THE BIOMASS OF TROPICAL ANCHOVIES (*Encrasicholina* SPECIES) AT BACAN, EASTERN INDONESIA ESTIMATED BY THE DAILY EGG PRODUCTION METHOD

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ABSTRACT

Tropical anchovies (*Encrasicholina* species) are the target of the large baitfishery for the pole-and-line skipjack tuna fleet in eastern Indonesia. Recent studies have shown that the tuna catches are constrained by a lack of bait. This may be due either to overexploitation by the "bagan" fishery or diversion of bait catches for human consumption. In order to set sustainable exploitation rates for the baitfishery, we need to know the biomass of bait available.

We estimated the biomass of the tropical anchovies *Encrasicholina heterolobus* and *E. devisi* at Bacan, northern Maluku during 1996-97 using the Daily Egg Production Method (DEPM). Eggs of anchovies were sampled throughout the baitground with vertical hauls of a plankton net of 250-μm mesh. Adult anchovies were collected at the same time from the bagan fishery to obtain estimates of the fecundity and proportion of the adult population that were spawning.

We conducted four surveys: September and November 1996 and April and July 1997. The mean biomass ranged from 81 ± 28 t in November 1996 to 2545 ± 287 t in April 1997 and was highly correlated with mean zooplankton biomass ($r^2 = 0.84$). This suggests that the biomass of anchovies in a region such as Bacan is likely to range widely in relation to environmental conditions and primary productivity.

Baitfish demand by the pole-and-line fleet in Bacan varies from a mean of 5 t per night to a maximum of almost 30 t. This can represent between 5 and 150% of the estimated biomass of anchovies in the baitground. The current baitfishery comprises about 20 active bagans and there is demand for its expansion to meet the demand for bait. However, our data suggest that even with an expansion of the number of bagans, there will still be periods when the catches of anchovies will not be sufficient to supply the current pole-and-line fleet because of natural fluctuations in the populations. The anchovy populations could sustain expansion of the bagan fleet at Bacan as long as the catches during periods of low biomass did not depress the populations to levels from which they could not recover.

KEYWORDS: ***Encrasicholina*, anchovy, biomass, daily egg production, sustainability.**

INTRODUCTION

Estimating the biomass of a population is very important for accurate assessment of sustainable exploitation rates of fishes. The Daily Egg Production Method (DEPM) has been widely used since the early 1980s to estimate the biomass of a range of temperate species that spawn pelagic eggs (Lasker, 1985). It involves estimating the number of eggs spawned, female fecundity, the proportion of the population engaged in spawning and the sex ratio of spawners (Saville, 1964). The method has been successfully applied to a range of temperate clupeoids (especially anchovies and sardines) that spawn over large geographic areas, have protracted spawning seasons and indeterminate fecundity (Lasker, 1985, Armstrong *et al.*, 1988; Fletcher *et al.*, 1996).

Few studies have attempted to apply the method to tropical species and only Somerton (1990) and Somerton *et al.* (1993) have used this method to make weekly estimates of the biomass of a tropical anchovy, Nehu *Encrasicholina purpurea* in Pearl Harbour, Hawaii. Tropical species differ from those species in temperate regions

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to which the method has been applied because the eggs hatch within 24 h (Clarke, 1989). Egg production is usually the most variable DEPM parameter estimated (Picquelle & Stauffer, 1985; Koslow *et al.*, 1995; Fletcher *et al.*, 1996). Thus, the application of the DEPM method to give precise estimates of the biomass of these tropical species is constrained by the number of plankton tows possible during the hatching period of each batch of eggs.

Tropical anchovies, *Encrasicholina* species, have similar characteristics to other species to which the DEPM has been applied - they spawn almost continuously throughout the year, in most inshore areas of the tropical Indo-Pacific region and have a variable, indeterminate fecundity (Milton *et al.*, 1995). Two species of tropical anchovy, *Encrasicholina devisi* and *E. heterolobus*, are the dominant anchovies in the region and the major component of the baitfish used by pole-and-line skipjack tuna fisheries (Dalzell & Lewis, 1989) as well as dried fish for human consumption in south east Asia. The spawning frequency, fecundity and egg production of both species have been studied in several areas of the south Pacific (Milton & Blaber, 1991; Milton *et al.*, 1995) and Indonesia (Wright, 1992). However, these data have not been used to estimate the biomass or yield of these species.

