METHODS FOR ANALYZING INTERACTIONS OF LIMITED-RANGE FISHERIES: HAWAII'S PELAGIC FISHERIES

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ABSTRACT

A review of previous studies indicated that local fishing intensity can affect local pelagic fish abundance, but overall abundance on a wider scale may have a greater local effect. Interactions of limited-range fisheries were explored using a theoretical model in which local catch per unit effort (CPUE) declines as the catch approaches or exceeds the rates of fish immigration and recruitment in a limited area. The model has the local catch increase with effort to an asymptotic level. This simple model was used to simulate local CPUE in relation to varying rates of immigration and local fishing. Simulated data were used to test an analytical approach--the regression of CPUE on catch--which was then applied to real data from Hawaii's troll fishery. Analyzing CPUE in relation to catch rather than effort was convenient because fishing effort is poorly documented in Hawaii and includes effort by diverse methods. The analysis indicated that the CPUE of yellowfin tuna (*Thunnus albacares*) in Hawaii's troll fishery was not affected significantly by total yellowfin tuna catch in Hawaii in 1987-90, but was directly related to an index of abundance for surface-caught yellowfin tuna in the western Pacific.

1. INTRODUCTION

In Hawaii and in many Pacific island nations, locally-caught pelagic fishes constitute a small fraction of stocks that extend far beyond the range of the local fisheries. Primary concern over the status of these stocks is appropriately focused on abundance and production throughout their range (Suzuki, 1989). However, the rate of replacement of fish within any area is finite. Theoretically, if fishing mortality in an area increases greatly in relation to net immigration and recruitment, local catch per unit effort (CPUE) will decline. If there are several fisheries in such an area, fishery interactions may occur.

Fishery production models, which typically are used to estimate maximum sustainable yields for pelagic species (Suzuki, 1989; IATTC, 1992), are not very useful for detecting fishery interactions. Nor are they useful for estimating the optimal level of fishing effort in localized fisheries that are too small to significantly affect the size of the stock or its level of production (Sathiendrakumar and Tisdell, 1987). In many areas of the Pacific, including Hawaii, tropical tuna and billfish production may be limited mostly by immigration from surrounding areas rather than by the reproduction and growth of resident fish. For such fisheries, a model in which the local catch increases with effort towards an asymptote was proposed by Sathiendrakumar and Tisdell (1987).

In this paper, I develop a simple model for the relationship between catch and effort in a limited-range fishery on a highly mobile pelagic stock. The model is similar to that of Sathiendrakumar and Tisdell (1987) but is explicitly formulated as a function of immigration, emigration, natural mortality, and catchability. I use the model to simulate data for a fishery in which immigration, emigration, and fishing effort are seasonal. The simulated data are used to test whether the effect of fishing intensity on local catch rates can be adequately quantified by regressing CPUE on catch rather than on effort. Using catch rather than effort to quantify fishing intensity is helpful if total fishing effort is poorly documented and derived from widely different fishing methods, as is the case in Hawaii. Finally, the CPUE in Hawaii's troll fishery for yellowfin tuna (*Thunnus albacares*) is analyzed in relation to the total catch by troll, handline, and longline fisheries to determine whether the troll CPUE has been affected by total fishing intensity.

2. REGULATING LOCAL FISHING EFFORT IN HAWAII

Local fishery managers in the USA Exclusive Economic Zones (EEZs) of the central and western Pacific can do little about the distant-water foreign fisheries, which operate outside the EEZs and harvest the majority of pelagic fish caught in the region (NMFS, 1991). The primary USA fishery-management objective is to prevent recruitment overfishing (NMFS, 1989), defined in relation to pelagic populations which are mostly exploited beyond USA jurisdiction. This objective is dysfunctional, since there exists no international management organization through which stock-wide objectives can be achieved (NMFS, 1991). Therefore the USA Western Pacific Regional Fishery Management Council (WPRFMC) has focused its objectives on "equitable domestic utilization of the resources. . ." among user groups (WPRFMC, 1991). Recognizing that the domestic catch within the EEZs of the USA may be large enough to reduce local CPUE and cause local fishery interactions, the WPRFMC has attempted to regulate fishing effort in Hawaii's EEZ (WPRFMC, 1991).

