was 1.0 unit day^{-1} in each 2×2 km^2 with a dispersion coefficient of 2.5, which was significantly higher than 1, therefore, the overall effort allocation was considered aggregated in space. The average density was 0.59 unit $square^{-1}$ day^{-1} for hook and line fishermen and 0.17 unit $square^{-1}$ day^{-1} for lift net fishermen. The respective dispersion coefficients were 5.4 and 4.6, indicating an even more aggregated distribution pattern for these two gear types (Table 1). Similarly, dispersion coefficients for all other gears indicated aggregated effort allocation (Table 1). Average densities for these other gears were low and ranged between 0.004 unit $square^{-1}$ day^{-1} for cyanide fishermen and 0.04 unit $square^{-1}$ day^{-1} for gill net fishermen.

Hook and line fishing was employed near most inhabited islands and coastal villages, therefore, concentrated in the densely populated south-east of the study area (Fig. 2). Fishing effort for lift nets was concentrated around the two islands where fishermen were specialised in this technique. The Danish seine fishery was concentrated in the inner shelf zone. The purse seine fishery was concentrated near the barrier reef in the outer shelf zone as was the hook and line fishery trolling for large pelagic fish.

Table 1. Characteristics of the medium-scale, small-scale and illegal fisheries in Spermonde Archipelago. Gear categories are sorted by scale and by relative importance in total effort within scale categories. Presented are the total number of boats observed, N, the arithmetic mean (AM) daily effort, f, the dispersion coefficient, DC, the number of boats included in the sample, n, and the AM CPUE. 95% Confidence limits, CL, are indicated with $2 \times SE$ as fraction of the AM f and the AM CPUE. The GM distance travelled from home port to fishing location is presented with the 95% observations range indicated by the Multiplier and divider ($\times / 10^{2s}$) of the GM. The most important target categories are listed per gear

Gear type	N	Daily f AM (units)	CL	DC	n	Daily CPUE AM (kg daytrip^{-1})	CL	Distance GM (km)	Multiplier/divider	Target categories
Medium scale										
Boat lift net	1165	82.9	0.14	4.6	75	176.5	0.28	17.0	4.0	Carangidae, Clupeidae, Engraulidae
Set lift net	246	18.9	0.55	18.8	–	n.a.	–	0.0	–	Clupeidae, Leiognatidae
Purse seine	99	7.6	0.61	9.2	24	160.8	0.48	20.4	4.2	Clupeidae, Engraulidae, Carangidae
Danish seine	87	6.6	0.31	2.1	21	503.7	0.41	9.8	2.5	Leiognatidae, Sauridae,
Long line	48	3.6	0.34	1.3	26	28.6	0.55	11.8	7.9	Dasyatididae, Carcharinidae
Flying fish	2	–[a]	–[a]	–[a]	2	175.0	0.29	2.5	2.5	Cypseluridae
Small scale										
Hook and line demersal fish	2959	200.0	0.08	5.4	414	2.9	0.10	6.2	6.0	Nemipteridae, Lutjanidae
Hook and line pelagic fish	1672	100.0	0.10	5.4	365	4.1	0.21	15.8	4.2	Clupeidae, Carangidae
Gill net	282	21.0	0.48	15.8	131	17.5	0.54	7.4	5.8	Clupeidae, Carangidae
Trolling live grouper	175	13.4	0.28	3.3	134	1.7	0.23	6.2	5.5	Serranidae
Gill net crab	168	12.6	0.41	6.8	12	0.9	0.70	4.6	4.2	Crustacea
Traps	161	12.4	0.52	10.9	16	8.6	0.71	12.0	8.7	Lethrinidae, Lutjanidae, Serranidae

Table 1. (Continued)

Gear type	N	Daily f AM (units)	CL	DC	n	Daily CPUE AM (kg daytrip^{-1})	CL	Distance GM (km)	Multiplier/divider	Target categories
Trolling Spanish Mackerel	131	9.6	0.47	7.0	36	3.7	0.44	9.3	6.6	Scombridae
Hook and line squid	75	5.8	0.28	1.5	8	0.4	0.67	4.2	4.2	Sepiidae
Shell fish collectors	17	1.3	0.54	–[b]	0	n.a.	–	0.0	–	Gastropods, Bivalves
Spear gun	19	1.2	0.64	–[b]	19	3.3	0.73	5.4	3.0	Lutjanidae, Scombridae, Serranidae
Sea cucumber diver	16	1.2	0.68	–[b]	0	n.a.	–	6.9	4.6	Holothuridae
Beach seine	12	0.9	1.05	–[b]	4	30.0	0.65	2.5	2.5	Miscellaneous
Gill net lobster	21	0.2	1.49	–[b]	0	n.a.	–	4.5	4.0	Nephropidae
Illegal										
Blast fishing	185	14.0	0.38	6.6	55	35.2	0.41	6.9	4.6	Caesionidae
Cyanide fishing	23	2.0	0.66	2.5	12	2.1	1.47	8.1	5.0	Serranidae
Mini trawl	6	0.5	1.15	–[b]	5	16.0	0.74	7.2	7.2	Miscellaneous