The pole-and-line skipjack tuna fishery in eastern Indonesia catches an estimated 70,000 t of tuna and relies heavily on adequate supplies of suitable baitfish. As the fishery expanded during the 1998s, the supply of baitfish from the independent bagan fishery declined and is now limiting the production of tuna (Naamin & Gafa, 1998). A lack of baitfish has been cited as the major cause of lost fishing time. There is insufficient data to determine whether the lack of bait is due to overfishing of the baitfish stocks or because the anchovies caught by the bagans are being diverted and sold for human consumption at a higher price.

The aims of this study were: (1) to assess the feasibility of using the Daily Egg Production Method (DEPM) to estimate the biomass of *Encrasicholina* in eastern Indonesia; (2) if feasible, to use the DEPM approach to estimate the biomass of anchovies at Bacan and (3) to relate the biomass estimates of anchovies to the production of the bagan fishery in order to estimate the number of bagans the anchovy populations will sustain.

MATERIALS AND METHODS

The model

The equation for the daily egg production method using the terminology of Parker (1985) is:

$$B = \frac{PAkW}{RFS} \qquad (1)$$

Where B is the spawning biomass (t), P is the daily egg production (eggs per 0.5 m^2 per day), A is the spawning area (km^2), W is the mean weight of mature females (g), R is the proportion of females by weight, F is the batch fecundity (eggs per spawning by an individual female of average weight), S is the proportion of females spawning each night and k = 2 which converts parameters from grams to tons and km^2 to 0.5 m^2.

Field Sampling

The plankton surveys to collect eggs for the estimation of daily egg production were made in the main baitground in Bacan during five sampling trips: April, September and November 1996, April and July 1997. Baitfishing in Bacan is normally conducted in two areas, on the northern and southern sides of Sambaki Bay (Figure 1). Up to three plankton surveys were conducted in each area during each sampling trip. The distribution of sampling effort and the sample design are shown in Table 1. All plankton were sampled with one plankton net (0.5 m^2) with 250 μ mesh size (September and November 1996) or two nets (total surface area: 0.75 m^2). All tows were made vertically by hand from 10 or 20 m. Nets were hauled from a small, diesel-powered fishing vessel, which restricted the number of tows possible during each day to a maximum of 60. Initially, in April and September 1996, tows were made from 20 m, but replicate calibration tows of variable length in the same area showed that anchovy eggs were concentrated in the upper 10 m. In order to increase the number of tows possible during each day, all tows were made from 10 m after November 1996.

In order to estimate the daily egg mortality (Z) and define the modal time of spawning, plankton tows were hauled throughout the night on at least one night during each sampling period. These hauls were usually made near one of the bagans from which the adults were collected. All plankton samples were fixed in 10% formalin.