Recent increases in the total catch of pelagic species in the USA Pacific EEZs have mostly been due to an expanding domestic longline fishery in Hawaii (Ito, 1991; WPRFMC, 1991). The less mobile, small-vessel troll and handline fisheries in Hawaii have experienced declines in total catch and CPUE (Boggs, 1991) as the longline fishery has expanded. Concern by troll, handline, and longline fishermen over reduced CPUE, together with gear conflicts, dangerous confrontations between fishermen, and overcrowding of dock facilities, induced the WPRFMC to pass regulations halting the entry of additional vessels into the USA domestic longline fishery in Hawaii in 1990. To prevent gear conflicts, the WPRFMC in 1991 also passed regulations closing nearshore areas (<50-70 miles, depending on location) to longline fishermen.

Scientific evidence in support of limiting longline-fishery participation in Hawaii has been sparse. Prior to 1986 the WPRFMC focused on the impacts of foreign longline fishing within Hawaii's EEZ on catch rates for pelagic management unit species (PMUS) which included billfish, mahimahi (*Coryphaena hippurus*), wahoo (*Acanthocybium solandri*), and pelagic sharks, but not tunas (Lovejoy, 1977, 1981; Wetherall and Yong, 1983; Skillman and Kamer, 1992). The possible impacts of foreign fishing in the EEZ were regulated by the original Pelagic Fisheries Management Plan (WPRFMC, 1986) but became irrelevant as no foreign longliners exercised the option to fish legally in Hawaii's EEZ after 1980. However, the expanding domestic longline fishery in Hawaii now catches more fish than the foreign longliners did before 1980 within the EEZ (WPRFMC, 1991). This catch increase, plus the inclusion of tunas as a Pacific Pelagic Management Unit Species (PPMUS) in 1992, provided some impetus to regulate the domestic fisheries.

Regulating fishing effort rationally requires a quantification of the effect of local fishing pressure on local CPUE for pelagic species, and a means of choosing a desirable level of fishing effort. An optimal level of fishing effort can be estimated if the cost of effort and the value of catch are defined and the relationship between catch and effort is quantified as an asymptotic curve (Sathiendrakumar and Tisdell, 1987). In the asymptotic catch model, although catch never declines because of overfishing, CPUE does decline as effort increases. Thus, detecting and quantifying an asymptotic relationship between local catch and fishing effort would help indicate whether regulating the local fishing effort is justified.

The optimization of fishing effort, in relation to the appropriate costs and benefits, depends on the relative mix of the fisheries comprising the total effort. Thus, the allocation of fishing effort among interacting fisheries is an additional problem. Changing the composition of effort by different gear types will alter the optimum. Furthermore, the decision as to which fishery to regulate, and how, may be strongly influenced by historical, social, or logistical considerations. For example, the least-mobile fisheries are most vulnerable to local declines in CPUE, and this could be a reason to limit the effort of the more mobile longliners in some areas rather than the effort of all the fisheries in those areas. In any case, evidence that local fishing pressure affects local CPUE should be the basis of any scheme for regulating fishing effort.

3. REVIEW OF PREVIOUS RESEARCH

Several previous studies suggest that localized fishing effort can reduce catch rates (CPUE) for wide-ranging pelagic stocks in a local area (Lovejoy, 1977, 1981; Wetherall and Yong, 1983; Squire and Au, 1990; Skillman and Kamer, 1992). Lovejoy (1977, 1981) simulated the pelagic fisheries in Hawaii's EEZ and predicted that small increases in the domestic catch of blue and marlin (*Makaira mazara*) and striped marlin (*Tetrapturus audax*) would result if foreign fishing in the EEZ was eliminated. Wetherall and Yong (1983) modelled blue marlin catch rates near Hawaii as a function of mid-Pacific abundance, recruitment, and fishing effort, and found that increases in local, adjacent, and mid-Pacific effort had negative impacts on CPUE near Hawaii. Skillman and Kamer (1992) found significant negative correlations between foreign longline effort and Hawaii's longline catch rates for blue and striped marlins. Most recently, Squire and Au (1990) found that local longline and troll catch rates of striped marlin rebounded when longline fishing was temporarily excluded from an area off Mexico. All of these studies found that local fishing effort affected local CPUE, but they lacked the appropriate model or sufficient data to accurately quantify the relationship, and thus provided no means of choosing an optimal intensity for local fishing effort.