[a] This gear fished off the shelf outside the study area. [b] Effort was too low to calculate DC. n.a., Catch data are not available.

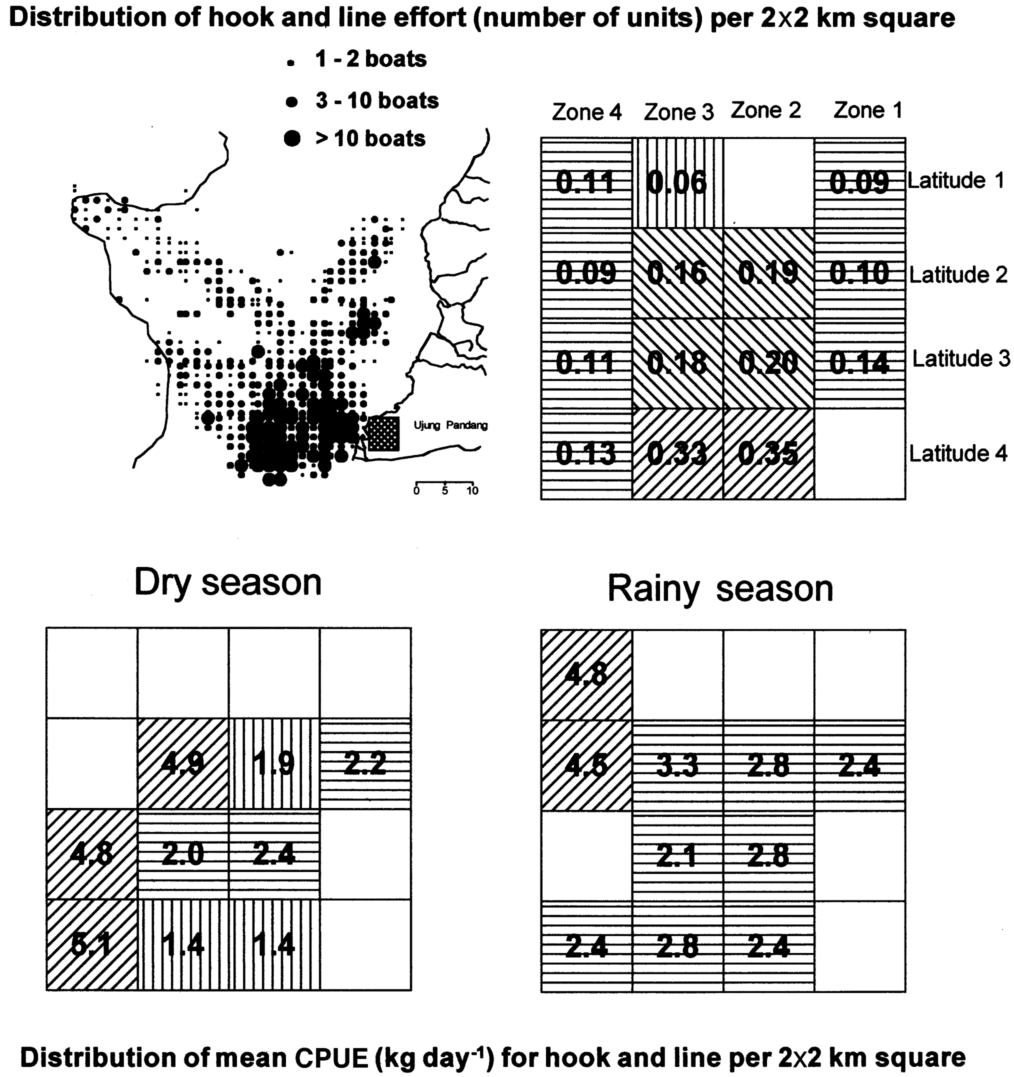

Figure 2. Spatial distribution of numbers of fishing units for the most frequently observed gear type, hook and line. The area is divided in four latitudinal sections (horizontal) and in four ecological shelf zones (vertical). The sizes of the dots indicate boat densities. The average proportion of squares with boats is presented per zone and latitude. Also the average CPUE is presented per zone and latitude for the dry and rainy season. The patterns that are shaded differently indicate significant ($P < 0.05$) differences.

