The skipjack fishery in Eastern Indonesia: distinguishing the effects of increasing effort and deploying rumpon FADs on the stock

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Abstract

Rumpons, (FADs) were widely deployed in Indonesia in the eighties. In the Halmahera area, rumpon increased CPUE by 41% , landings of fish per ton of live bait increased by 24%, the consumption of diesel oil for tuna catches reduced by 46%, and profits increased from Rp 10 to 60 million by boat per year[1]. Tuna aggregation around rumpon increased catchability by more than 40% compared to free swimming tuna. The Halmahera skipjack fishery was assessed by combining catch and effort data from rumpon and pre-rumpon areas of the fishery, and showed that controlled effort could increase landings of approximately 15,000 t per year. Tagging data show that the Halmahera skipjack fishery is probably supported by a local unit stock. Philippine rumpons (payaos) were fished with small mesh purse seine and ring nets fishing small sized tunas 12-35 cm FL (40-50% of landings) and caused recruitment overfishing. Indonesian rumpons were fished with pole-and-line causing neither recruitment nor growth overfishing.

Introduction

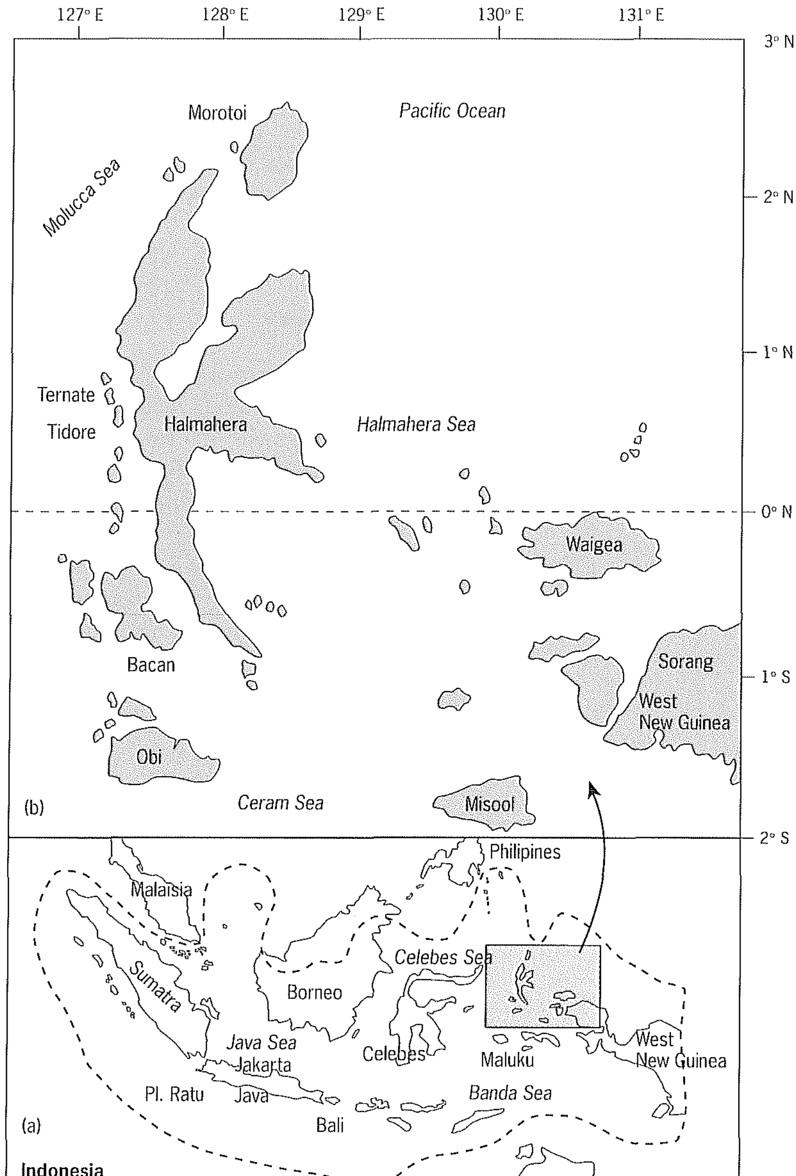
Many kinds of rumpon, or Fish Aggregating Devices (FADs), have been used traditionally in eastern Indonesian waters (Reuter, 1938; Nasution *et al.*, 1986) and in the Philippines (Aprieto, 1988a, b, c, d, 1990, 1991, 1994). Rumpons currently take large and small pelagic fish in the Philippines (Aprieto, 1990, 1991, 1994) and in Indonesia (Monintja, 1993).