The model of Lovejoy (1977) demonstrated that short-term abundance of transient populations was reduced by increasing local fishing effort, but the relative magnitude of the reduction was dependent on the actual (but unknown) number of fish in the area. Lovejoy (1977) used monthly Japanese longline CPUE data (1962-75) to model the spatial distribution, abundance, and catch of marlin in 27 subareas of Hawaii's EEZ and a single

Pacific (pooled) area. Fish movements through the EEZ were simulated to match geographic changes in Japanese CPUE in the 27 Hawaiian areas, assuming general north-south movements for blue marlin and northwest-southeast movements for striped marlin. However, the estimates of abundance and catchability were essentially guesses, and the catches predicted by the model were very sensitive to these parameters. This marlin-fishery simulation (Lovejoy, 1977) was repeated with the removal of the fishing mortality caused by longline fisheries in the EEZ (*i.e.*, set to zero). When Japanese longline fishing in the EEZ was eliminated, the changes in the fish abundance were small in areas fished by the small-vessel trollers, as were the effects of changes in abundance on troll catches of blue and striped marlins (2 and 5%, respectively). The simulated increases in troll catches were larger when domestic longline fishing also was eliminated (5 and 21%, respectively). Though smaller than the Japanese fishery in the EEZ at that time, the domestic longline fishery had a greater simulated impact because it had a greater geographic overlap with the troll fishery.

The sensitivity of the Lovejoy (1977) simulations to parameter estimates was illustrated when the estimated abundances of the marlin stocks were altered (Lovejoy, 1981). When the number of marlins moving from the Pacific-pooled area to Hawaii's EEZ was halved (Lovejoy, 1981) and catchability was increased to simulate the same catches as in the original model, eliminating all longline-fishing mortality increased the simulated troll catches of blue marlin by 13% and striped marlin by 45%, respectively. In contrast, when abundances were doubled, eliminating all longline fishing increased the troll catch of blue marlin by only 1% and striped marlin by 3%.

Exogenous factors may overwhelm the influence of local fishing effort on local catch rates of highly-mobile pelagic fish. Indices of abundance (CPUE) in local areas, for example, have been found to be significantly correlated with CPUE over a much wider range. Using Japanese longline catch-and-effort statistics for 1962-79 to compute estimates of abundance, Wetherall and Yong (1983) found that variation in blue marlin catch rates at the beginning of a year in a mid-Pacific area explained 80% of the annual variation in peak third-quarter catch rates in a 5x10 degree (latitude x longitude) area around the main Hawaiian Islands. No other statistically-significant predictors of local catch rates were found, but by including the variables for a recruitment trend and the foreign fishing effort in local, adjacent, and mid-Pacific areas, Wetherall and Yong's (1983) regression model increased the amount of accountable variation from 80% to 95%. Their analysis suggests that the impact of local effort on Hawaii's blue marlin fishery was small compared with the impact of abundance on a wider scale, under the conditions prevailing in 1962-79.

Pronounced seasonal cycles characterize the local, apparent abundance of large, tropical, pelagic species, especially towards the higher latitudes. The effect of local effort on CPUE may well depend on the season. Wetherall and Yong (1983) and Squire and Au (1990) accounted for seasonal effects by eliminating all but the data for the season of peak CPUE. Another method used by Skillman and Kamer (1992) was to decompose the seasonal and nonseasonal components of quarterly and monthly time series and examine the nonseasonal component. At a quarterly resolution, deseasonalized, local, domestic longline CPUE statistics for blue and striped marlins in Hawaii (1962-78) were significantly negatively correlated with foreign longline effort in local and adjacent areas ($P < 0.05$), whereas no significant correlation was found at the annual resolution

(Skillman and Kamer, 1992). The correlation coefficients were low (-0.26 to -0.32, nonparametric Spearman coefficients), and no attempt was made to quantify the relationships. Domestic longline CPUE statistics were most negatively correlated with Japanese longline effort in the local area, again suggesting a stronger relationship with increased proximity.

An unintended "experiment" on the effect of local fishing effort on local marlin CPUE was performed by the government of Mexico in 1977 when it enforced regulations against foreign longline fishing within its 200-mile exclusive economic zone. The enforcement caused a major decrease in fishing effort, allowing an interesting comparison to be made between catch rates before and after 1977 (Squire and Au, 1990). Striped marlin catch rates by troll fishermen in the area west of Mazatlan and around the tip of Baja California doubled during 1977-80 (Squire and Au, 1990). Joint-venture longline operations beginning in 1979-80 in the area also experienced catch rates twice as high as those in 1976. This series of events suggests a much stronger effect of local fishing effort on CPUE than that indicated for Hawaii's fisheries (Lovejoy, 1977; Wetherall and Yong, 1983; Skillman and Kamer, 1992). The opportunity to make a comparison like that of Squire and Au (1990) between CPUE statistics before and after the abatement of foreign longline fishing in Hawaii's EEZ (1980) was given as a reason for regulating foreign longline fishing (WPRFMC, 1986). Unfortunately this analysis was never undertaken, partly because of a severe decline in reporting of Hawaii's fishery statistics beginning around 1979 (S. Pooley, Honolulu Laboratory, National Marine Fisheries Service, Honolulu, HI 96822-2396, unpubl. manuscr.).