The average proportion of squares in which fishermen were observed differed significantly between seasons ($P < 0.01$) (Table 2). During the dry season the proportion for all gears combined was higher (0.34) than during the rainy season (0.25), indicating also that fishing effort was dispersed over a larger area in the dry season.

The proportion of squares with hook and line fishermen varied significantly between zones and latitudes (Table 2), therefore, confirming what could also be concluded from the graphical presentation of patterns in the allocation of effort for this gear (Fig. 2). The proportions in the most inner zone (1) and outer zone (4) were significantly lower, meaning that fishermen mostly concentrated their effort in the intermediate zones 2 and 3. The most southern latitudes in these zones 2 and 3 showed the highest proportions of squares with hook and line fishermen (0.35 and 0.33). The distribution of effort by lift net fishermen showed no significant spatial contrasts throughout Spermonde (Table 2). Fishing effort for hook and line fishermen and lift net fishermen was dispersed over a larger area in the dry season than during the rainy season, indicated by the significant difference in the proportion of squares with fishing units for these gears between the two seasons (Table 2).

Large-scale patterns in CPUE in space and time

The average total catch from the research area was 21 t day^{-1}, of which only 5% originated from hook and line units and nearly 70% from lift net units. Total annual catch was 3.13 t km^{-2} yr^{-1} taking into account that lift net and purse seine fishermen operate only 3 out of 4 weeks per month. Average CPUE differed between gear types with highest catch rates for Danish seine, lift net and purse seine at 500, 175 and 160 kg day^{-1}, respectively, and the lowest catch rate for trolling for live grouper (1.7 kg day^{-1}) (Table 1). Overall mean CPUE (4.1 kg daytrip^{-1}) was much related to the patterns in effort distribution for the various gears as 44% of the total variance around the geometric mean CPUE ($s\log_{10}CPUE = 0.70$) was explained by gear type (Table 2). Overall mean CPUE was significantly higher in the most outer zone (4) with 7.2 kg daytrip^{-1} than in the most inner zone (1) with 2.3 kg daytrip^{-1}, and was greater during the dry season (9.8

Table 2. Analysis of variance (mean squares) for main effects of zone, location depth and season. The effort analysis is presented for total fish density and for densities of hook and line per 2 × 2 km^2 and lift net. The catch analysis is presented for total CPUE and for CPUE of hook and line fishery and lift net fishery . All data were $\log_{10}$-transformed

		Effort density			CPUE		
		Total	Hook & Line	Lift net	Total	Hook & Line	Lift net
Effect	df	ms	ms	ms	ms	ms	ms
Gear	8	–	–	–	36.76***	–	–
Zone	3	ns	1.67**	ns	1.06***	1.01**	ns
Latitude	3	4.13**	4.20**	ns	ns	0.50*	ns
Depth	4	0.32*	0.68**	ns	ns	0.46*	ns
Season	1	0.43*	0.79**	1.4**	1.29**	2.17**	ns
Error		0.11	0.095	0.096	0.18	0.15	0.24
		(2194)	(1202)	(407)	(555)	(507)	(49)

The level of significance is indicated * $P < 0.05$, ** $P < 0.01$; *** $P < 0.001$; ns, not significant.

kg daytrip^{-1}) than during the rainy season (7.9 kg daytrip^{-1}). The variance in catch rates differed between gear types, with lowest coefficient of variation, CV, in Danish seine and hook and line catches and highest CV in gill net catches (Fig. 3). The