Rumpons were traditionally constructed with palm fronds and locally harvested wood and fibres, and were placed in fairly shallow, inshore coastal waters (<50 m deep). Since the mid 1980s, they have also been constructed with polypropylene and polyethylene mooring lines, cement and other types of anchors and with other industrial materials of Indonesia. Monintja (1993) described ten different types of rumpon from Indonesia and more than 20 types from around the world.

1. US$1.00 = Rp 1,000-2,000 in the 1980s.

New and larger rumpons were installed in Ternate, Tidore, Bacan and Sorong in waters around Halmahera and in the Halmahera Sea, in December 1984 (fig 1).

Figure 1
(a) Map of Indonesia;
the box shows the area
covered in figure 1b.
(b) Maluku Islands showing
the study area,
the main study area
and the surrounding seas.



Rumpons cause overfishing through increasing vulnerability and accessibility of fish to various types of gear (de Jesus, 1982; Aprieto & Ganaden, 1985). They act analogously to artificial reefs, which are now regarded as FADs placed more permanently on the bottom, increasing the proportion of a stock taken by fishermen without increasing recruitment. Where stocks are fished around maximum sustainable yield (MSY), installation of FADs or artificial reefs will lead to economic and biological overfishing (Munro, 1996).

Rapid deployment of rumpon in the Halmahera area raised questions about:

- effects on landings caused by fish aggregating around rumpon;
- increasing effort on stocks caused independently of rumpon.

This paper attempts to dissect these effects and to identify rumpon deployment on effort, so as to facilitate assessments.

Large-scale rumpon-based fishing was introduced into Indonesia by the government owned but commercially operated PT Usaha Mina company (PTUM), together with Nucleus Estate Small Holder (NES) which employ local fishermen, encourage cooperatives and combine to stimulate growth of artisanal fisheries in unexploited areas (Nikijuluw, 1994).

Material and methods

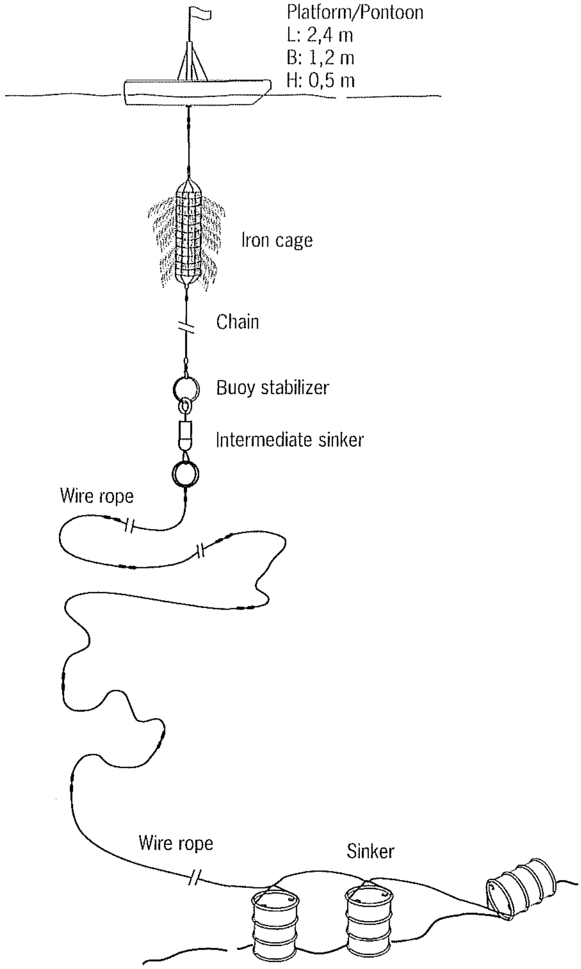
The standard PT Usaha Mina rumpon was the main kind used in this study (fig. 2; Monintja, 1993). Catch and effort data were supplied by PTUM which used a standard 35 GT pole-and-liner effort expended by PTUM are unbiased by changes in fishing power or technology over the study period. Live bait, mainly *Stolephorus* spp., was used. No purse seining occurred.