Squire and Au (1990) described the Mexico striped marlin fishery as operating in a "core area" in which fish naturally aggregate in concentrations that are much higher than throughout the population range. When they analyzed catch rates of the joint-venture fishery and the foreign longline fishery off Mexico in relation to fishing effort during 1962-84, they found no clear quantitative relationship. This was largely because the CPUE in the core area declined in 1981-84, despite relatively low levels of effort. Squire and Au (1990) suggested that a reduction in core-area fishing effort disproportionately raises the local CPUE, because core-area CPUE depends more on the formation and fishing down of "hot spots" than on stock production. Hypothetically, the relationship between fishing effort and CPUE in "hot spots" could be different from that in a larger area. Such a relationship could be demonstrated only if the data had very fine geographic resolution.

4. ASYMPTOTIC MODEL FOR LOCAL CATCH

A model for a local fishery in which the catches reach an asymptote as fishing effort increases was proposed by Sathiendrakumar and Tisdell (1987) to determine the optimal level of local fishing effort. I propose a similar model except that the parameters are defined in relation to immigration, emigration, mortality, and catchability. Emigration is treated as if it were analogous to natural mortality, so the two are combined. In the simplest case of this model (*i.e.*, assuming steady-state equilibrium and constant "natural mortality" and catchability), the asymptotic maximum catch is governed by the level of immigration (Figure 1). The parameters and derivation of the model are as follows (all fluxes--immigration, catch, and mortality--are annual, and numbered expressions are considered axiomatic):

I = local immigration (metric tons)--analogous to biological production but independent of local biomass;

C_i = catch (metric tons) at effort level i;

f_i = effort (10^3 hooks) at level i;

q = catchability ($1/10^3$ hooks) [assumed constant];

F_i = fishing mortality $[F_i = qf_i]$; (1)

M' = "natural mortality" including emigration [assumed constant],

Z'_i = total "mortality" including emigration $[Z'_i = M' + qf_i]$; (2)

B_i = equilibrium biomass (metric tons) in the local area $[B_i = I/Z'_i]$; (3)

$C_i = B_iF_i$ (metric tons); (4)

$$C_i = \frac{IF_i}{Z'_i} \text{ (metric tons)} \qquad \text{[from (3)]};$$

and

$$C_i = \frac{Iqf_i}{M' + qf_i} \text{ (metric tons)} \qquad \text{[from (2)]}.$$

The example shown (Figure 1) uses arbitrary values: I = 5,000, 10,000, and 20,000 metric tons, q = 0.0001/1,000 hooks, and M' = 0.06. When fitting the model to data where I, q, and M' are unknown, the model can be simplified:

If $a = \frac{Iq}{M'}$ and $b = \frac{q}{M'}$,

then $C_i = a\left(\frac{f_i}{1+bf_i}\right)$ (metric tons).

Algebraic manipulation of the model equation yields the following linear relationship between CPUE and catch (Figure 2):

$$\frac{C_i}{f_i} = a - bC_i \text{ (metric tons/}10^3\text{ hooks),}$$

which makes the model easy to fit.