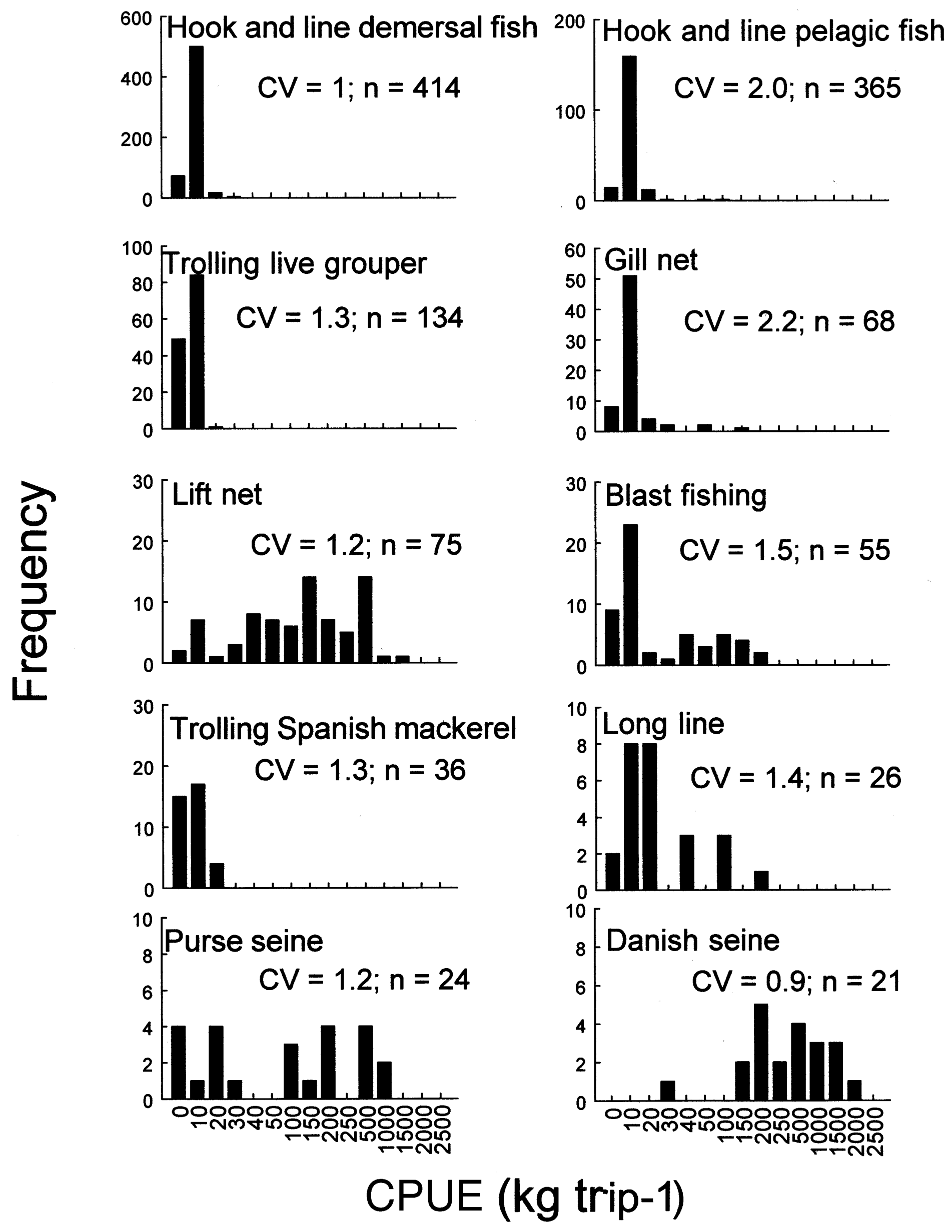

Figure 3. CPUE frequency distributions for ten of the most commonly observed gear types. The frequency of zero catches is indicated also. CPUE categories are indicated by the mid value of 10, 50 and 500 kg categories. All graphs have the same x-axis.

proportion of zero catches was highest for fishermen who troll for Spanish mackerel, *Scomberomorus maculatus* Houttuyn.

Average CPUE for the most abundant gear, hook and line, was 3.3 kg daytrip^{-1} ($slog_{10}CPUE = 0.31$) and individual catch rates were significantly affected by zone, latitude and depth (Table 2). CPUE was highest in the outer zone and in the northern section of the research area (Fig. 2) where depths were highest. CPUE was significantly higher during the dry season (2.5 kg daytrip^{-1}) than during the rainy season (1.9 kg daytrip^{-1}). There were no significant spatial or temporal patterns in the distribution of CPUE for lift nets (Table 2). For no gears was CPUE per 2×2 km^2 correlated with the total mean number of boats per square (Pearson $P > 0.05$).

Small-scale distribution of fishing effort in space and time

At the scale of individual resource spaces the dispersion coefficient was larger than unity at grid sizes of 1×1 km^2 for each of the six observed gear types, indicating an aggregated pattern of fishing effort in their resource space. At grid sizes of 2×2 km^2, the spear gun fisherman and the blast fisherman allocated their effort randomly, but at grid sizes of 5×5 km^2 effort allocation of the purse seine fisherman became random. Most fishing units (55%) took a north-west direction from their origin when travelling to their fishing locations. The relative size of the resource space, indicated with the geometric mean distance travelled, was highest for purse seines that travelled some 20 km to their fishing locations. The average distance travelled by fishermen with small boats was significantly shorter but their relative variation ($slog_{10}Distance = 0.32$) was higher than for fishermen operating from medium-scale boats ($slog_{10}Distance = 0.26$). The proportion of the individual resource space relative to the surface area of Spermonde indicates a limited reach for small canoe operations (Fig. 4).