Data were obtained on the structure and operations of 108 rumpons located near Bacan, Tidore, and Ternate off Western Halmahera (Maluku) and off Sorong, Waigeo and Gag (Irian Jaya; fig. 1a). Date, position, date of installation and estimated loss were recorded. Catch data were provided for each type of gear used around each rumpon by PTUM. Effort and catch data were also obtained from PTUM and local fishery service officials for a total of 405 rumpons deployed in Indonesia.

Catch per unit effort (CPUE) was calculated for Halmahera standard PTUM boats in the pre-rumpon area (1980-1984) and the rumpon area (1985-1989).

Skipjack CPUE, size frequencies and distance of each set from rumpon were obtained in 1989 during commercial fishing around 108 rumpons at Bacan, Tidore and Ternate Islands located west of Halmahera Island. Economic data were obtained in 1987 by interviewing 44 out of 189 skippers. Resulting data were used in a multiple regression study of the factors that influence net profitability, which was estimated for each boat using a tailor-made program available from the Faculty of Marine Fisheries, Tokai University, Japan.

Figure 2
Structure of the rumpon (FAD) used by PT Usaha Mina.



Results

A total of 405 rumpons were deployed in areas ranging from West Sumatra to Irian Jaya covering a 2,000 nautical miles range; 287 rumpons (71%) were installed in the Halmahera area. On the 405 rumpons deployed in 1987, 215 (53%) were lost in 1989. Rumpons deployed in less exposed eastern waters survived longer.

Survival time of rumpons (n = 98) decreased with increasing depth, falling from 8.0 months (in waters 0.44-0.88 km deep), to 7.4 months (0.88-1.76 km deep), 6.24 months (1.76-2.64 km deep) to only 3.9 months (2.66-3.59 km deep). Heavier wave action, faster winds and currents, and perhaps shark bite, led fishermen to prefer shallower localities and may have shortened the life time of more exposed rumpons.

Survival time (n = 108) was also influenced by the kind of mooring line: 24 mm polyethylene line lasted a mean of 7.3 months (n = 52) compared to 16 mm polyethylene (6.0 months, n = 20), and 18 mm and 16 mm polypropylene lines (6.9 months, n = 17; 6.5 months, n = 19). The time needed for fish to occupy a newly deployed rumpon ranged from 5 to 64 days. Mean survival time varied from 24.5 days (95% confidence intervals - 95% CI = 15-34; n = 17) in Sorong, to a mean of 10.3 (95% CI = 7.6-13.0, n = 14) in Bacan. The time required for tuna, to appear around rumpon was short compared to the time needed for fish to grow to the observed large sizes (at least one year for small tuna). The corollary is that rumpons are unlikely to increase recruitment, and may affect tuna distribution and abundance in neighbouring areas.

Skipjack mature at sizes more than 40 cm FL in the Philippines (Aprieto, 1994) and Indonesia (Suhendrata & Wahyno, 1987) and from 40-45.4 cm FL in Papua New Guinea, USA, Philippines and Indonesia (Tandog-Ednalin *et al.*, 1990). Figure 3 includes the Indonesian minimum size at maturity: only mature skipjack aggregated around rumpons. Yellowfin mature at similar or slightly larger sizes than skipjack (> 50 cm FL; Collette & Nauen, 1983). Most yellowfin taken around rumpons were approximately more than 40 cm FL.

Skipjack CPUE fell markedly with increasing distance of the set from the rumpon (tab. 1).

Figure 3
Length frequency distributions of skipjack tuna taken at different distances from rumpon located on the Bacan fishing grounds.
A: 0-500 m.
B: 501-1,000 m.
C: 1,001-5,000 m.
D: >5,000 m.
Arrows indicate size at first maturity.