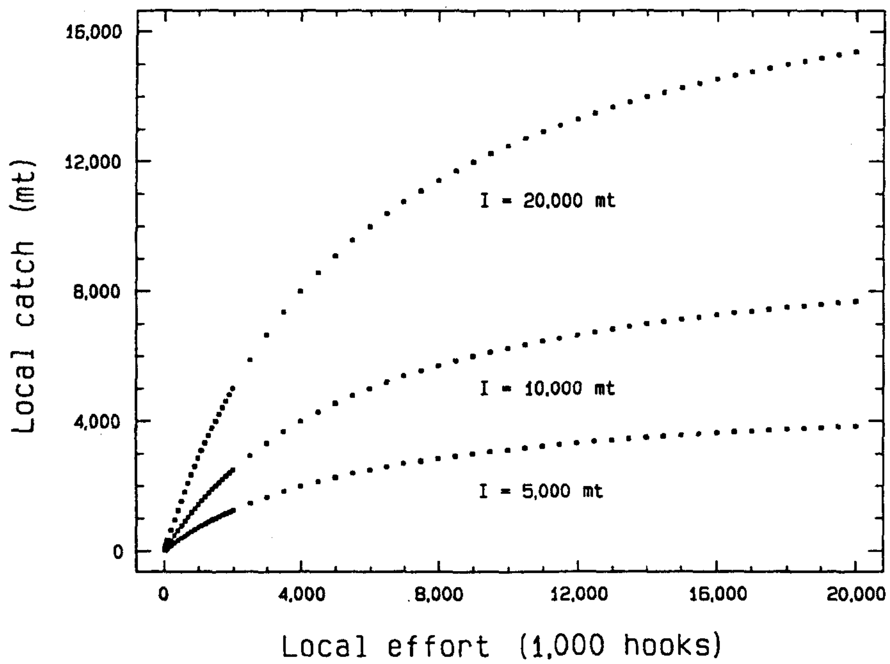

Figure 1. Asymptotic catch model for a limited-range pelagic fishery that catches a small fraction of the stock of a highly-mobile pelagic species. Natural mortality, emigration, and catchability are constant, and the local biomass of fish is at equilibrium. Annual immigration (I) determines the annual asymptotic catch in metric tons (mt).

Unfortunately, in reality, immigration, emigration, and effort vary seasonally, and equilibrium is not achieved instantaneously. A more realistic model was created by making immigration, natural mortality (plus emigration = M'), and fishing effort vary according to annual cycles, with effort also increasing over time. Simulated data were obtained by calculating the catch, mortality, and the resulting nonequilibrium local biomass at 10 time steps per day for 4 years, summarized by month (Figure 3). The annual cycles of immigration and emigration were chosen to produce a cycle of local biomass roughly resembling the pattern seen in CPUE data from Hawaii's yellowfin tuna fisheries.

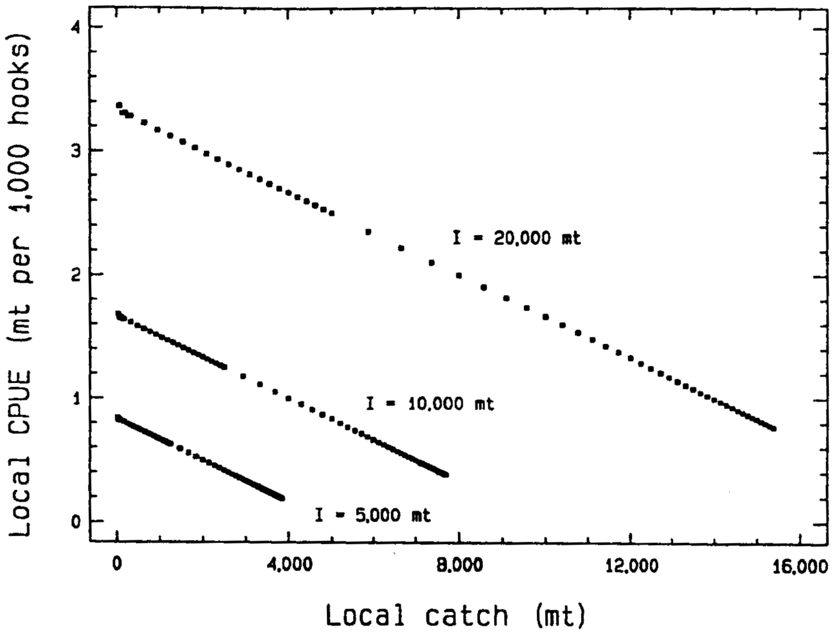

Figure 2. Relationship between local CPUE and total local catch in metric tons (mt) according to the asymptotic catch model in Figure 1.