The distance travelled between place of origin and fishing location depended mostly on boat type (Table 3). The overall geometric mean distance of 6.9 km ($slog_{10}Distance = 0.32$) was affected by weather conditions. Under sunny conditions fishermen travelled further before they started fishing. A similar behaviour was observed for hook and line fishermen, whose strategy was also affected by wave height (Table 3). Again, the type of boat operated by the hook and line fisherman contributed most (88%) to the variance explained (29%) in distance travelled.

Small-scale patterns in CPUE in space and time

Within their individual resource space, fishermen reacted on really high CPUE (kg daytrip^{-1}) by allocating their next day fishery again at that location with the high CPUE. Daily catch weight of individual fishermen and the distance between locations on successive days showed a significant negative correlation, except for blast operations (Fig. 5). So fishermen reacted to a high catch by selecting that location again. After a day with low CPUE, fishermen selected their new fishing location more randomly, but this strategy was without any rewarding effect. Auto-correlation of daily catches with a lag of 1 day

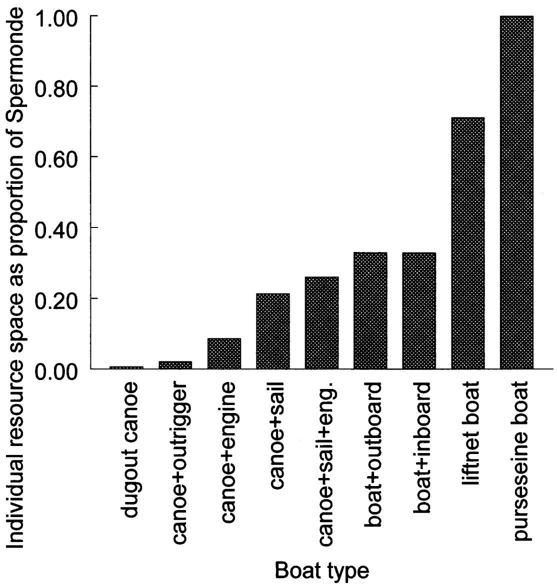

Figure 4. Size of individual resource spaces as proportion of the Spermonde for each of the nine boat types based on geometric mean distance travelled to a fishing location.

was not significant, which means the strategy of selecting locations nearby the one with the profitable catch did not result in a significantly higher or lower than average catch on the succeeding day.

A contrast was found between the catch rates of hook and line fishermen originating from two coastal villages, situated close to each other and south of Ujung Pandang. A small group travelling from these villages fished at locations in the far north-west of Spermonde (average distance = 65 km, SD = 4.4 km) and they caught on average (GM)

Table 3. Analysis of variance (mean squares) for main effects of boat type, wind strength, wave height and weather condition. The analysis is presented for distances travelled between home port and fishing location by hook and line, cyanide, grouper trolling and trap. All data were $\log_{10}$-transformed

		Total	Hook & Line	Cyanide fishing	Traps	Trolling live grouper
Effect	df	ms	ms	ms	ms	ms
Boat type	9	4.05***	2.5 ** (4)	0.41 ** (1)	0.58 ** (5)	0.71 ** (6)
Wind strength	3	ns	ns	ns	0.14 *	ns
Waves height	3	ns	ns	0.19 **	0.27 **	ns
Weather	3	0.90***	0.88 *	-	ns	0.28 *
Error		0.10 (831)	0.12 (741)	0.012 (4)	0.018 (5)	0.10 (114)

The level of significance is indicated * $P<0.05$, ** $P<0.01$; *** $P<0.001$; ns, not significant.