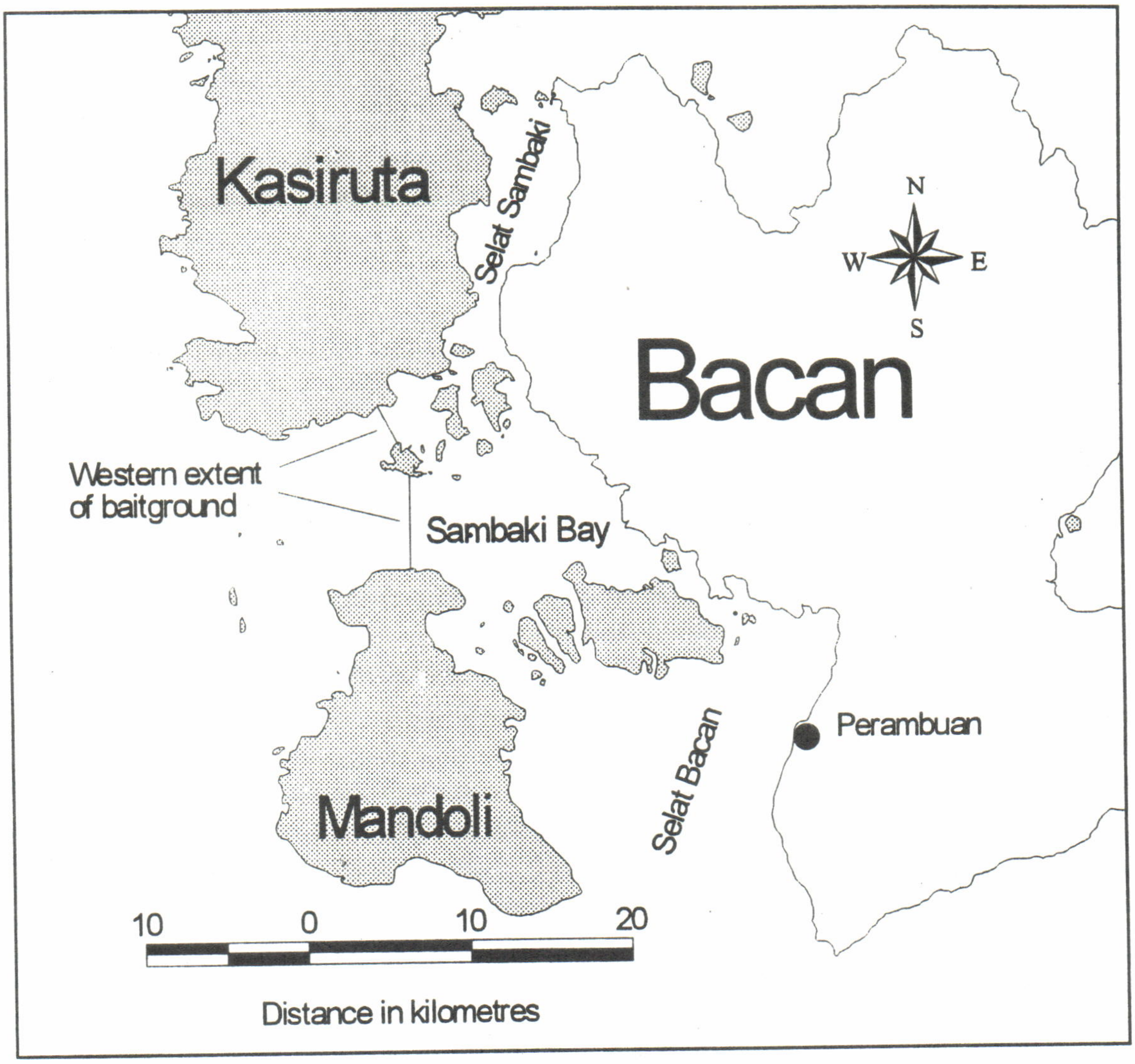

Figure 1. Map of the baitground in Bacan, northern Maluku showing the extent of the baitground in Sambaki Bay and the Usaha Mina base at Perambuan.

Table 1. The sampling design, number of days that plankton and adult anchovies were collected for biomass estimation at Bacan between April 1996 and July 1997. (*One extended survey was conducted in September and November 1996).

Sampling design	Sampling period	Area	Plankton surveys (days)	Nights of adult samples
Random	Apr-96	South	3	3
Systematic	Sep-96	Both	10*	3
Systematic	November 1996	Both	5*	2
Random	Apr-97	North	2	2
		South	2	2
Random	July 1997	North	2	2
		South	2	2

Samples of adults were obtained each night from at least two commercial bagans in the region that the egg survey would be conducted the following day. Adult samples were collected after the bagan was hauled, usually between 03:00 and 06:00 h. Catches were sorted into species groups and a random sample of at least 300 mixed anchovies preserved in 10% formalin for analysis in the laboratory.