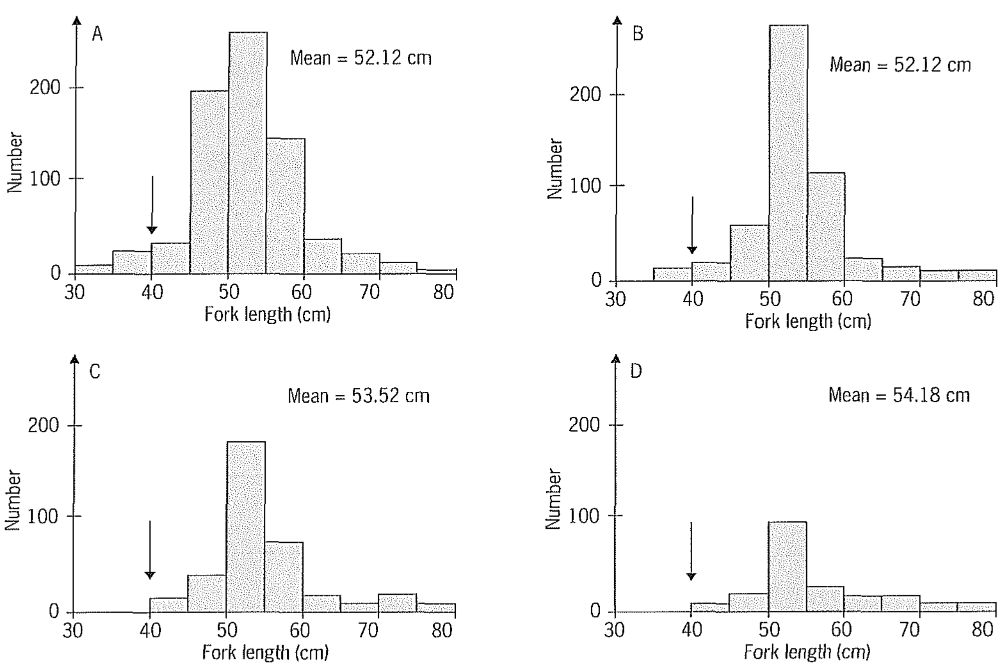


Table 1 - Effects of increasing distance (m) from the rumpon on catch rates of skipjack. Catch rates are in t/h of actual fishing time, i.e. from dropping the net to completion of the set. Most sets lasted less than one hour, many less than half an hour.

Distance from rumpon	Mean catch rate (t/h)	95% CI	Sample size
< 500	12.132	42.04	27
> 500-1,000	9.048	22.73	27
> 1,000-5,000	6.007	27.90	27
> 5,000	2.552	17.35	27

Capture time and distance from rumpon affect CPUE (fig. 4). Higher rates (1-12 t/h) occurred from 6 am to 10 am (n = 56 out of 76 observations) mostly <1,000 m from rumpon. Lower catch rates (1-4 t/h) occurred from 11 am to 5 pm (n = 19 out of 76), *ca* 1,000 to over 5,000 m from rumpon. Effort is targeted towards the morning hours when skipjack are more active. Figure 4 also suggests that there may be a much weaker afternoon peak (*ca* 3.0-4.0 t/h) from 3 pm to 5 pm.

Table 2 summarises landings and effort from different fleets in Sorong, Halmahera and Bacan waters. Total effort (days/year) in company boat expended on the skipjack stock each year was estimated by dividing company CPUE into total skipjack landings from all fleets (tab. 2, column j).

The Wilcoxon rank sum test showed that CPUE ranks for pre-rumpon and rumpon areas were 16 and 39 respectively, with $T_{0,05}$ = 19,35: CPUEs during the two areas were also significantly different. Mean landings were also significantly higher ($T_{0,05}$).

The ratio of the mean $CPUE_x$ = 1.0074 (x denotes the rumpon area CPUE) to $CPUE_y$ = 0.7170 (y denotes the pre-rumpon area CPUE) was: 1.0074/0.7170 = 1.41 = $CPUE_x/CPUE_y$

Rumpon area catches were higher than pre-rumpon catches (tab. 2, column i): rumpon increased landings at the comparable effort levels.