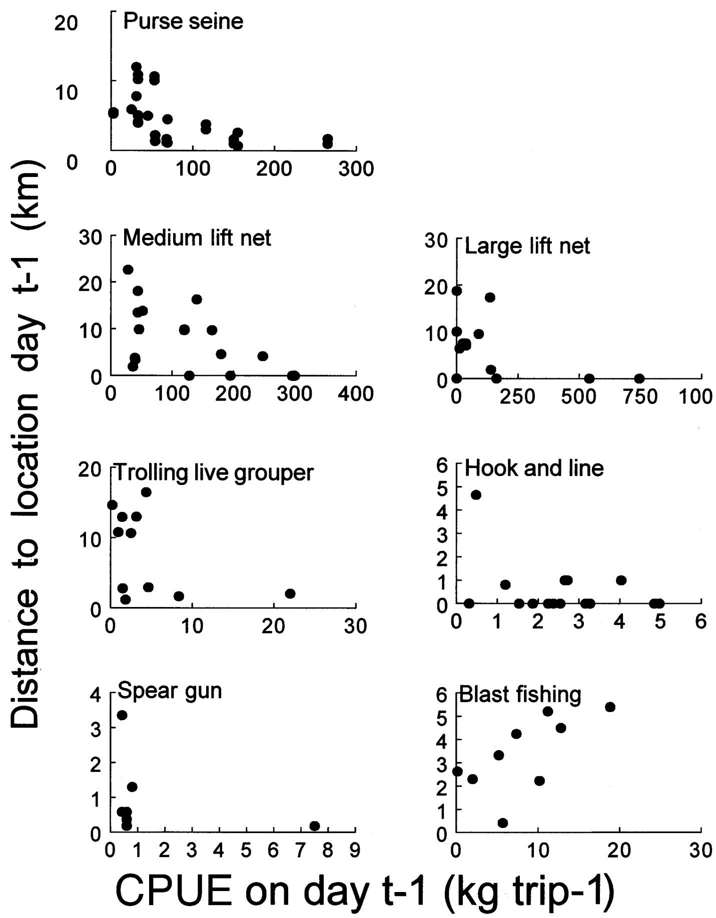

Figure 5. Distance (km) between fishing locations on day t and day t − 1 plotted on the CPUE on day t − 1 for seven types of fisheries.

1.4 kg h^{-1} ($slog_{10}CPUE = 0.51$). This CPUE was twice the catch rate (GM) of 0.7 kg h^{-1} ($slog_{10}CPUE = 0.41$) that was achieved by the group of fishermen from the same villages that fished nearby (average distance = 19 km, SD = 8.9 km) (Fig. 6). Not only were catch rates higher, catches at the farther locations included a larger proportion of highly valuable piscivores (Fig. 6), especially sharks and groupers, and the mean sizes of most taxonomic fish categories were larger.

Discussion

At the large spatial scale of the Spermonde Archipelago, distinct patterns were found for allocation of total fishing effort and for distribution of CPUE. Most fishing effort was concentrated in the south-east near population centres where CPUE was lower than in the north-west where fishing effort was lowest and CPUE highest. Patterns were less distinct at the large temporal scale of seasonal differences. Lack of employment alternatives outside the fishery causes fishing effort to remain constant throughout the year and the only seasonal effect was a slightly higher spatial aggregation during the rainy season, which combined with a slightly lower CPUE. At the small spatial scale of individual resource spaces, effort was aggregated at gear-specific habitats. The size of the resource space varied with boat type and was smaller during unfavourable weather conditions. These trends are typical for coastal fisheries in Indonesia and are often explained by intrinsic constraints related to the small-scale nature of the fishery (Sloan & Sugandhy 1994; Butcher 1996; Ruddle 1996; Tomascik, Mah, Nontji & Moosa 1997).

Fishermen that operated their gears from medium-sized boats could theoretically reach and fish an area half the size of Spermonde. Lift net boats and purse seine boats could even cover the total area of Spermonde. Irrespective, all medium-scale fishing units aggregated their effort in space and not at just any location within a specific habitat. Such patterns can not be explained simply from intrinsic constraints similar to those that affect effort allocation of the small-scale gears. Therefore, fishing strategies and their rationale are discussed for small- and medium-scale gears separately.

Fishing strategies for small-scale gears

Small-scale fishing activities occurred throughout the year and across Spermonde. Densities of hook and line fishermen at sea were highest near the islands and villages in the south-east, where CPUE for this gear was significantly lower than in the less densely

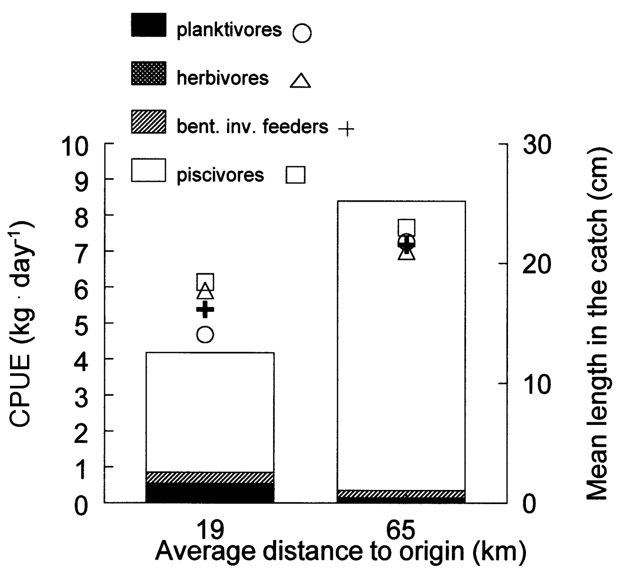

Figure 6. Biomass and mean individual fish length per trophic group in catches of hook and line fishermen from the same two villages operating at nearby and far fishing locations.