Laboratory Studies

Plankton samples were sorted in the laboratory and all anchovy eggs removed and identified to species according to Delsman (1931). Eggs were then staged using the criteria of Moser & Ahlstrom (1985). The remaining plankton was then split with a Fulsom splitter and one half was dried at 40°C to a constant mass.

Adult anchovies were measured, weighed, sexed and their gonads removed and weighed (± 0.001 g). Ovaries were embedded in paraffin, sectioned and stained with haematoxylin and eosin. Ovarian sections were examined for the presence of post-ovulatory follicles or hydrated eggs and their development staged by the criteria of Milton & Blaber (1991). Batch fecundity was estimated from those ovaries that were shown to have enlarged, but not hydrated eggs in the histological sections. A subsample of about a third of the ovary from each of these fish was weighed and the number of enlarged eggs counted. The batch fecundity was estimated by scaling up the subsample egg count. Sexual maturity of female anchovies was defined as those fish that had mature eggs (Stage 4 of Milton & Blaber, 1991) present in their ovaries.

Parameter Estimation

The spawning area of anchovies (*A*) at Bacan was defined by the extent of the baitground and the systematic surveys in September and November 1996. The survey in September 1996 showed that the distribution of eggs was virtually confined to the area of the baitgrounds, with few eggs in samples outside these regions. The next survey in November 1996 provided further evidence of the extent of spawning in this region. All subsequent surveys were confined to the baitground in an attempt to reduce the variance of the daily egg production estimate (*P*).

The egg production (P_0) was estimated by fitting an exponential mortality function to the abundance of eggs of different ages by the equation:

$$P_t = P_0\, e^{-Zt} \qquad (2)$$

where P_t is the abundance of eggs per 0.5 m^2 in the different age categories (t), P_0 is the daily egg production per 0.5 m^2 at spawning and is the best estimate of P. t is the estimated time in hours elapsed since spawning, and Z is the instantaneous hourly egg mortality rate.

The spawning fraction (*S*) was estimated from the proportion of females with Day-0 postovulatory follicles or hydrated eggs in their gonads. Other parameters (*W* and *R*) were estimated from the dissected fish and these samples were assumed to be representative of the population in the region sampled for eggs the following day. For batch fecundity (*F*), linear regression of batch fecundity against ovary-free weight was used to estimate the batch fecundity of all females in each sample. These estimates were used to calculate the daily mean batch fecundity. The variance about the slope of the regression was also used in the calculation of the variance of the mean (Picquelle & Stauffer, 1985). The coefficients of variation (CV) of each parameter and covariance (COV) of each pair of parameters were calculated enabling the variance and bias of the biomass estimate to be estimated from the equations of Parker (1985).

The relationship between plankton biomass and egg density was assessed for the early and late stage eggs. The densities of early (stage 1 or 2) and late (stage 12 or 15) eggs in each tow were correlated with zooplankton biomass in each tow. Diurnal and seasonal differences in zooplankton biomass were compared by nested analysis of variance with days nested within trips (seasons) and diurnal patterns estimated by a sine-cosine curve (Milton & Blaber, 1991).

RESULTS AND DISCUSSION

The study showed that plankton surveys in the baitground at Bacan can collect *Encrasicholina* eggs and that we can also sample the adults concurrently. Thus we have the data to apply the Daily Egg Production Method (DEPM) to estimate anchovy biomass. The precision of the biomass estimate is most affected by the egg production, as it varies widely both spatially and temporally. We found egg production was mainly confined to the main bay in the baitground during the extended surveys in September and November 1996 (Figure 2). As a consequence, we decided to attempt to reduce the variability of the egg production estimates by increasing the sampling intensity during the April and July 1997 surveys. However, the variances of the mean egg production in April and July 1997 were similar to that found during the broader scale surveys in 1996. This suggests that the scale of egg patchiness is quite small (10's of m) and that like other clupeoids, the eggs can be very concentrated (Blaxter & Hunter, 1982). Thus, more intensive sampling only increases the probability that dense patches of eggs are encountered.