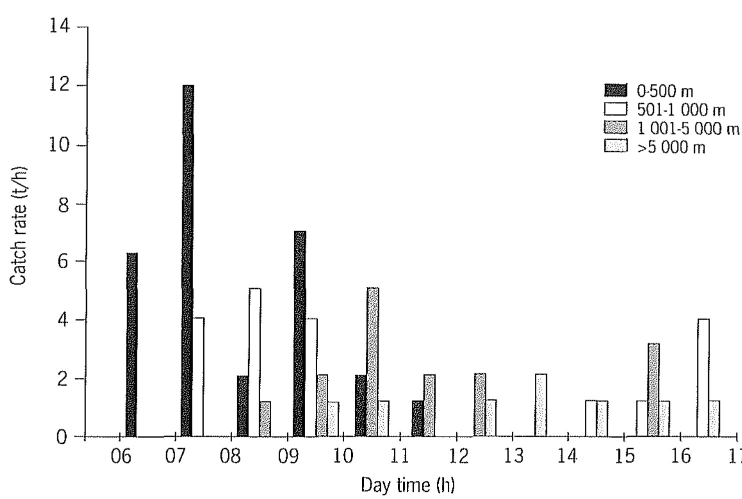


Figure 4
Relation between catch rates (t/h), distance from the rumpon, and time of day, for skipjack caught around rumpons on the Bacan fishing grounds. Most sets lasted less than 1 h, and many sets were unsuccessful.
Only successful sets were included in the analysis.
The different histogrammes indicate the distance of capture from the rumpon.

Table 2 - Data on skipjack landings, effort and catch per unit effort for boats operating in the Halmahera Sea rumpon fishery. Standard boat: 35 GT pole-and-liner; effort: boat.day/year; catch in t/year, whole fresh fish; CPUE/catch per unit effort: t/boat.day/year

Standard unit effort: boat.day/year; total effort for all fleets combined, in standardized unit effort.

1980-1984: Pre-rumpon area. 1985-1989: Rumpon area.

Year	a	b	c	d	e	f	g	h	i	j	k
	Landings			Effort			Landings			Total effort	
	Company t/yr	NES t/yr	Subtotal t/yr a + b	Effort (C + NES) boat.days/yr (non rumpon)	Effort (C + NES) boat.days/yr (rumpon)	CPUE t/bt.day/yr (a/effort)	Artisanal t/yr	Other t/yr	Total Landings t/yr c + g + h	(unadjusted) bt.day/yr i/f	Adjusted bt.day/yr
1980	3696		3696	5746		0.6432	709	2637	7042	10948	7764
1981	3574		3574	4680		0.7637	275	2125	5974	7823	5548
1982	2462		2462	4192		0.5873	1219	2842	6523	11107	7877
1983	3844		3844	4161		0.9238	986	2375	7205	7799	5531
1984	2368		2368	3551		0.6669	1207	1400	4975	7460	5291
1985	4105		4105		3732	1.0999	2366	857	7328	6662	6662
1986	3404	2102	5506		3464	0.9827	3227	1143	9876	10050	10050
1987	2859	6858	9717		3362	0.8504	3350	1350	14417	16953	16953
1988	2501	6471	8972		2273	1.1003	2393	1262	12627	11476	11476
1989	2297	6755	9052		2288	1.0039	2490	1470	13012	12961	12961

NB: Mean CPUE from 1980-1984: 0.7169 t/boat.day; mean CPUE from 1985-1989: 1.0074 t/boat.day. Ratio: 1.0074/0.7169 = 1.405. Total adjusted effort was calculated for non-rumpon years: k = j/1.41. For rumpon no adjusment was needed (see text).