fished north-west section of Spermonde. The tendency to fish further out during the good weather indicated that fishermen perceived small-scale contrasts in their resource spaces. Yet the fishing patterns indicated that most fishermen were either not aware of the large-scale contrasts in catch rates or that they were not free to select the better locations. Travelling further than the average distance of 6 km imposes greater physical risk and economic costs that must be compensated for by larger catch rates that are less certain unless they have sampled the more distant locations or have received such information.

The Catch Assessment Survey showed that the small group of hook and line fishermen in the north-west had travelled distances up to 65 km from two villages south of Ujung Pandang. The generally small average distance travelled each day to practice 6 h of fishing, indicated that these particular fishermen must have traded fishing time for travelling. They made multiple daytrips. Daily catch rates were higher and catches included larger fish and larger proportions of highly valued fish. Thus, it appears that it is not so much an inability to reach further locations but rather a different fishing strategy. The question is: are hook and line fishermen unable to perceive the apparent spatial contrasts in CPUE and catch composition or are they reluctant to adjust their current strategy to make multiple daytrips?

Historical developments in the Spermonde fishery indicate that socio-cultural attitudes to fishing may differ between islands or villages (Meereboer 1998), yet it is more likely that the particular knowledge on better catch opportunities is not wide-spread. Withholding information remains a common survival strategy in competitive fisheries, even when it has been shown to cause inefficient exploitation of the resources at the level of the total system (Allen & McGlade 1986). The day-to-day experience of hook and line fishermen offers them no obvious reason to travel and explore farther locations with suitable habitat and the constraints placed by their boats cause them to be area specialists rather than area movers (Hilborn 1985). At the small scale of the individual resource spaces, fishermen in Spermonde reacted on an ad hoc basis on the size of their daily catch, but this was not an effective strategy. Consequently, their daily experience seems not to contribute to their knowledge base on possible local patterns in the spatial distribution of the fish.

The uncertainty around their generally low CPUE means that small-scale fishermen do not easily escape their present situation by switching to other gear or boat types (Smith 1990). It is concluded that small-scale fishermen in Spermonde cannot easily observe the large-scale contrasts in CPUE and aim to minimise physical and economic risks by selecting suitable habitats close to their villages, rather than to maximise catch rates by switching between gears or locations.

Fishing strategies for medium-scale gears

The large-scale patterns in effort allocation by medium-scale gears cannot simply be explained by risk minimisation because, in theory, the boats from which these gears are operated can reach more distant locations than where they actually fish. Purse seine and lift net boats could fish at any location with a suitable habitat within Spermonde. Yet at the large spatial scale of Spermonde, habitat characteristics do not affect the density of these medium-scale fishing units. In spite of the wide-spread distribution of suitable sandy habitats, Danish seiners aggregated at an average distance of less than 10 km from their villages. Purse seine units, on the other hand, travelled more than 20 km straight west to fish in the outer zone without exploiting areas nearer their villages. Only lift net units appear to utilise all locations within their reach, but the highest densities are still found near their origin.

The revenues from the high average catch of 500 kg daytrip^{-1} for Danish seiners would theoretically allow for some exploratory fishing, yet there is hardly any reason to change their strategy. The technical operation of the gear is time-consuming and they apparently prefer to use their time for fishing rather than for travelling. Although the possibility that they are already fishing the maximum CPUE for this gear in the area cannot be eliminated, the relatively high variability in catch rates suggests that Danish seine fishermen minimise economic risk instead, by spending maximum time on operating their gear.