The density of early or late stage eggs were not correlated with high plankton biomass (all $r^2 < 0.1$; $P > 0.8$). This result suggests that anchovy spawning is not concentrated in areas of high food availability. Tropical anchovies spawn throughout the year so may not necessarily need to match their spawning with particular periods of high plankton production (Milton & Blaber, 1991). Spawning appears to be concentrated in regions of high current that will ensure that eggs disperse from the spawning grounds before they hatch, possibly reducing cannibalism.

Unlike previous studies of other species that have applied the DEPM to estimate biomass, we have not surveyed the entire extent of spawning by anchovies in Bacan. Anchovies would also be spawning in Selat Sambaki north of the baitground and further northeast along the north coast of Bacan. However, our primary focus was to estimate the biomass of anchovies available for the baitfishery.

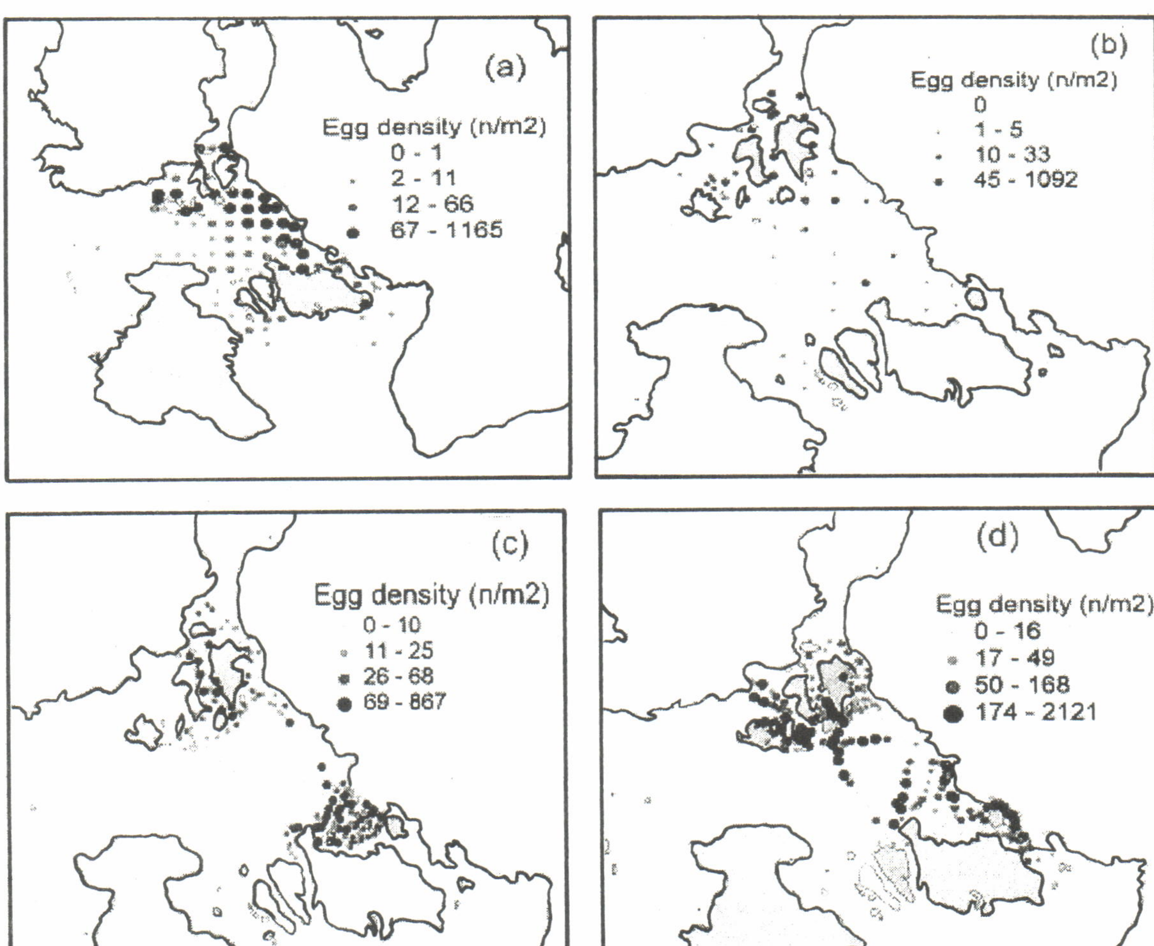

Figure 2. Egg production ($n.m^{-2}$) at Bacan during the four survey periods (a) September 1996, (b) November 1996, (c) April 1997 and (d) July 1997.

Daily and seasonal estimates of anchovy biomass at Bacan varied between 81 and 2545 t depending on the time of year of the survey (Table 2). Mean egg production was similar in most months except during July 1997 when the overall mean density of eggs was much higher than at other times. The spawning fraction varied most among periods, with a smaller fraction spawning during April and September 1996 and larger