The number of boat per day in the pre-rumpon and rumpon areas were not significantly different ($p = 0.285$) while the regressions of total catch on total effort for the two areas were significantly different from zero ($p<0.05$) but not from each other ($p>0.05$).
However, rumpon affected skipjack behaviour: aggregation around rumpon increased skipjack accessibility and vulnerability, and presumably increased catchability, by increasing the fraction of the stock removed per unit effort. A standard boat captured 1.00 t/day in the pre-rumpon area and 1.41 t/day in the rumpon area. Total pre-rumpon effort (tab. 2, column j) was therefore converted to rumpon area effort (tab. 2, column k) as follows:
Pre-rumpon effort (boat per day)/1.41 = effort in rumpon area boat per day.
This procedure converts pre-rumpon effort data (tab. 2, column j) into rumpon area effort units, producing homogeneous effort units over the whole time series (column k). These adjusted data were therefore used in the assessment.
Changes in CPUE caused by introduction of rumpon have other effects:
- mean fuel consumption fell from 0.869 t of diesel oil/t of skipjack landed during the pre-rumpon area to 0.467 t/t of skipjack during the rumpon area (tab. 3) giving a reduction in fuel consumption of 0.402 t oil/t of skipjack (53.8% of the pre-rumpon area). This provided a mean cost reduction of US$ 65/t compared to ex-vessel skipjack prices of US$ 130-420/t (Nikijuluw, 1994);
- rumpon also reduced live bait consumption from 26.9 t of skipjack/t of bait (pre-rumpon) to 33.0 t of skipjack/t of bait (rumpon area, tab. 4).
The Halmahera skipjack stock was assessed by fitting catch and effort data (tab. 2, column k) using Genprod, Prodfit (Hall, 1988) and Climprod (Fréon *et al.*, 1992), who provide slightly different fitting routines. The best fit gave an MSY of *ca* 32,500 t/year at 61,000 boat.days/year with catchability = 0.000353. Estimates of MSY and optimal effort varied by 9,500 t/year and 20,000 boat.days/year because of the different fitting routines and the narrow effort range. Modelling showed that the stock can provide greater landings than those observed in 1989, but assumed that Halmahera skipjack belong to a unit stock (see below).
Multiple regression analysis was applied to data from interviews with skippers ($n = 44$) in three different areas:
- Tidore where boats were owned and operated by independent fishermen, fishing without rumpon;
- Ternate where fishermen owned boats and market their catch, but fished around rumpons provided by the government;
- Bacan where PTUM (a government owned, private sector company) operated boats with company managed rumpons, and marketed the catch.

Table 3 - Comparison of the catch (c) and fuel consumed (fc) before and during rumpon period. Catches and fuel consumed are given in t/year; fc/c: t of skipjack/t of fuel/year.

Non-rumpon period				Rumpon period			
Year	c	fc	fc/c	Year	c	fc	fc/c
1980	3,696	3,149	0.8520	1985	4,105	2,363	0.5756
1981	3,574	3,005	0.8408	1986	5,506	2,592	0.4708
1982	2,462	2,577	0.0467	1987	6,717	2,865	0.4265
1983	3,844	2,708	0.7045	1988	8,972	3,724	0.4151
1984	2,368	2,204	0.9307	1989	9,053	4,079	0.4506
		Mean fc/c = 0.8689 SD = 0.1279			Mean fc/c = 0.4677 SD = 0.0640		

Wilcoxon's rank sum test. $R_1 = 40$, $R_2 = 15$, $T_{0.05} = 19.36$

Table 4 - Comparison of the catch (c) per live bait consumption (b) before and during rumpon period. Catch: t/year; bait consumption: t/year; c/b: (t of skipjack/year)/(t of baitfish/year)

Non-rumpon period				Rumpon period			
Year	c	b	c/b	Year	c	b	c/b
1980	3,696	128.6	28.7	1985	4,105	114.2	36.0
1981	3,574	121.7	29.4	1986	5,506	159.4	34.5
1982	2,462	92.7	26.6	1987	6,717	225.6	29.8
1983	3,844	152.7	25.2	1988	8,972	245.9	36.5
1984	2,368	95.9	24.7	1989	9,053	307.4	29.5
	Mean fc/c = 26.9 SD = 2.1				Mean fc/c = 33.3 SD = 0.3		

Wilcoxon's rank sum test. $R_1 = 15$, $R_2 = 40$, $T_{0.05} = 19.36$

Data on the following factors were analysed. Factors used in the final analysis are shown in bold:

Y : Net profitability (Rp/boat/year)
X1 : Overall vessel size (m)
X2 : Engine power (HP)
X3 : Fuel consumption (t/boat/year)
X4 : Live bait used (kg/boat/year)
X5 : Fishing days/boat/year
X6 : Fishermen/boat/year
X7 : Operating costs (Rp/boat/year)
X8 : Total power (estimated by converting manpower to HP, using 1.0 manpower = 0.18 HP; Dalzell *et al.*, 1987)
X9 : Arbitrary (dummy) variable, assigned arbitrary values of 0.0, 0.5 and 1.0 defined as follows:

- X9 = 0.0: Tidore fleet (n = 14), skipjack fished without rumpon;
- X9 = 0.5: Ternate Island (n = 10), skipjack fished with privately owned boats and rumpons provided by government.
- X9 = 1.0: Bacan (n = 20), skipjack fished by boats and rumpons owned by PTUM.

Vessel size (varying by to less than 5 m) and operating costs (highly influenced by fuel consumption, r = -0.4714) were eventually excluded from the analysis.
Results of the stepwise multiple regression led to selection of only four factors, of which the last three were forced into the regression (which normally excludes all factors with F<4.0):

Variable	Coefficient	Standard error	T	p
Y	-29.3784	18.1645	-1.6174	0.1141
X9	35.8385	9.3115	3.8488	0.0004
X4	4.8113	1.7557	2.7404	0.0093
X8	0.4654	0.3862	1.2048	0.2357
X3	0.3891	0.3591	1.0835	0.2854

Therefore:

$$Y = -29.3784 + 35.8385 \times X9 + 4.8113 \times X4 + 0.4654 \times X8 + 0.3891 \times X3$$

Y is expressed in million of Rp/year, negative values of Y showing losses. The model is significant ($F_{4,38} = 5.1387$, $p = 0.0021$; $r^2 = 0.3510$). However, only the first two variables (X9, the dummy variable for fishing grounds; and X4, baitfish consumed) have a strong effect on values of Y (net profitability). Using constant X4 = 5, X8 = 10 and X3 = 20 and with X9 varying from 0.00 to 1.00, Y (net profitability) varied as follows:

X9 = 0.0, Y = 7.107
X9 = 0.5, Y = 25.027
X9 = 1.0, Y = 42.949

Fishing without rumpon (X9 = 0.00) is less profitable than fishing with rumpon (X9 = 0.5 -1.0). Fishing with company managed rumpons (X9 = 1.0) is substantially more profitable than fishing with government organized rumpons (X = 0.5), and very much more profitable than fishing without rumpon (X9 = 0).
The amount of bait used was positively correlated with profitability on all fishing grounds but varied counter-intuitively between fishing grounds. Data on steaming time, access to bait and other factors not studied may affect bait consumption, complicating this part of the analysis.
The presence/absence of rumpon is only one of many characteristics affecting fleet profitability. Nevertheless, deployment of rumpons in a skipjack fishery clearly has a very significant positive effect on net profitability.

Discussion

Skipjack and yellowfin attracted to rumpon were substantially older and larger than those attracted to payaos in the Philippines. Aprieto (*op. cit.*) and Barut & Arce (1990) showed that small-mesh seine and ring nets take more than 90% of tuna caught around payaos (rumpons) by "municipal" boats (<3 GT). Municipal boats take predominantly immature 12-35 cm FL tuna, and land more than 50% of all Philippine skipjack and yellowfin tuna; therefore *ca* 40 to 50% of these species by volume are landed at *ca*12-35 cm FL, causing recruitment overfishing (Aprieto, 1994).

Indonesian boats used pole-and-line and took negligible amounts of tuna of less than 40 FL (fig. 3). Rumpons did not cause recruitment overfishing in Indonesia because they were not fished with seine and ring nets. Surplus production modelling showed that catches could be increased, i.e. that growth overfishing had not yet occurred.