Average catches of lift nets and purse seines are lower than for Danish seiners, yet the variability in catch rates is high due to the migratory and schooling behaviour of their pelagic target species (Dudley & Tampubolon 1986). Because there were no significant spatial patterns in CPUE for lift nets it is difficult to understand why a relatively large number of the lift net boats fish far from their origin. Most lift net boats do not regularly return to their islands and an average monthly trip includes some 20–25 days away from home in which they travel only small distances from day-to-day. Their experience within their individual resource space contributed nothing to their knowledge on possible spatial patterns in abundance of their target fish and simply confirms the inconsistency in allocating effort at these distant locations. To maximise catch rates or minimise the variability in catch rates, it was equally efficient to respond to high catches as it was to select random locations. In this respect, it is strange that the lift nets are not distributed more randomly through space. Possibly some lift net fishermen deal with their high catch uncertainty by low risk Cartesian behaviour, and others by high risk stochastic behaviour, thus becoming either area specialists or area movers (Allen & McGlade 1986). The absence of distinct spatial contrasts in CPUE together with the high overall variability in catch rates indicates that neither of these groups is successful.

Finally, the concentration of purse seine fishermen at the shelf edge can be explained if catches are higher further out than near shore. The aggregated distribution pattern does not allow such spatial comparison but the data indicate a very high variance in catch rates so it is questionable whether these fishermen are able to distinguish between locations. Therefore, their selection of remote locations cannot be explained by what is found for other gears. The high variance in catch rates seems characteristic for this gear (Dudley & Tampubolon 1986) and could partly be explained by the competition phenomenon described for purse seine units off Java, Indonesia (Poitier, Petitgas & Petit 1997). Several boats cooperate in search of fish concentrations, yet compete for space to operate their gear at the selected location. Such large-scale interactions force some of the fishing units to fish near the edge of the fish aggregation rather than in the centre and this must have caused part of the differences in catch rates amongst the group of purse seines.

Implications for management

Fishing strategies and the distribution of fishing effort may differ between gear types, yet one feature is common to all. The observed aggregation of fishing effort in this small-scale tropical fishery is not related to patterns in fish abundance. At the large scale of Spermonde, patterns are distinct but fishermen who do not have such overview experience a relative high uncertainty regarding weak contrasts in their resource spaces. Even in the statistical analyses, the effects included in the models explained little of the variance. Beddington, Arntz, Bailey, Brewer, Glantz, Laurec, May, Nellen, Smetacek, Thurow, Troadec and Walters (1984) mentioned how responses of individuals to uncertainty are unpredictable. This study illustrated that constraints imposed by the physical and economic environment cause small-scale fishermen to minimise risks rather than to maximise catch rates. The continued high fishing effort during the rainy season also, implies that minimisation of economic risks prevails over minimisation of physical risks, which is a quite different attitude from that of trawl vessels that operate in temperate waters who fear physical risks above all (Hanna & Smith 1993). These large vessels are generally more successful in locating high fish abundance as they experience fewer constraints to their selection of locations (Gillis *et al*. 1993).

This study illustrates the point raised nearly two decades ago by Gates (1984) and Beddington *et al*. (1984) that predictions on future developments in fisheries need a multi-disciplinary approach to describe fishing behaviour. This should incorporate socio-cultural, economic, technological and biological aspects of the fishery. Since then a number of new concepts have been presented, which have increased knowledge of the diversity in strategies used to deal with uncertainty and risk. Most studies describe large- to medium-scale temperate fisheries (see Mangel & Beder 1985; Smith & McKelvey 1986; Lane 1988; Smith 1990; Sampson 1991; Wilson & Kleban 1992; Hanna & Smith 1993; Ehrhardt & Legault 1997), because small-scale tropical situations are constrained by logistical difficulties in monitoring of these multi-gear and multi-species fisheries. The present results indicate the relevance of distinguishing between medium- and small-scale fishing gears, because most of the variance observed was explained either by the type of gear or boat. Experience in agriculture has shown that discussion of management options for small-scale activities benefits largely from increased understanding of strategies that underlay patterns of resource utilisation (Fresco & Kroonenberg 1992; von Benda Beckmann, von Benda Beckmann & Marks 1994), as will future management of fishery resources in Spermonde.

Poizat and Baran (1997) mentioned that even small-scale fishermen aggregate information at a great variety of temporal scales and that they have a clear and rather unbiased understanding of local patterns in fisheries ecology which is probably also true for the fishermen in Spermonde within their individual resource space as they selected particular habitats where their targets aggregated. It is maintained, however, that perception of trends at large spatial and temporal scales is hindered unless they can aggregate their catches over time. Therefore, the present inability to perceive a relation between effort and catch at the large spatial scale of Spermonde and to influence individual catch rates at the small spatial scale of the individual resource spaces means both small- and medium-scale fishermen cannot use information derived from their catch rates to allocate their fishing effort more efficiently. All will have difficulty understanding the use of effort regulations to improve individual catch rates.

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