fraction during November and April 1997. The large biomass estimate in April 1996 occurred because only a small fraction were spawning and the fecundity was lower during that period. The seasonal mean estimates of anchovy biomass were correlated with mean zooplankton biomass in the survey area (r^2= 0.84; P<0.05, N=5). Somerton *et al.* (1993) found similar results for the Nehu *E. purpurea* in Hawaii. They found that weekly estimates of Nehu biomass were correlated with seasonal variations in spawning and fishing mortality.

The bagan fishery currently comprises about 20 active bagans (Rawlinson *et al.*, 1998) and their demand for bait has been relatively constant throughout the year during the last ten years (Figure 3). Mean nightly demand was about 5 t for the entire fishery, but could approach 30 t at maximum demand. This contrasts with the biomass estimates from the DEPM study (Table 2). Biomass fluctuated widely, both between days during a survey and between surveys. These fluctuations in the biomass of anchovies meant that the mean and maximum demand could be up to twice the estimated anchovy biomass or as low as 5% (Figure 4). For example, bagans caught approximately 1 $t.nt^{-1}$ each in July 1997, yet the total catch only corresponded to about 6% of the biomass of anchovies available in the baitground (mean 350-t and daily range 70-370 t). This indicates that the anchovy populations in Bacan could have sustained much higher catches at this time, whereas in November and April, the demand exceeded the supply of bait on most nights.