Depoutot (1987) fitted regressions to mean monthly $CPUE_x$ (for tuna caught around FADs) and $CPUE_y$ (for free-swimming tuna, i.e. without FADs) over several years. The regressions were significant ($p<0.05$), while the slopes were not significantly different from each other:

Species	r	slope	95% CI of slope
Skipjack	0.61	1.58	0.74 - 2.34
Yellowfin	0.68	1.54	0.60 - 2.56

For skipjack, the overall mean $CPUE_x$ was 37.0 fish per day, while $CPUE_y$ was 25.3 fish per day, so that $CPUE_x/CPUE_y$ was 1.46. This is very close to the value of $CPUE_x/CPUE_y = 1.41$ observed in the Halmahera skipjack fishery. This is gratifying because our study implicitly assumed that all differences between rumpon and pre-rumpon era CPUEs were due to increased catchability. Depoutot's estimates of $CPUE_x$ and $CPUE_y$ are synoptic and make no such assumption.

The ratio of $CPUE_x/CPUE_y$ (*ca* 1.4) for skipjack is probably a function of biological interactions between skipjack and rumpon, depending on presently unknown details of skipjack behaviour and rumpon structure.

Depoutot (1987) also noted that fishing around FADs reduced fuel consumption by about 25%: less than but comparable to the reduction in fuel consumption in Halmahera (46.3%). Fuel costs will be affected by steaming time and weather around Halmahera and Papeete, not described in either study.

Bait fish consumption varied between the Solomon Islands, Kiribati and Fiji, from 4.5 to 16.5 t/t/year compared to 26.9 t/t/year in the pre-rumpon area 33 t/t/year in the rumpon area. The Halmahera fishery used much less bait at all times, but was even more efficient when rumpons were deployed. Bait fish from the Pacific Islands included many species (e.g. *Enchrasicolina* spp., *Herklotsichthys* spp., *Apogon* spp.) not used in Eastern Indonesia, where preferred species appear to be easier to catch, perhaps because they are more abundant or accessible (Blaber *et al.*, 1992).

The assessment succeeded in dissecting the effects on the stock of rumpon which:

- attract fish, increasing CPUE and catchability, and
- increase effort on the stock independently of the number of boats and the type of gear used.

The assessment assumed that Halmahera skipjack pertain to a unit stock. Tagging studies in Eastern Indonesia support this idea:
- Gafa & Subani (1987) tagged 2,664 skipjack in North Sulawesi waters and recaptured 66 fish, of which 50 were recaptured after a mean of 25.2 days at liberty and had moved less than 1.0 nautical miles. The remaining 16 skipjack moved from 12 to 223 nautical miles (mean 71.7 nautical miles) and were at liberty for a mean 184.9 days;
- Gafa & Subani (1987) tagged 4,850 skipjack and 2,702 yellowfin (total 7,532), out of which 1,294 were recaptured near their point of release. A few skipjack released near Waigeo Island and Ceram travelled up to 1,300 nautical miles into the West Pacific, but most travelled less than 500 nautical miles. Out of 1,215 recaptures in Indonesian waters 1,138 (93.4%) were taken in the general area of their release (tab. 5);

Table 5 - Numbers of tagged tuna recaptured in different areas in Indonesia (from Gafa & Subani, 1987).

Release area	Number released	Waigeo Gag	Ceram Sea	Bacan	Tomini Bay
Waigeo and Gag Islands	4,716	966	6	5	0
Ceram Sea	1,854	32	36	23	4
Bacan	554	4	1	108	2
Tomini Bay	408	0	0	0	28
Total	7,532	1,002	43	136	34

- only 59 out of 7,532 (0.78%) of skipjack tagged in eastern Indonesian waters were recaptured outside of Indonesian waters. Out of 162 returns of fish tagged outside of, and recaptured in, Indonesian waters during the same period, 119 (73%) were recovered neighbouring Philippine and Papua New Guinea waters;
- Aprieto (1994) reported a large number of tag returns from the Philippine and Celebes Seas suggesting that skipjack populations in these areas show very little exchange of fish with each other or with the Halmahera stock.

The assessment presented here may provisionally be regarded as applicable to a stock that is largely confined to the Halmahera and Maluku Seas, perhaps because highly indented island coastlines located in several interdigitating localities discourage migration and provide abundant habitats.

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