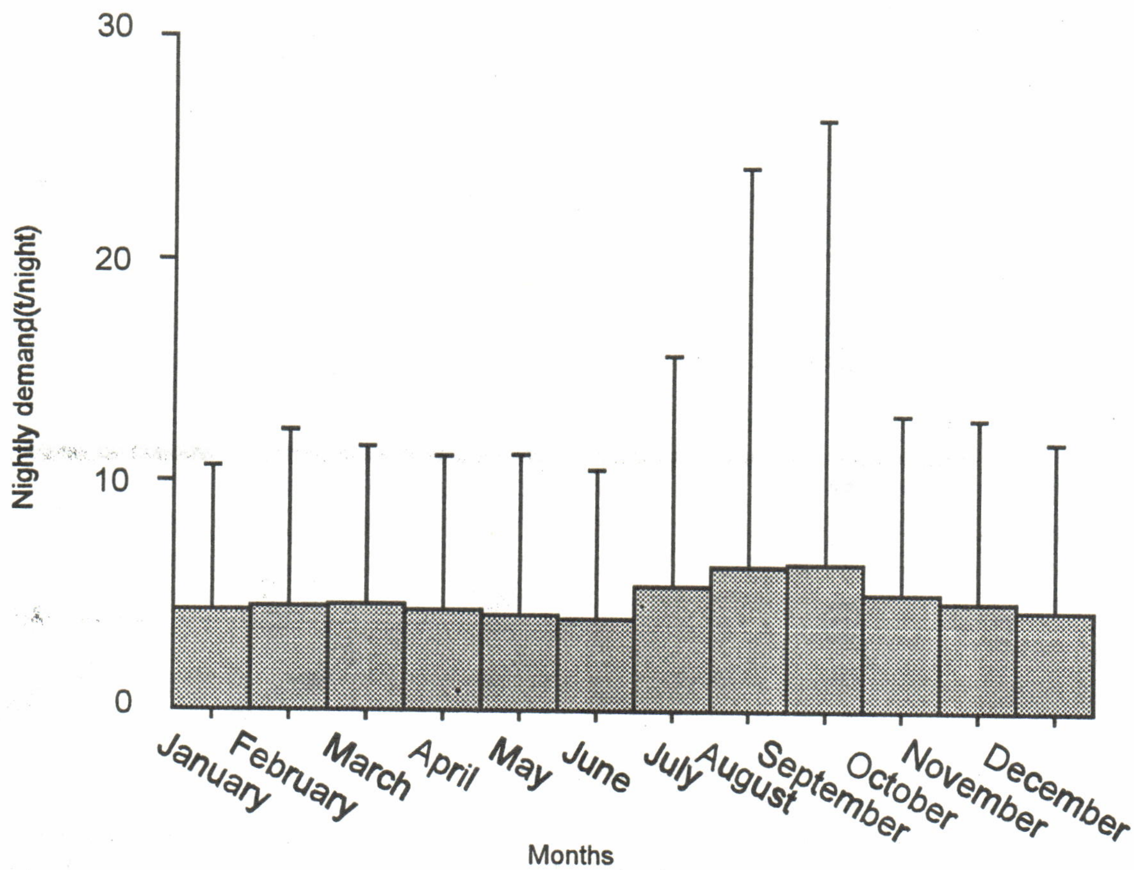

Figure 3. The mean and maximum daily bait demand (t) by the bagan fishery in Bacan since records of the fishery began in 1988.

Table 2. Estimates of the weighted means and coefficients of variation of each parameter used to calculate the biomass of anchovies at Bacan between April 1996 and July 1997.

Parameters	Apr-96	Sep-96	Nov 1996	Apr-97	July 1997
Survey area (A) (km^2)	98.1	630	120.0	98.1	98.1
Egg production ($eggs.m^{-2}.d^{-1}$) (P)	192.0 ± 19.3	117.7 ± 26.2	128.7 ± 35.4	146.3 ± 10.3	372.8 ± 42.1
Egg mortality (Z)	0.15 ± 0.04	0.15 ± 0.04	0.15 ± 0.04	0.14 ± 0.03	0.15 ± 0.05
Mean weight (g) (W)	2.74 ± 0.03	4.05 ± 0.04	4.83 ± 0.05	3.16 ± 0.03	3.49 ± 0.03
Mean fecundity (F)	2069 ± 10	4034 ± 137	5702 ± 128	3976 ± 101	4277 ± 124
Sex Ratio (R)	0.49 ± 0.01	0.43 ± 0.03	0.45 ± 0.02	0.50 ± 0.01	0.53 ± 0.01
Spawning fraction (S)	0.04 ± 0.01	0.06 ± 0.01	0.75 ± 0.02	0.51 ± 0.01	0.33 ± 0.01
Biomass (t) (B)	2545 ± 287	1229 ± 316	81 ± 28	89 ± 14	352 ± 45
Zooplankton ($g.m^{-2}$ dry wt)	0.10 ± 0.03	0.024 ± 0.002	0.014 ± 0.001	0.022 ± 0.003	0.009 ± 0.001

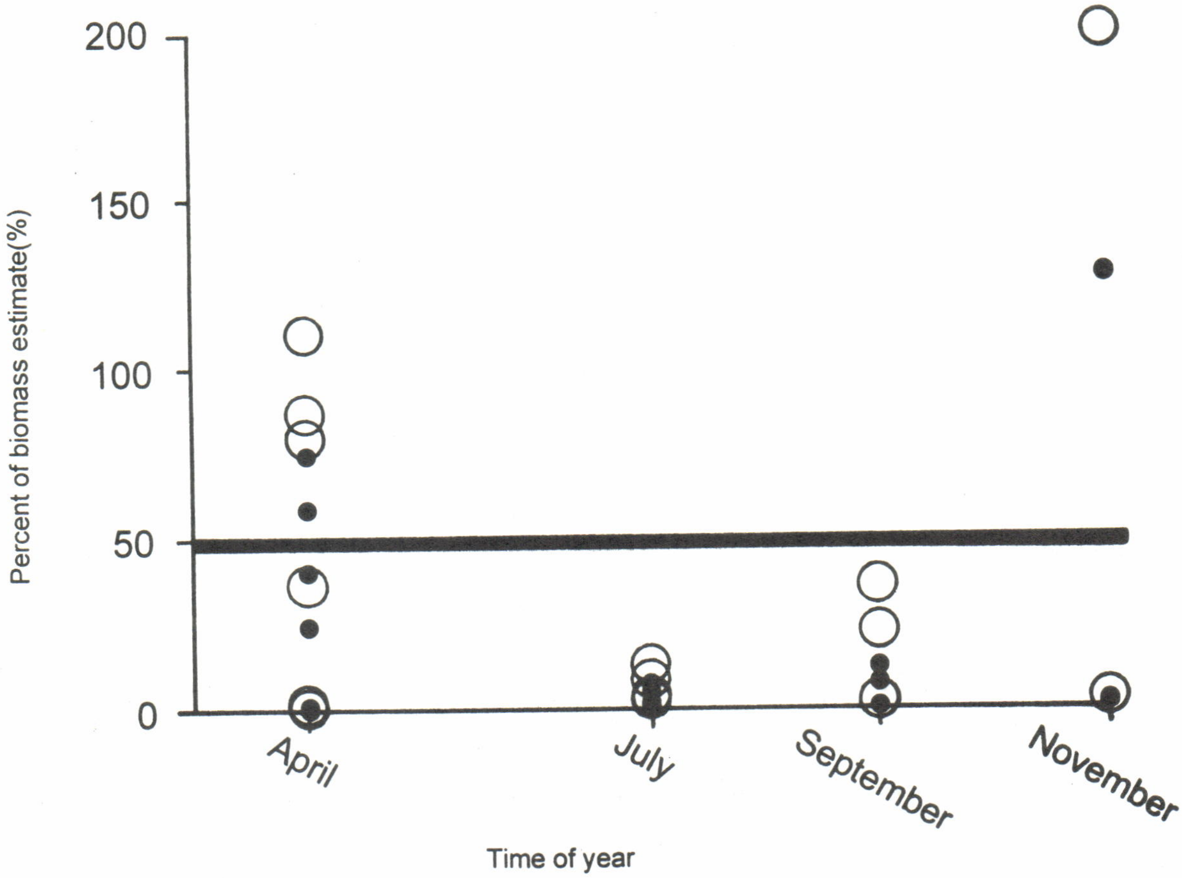

Figure 4. The mean and maximum demand for baitfish in the four months that were surveyed in Bacan, expressed as a percentage of the daily estimates of anchovy biomass in 1996 and 1997. The line corresponds to the recommended maximum level of exploitation (50% of the biomass).

The consequences of these findings for the management of the bagan fishery are fairly dramatic. The results suggest that the anchovy populations fluctuate on both short and longer-term time scales. The current level of exploitation should be sustainable and could even increase. However, there will be periods when the anchovy populations are reduced and bait will be in short supply. At these times, the exploitation rates will exceed the recommended levels and will temporarily drive down the biomass of anchovies. The precautionary approach to fisheries suggests that these periods of over-exploitation should be kept to a level that ensures that the populations recover when conditions are favourable. If the number of bagans is kept to between 20 and 30, then our data suggest that this is unlikely to increase the periods when demand exceeds supply.

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