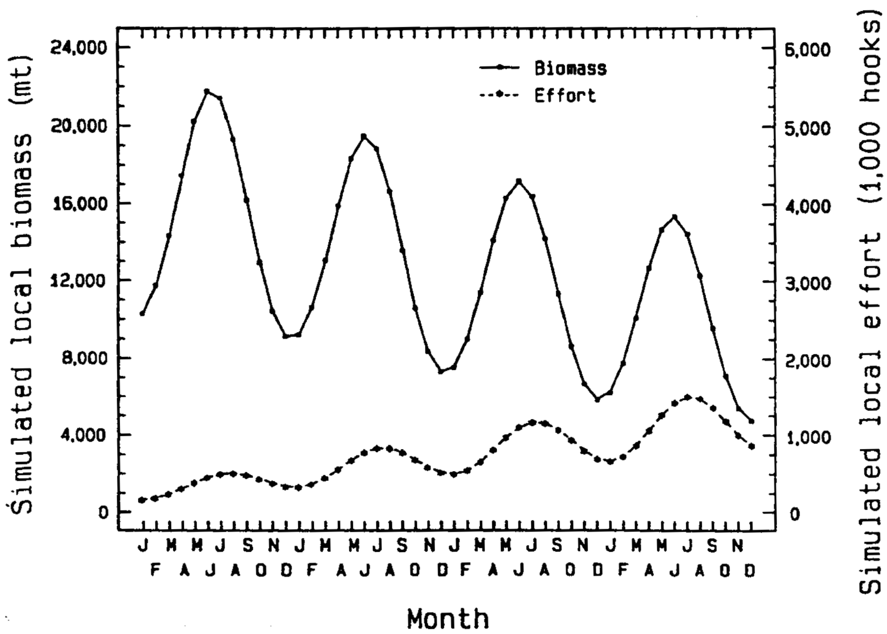

Figure 3. Simulated monthly biomass in metric tons (mt) and fishing effort in a limited-range fishery like that in Hawaii. Immigration, emigration, and effort vary in an annual cycle, and effort increases threefold over 4 years. Local biomass is not in equilibrium.

When the simulated CPUE data and catch are plotted, there is a clear relationship between CPUE and catch, although the slope is different for each month of the year (Figure 4) in keeping with the monthly changes in *I*, *M'*, and *F*. The nonlinearity of relationships for each month is due to lag effects under nonequilibrium conditions (the nonlinearity disappears when CPUE for each month is plotted *versus* catch for the 5-month period ending that month). Ignoring the nonlinearity, multiple regression of seasonally-adjusted CPUE on catch and first-order interactions between catch and months explains 96% of the variance in the simulated data, suggesting that this simple analytical approach could work with real data. However, the simulated data contain no random components which might obscure weak relationships.

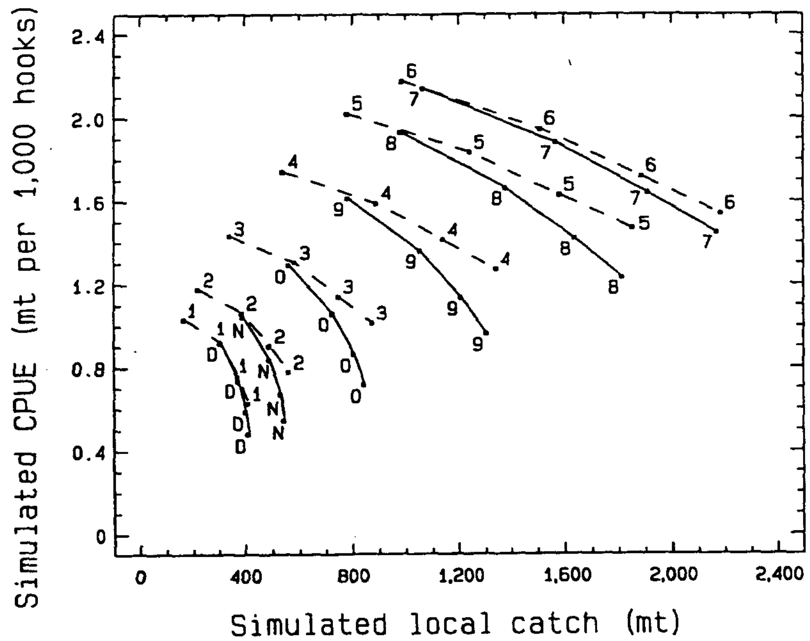

Figure 4. Simulated local catch per unit effort (CPUE) plotted versus simulated local catch in metric tons (mt) for the limited-range fishery model with seasonal variation and increasing effort as in Figure 3. Relationships between CPUE and catch for the first (dashed lines) and last (solid lines) 6 months of each year are identified by characters (1-9 for January-September, and O, N, D for October, November, and December, respectively).

Further realism was added by making immigration vary annually as well as seasonally. When immigration was reduced by 40% in alternate years, the resulting relationship between simulated CPUE and catch was hard to perceive (Figure 5). However, using a dummy variable (1 or 0) for high and low immigration years (and including first-order interactions between immigration and months) made it possible to use multiple regression to describe the slopes and intercepts of the CPUE- *versus*-catch relationships for each month and level of immigration (Figure 5). These slopes and intercepts were then used to compute the asymptotic relationships between catch and effort (Figure 6).

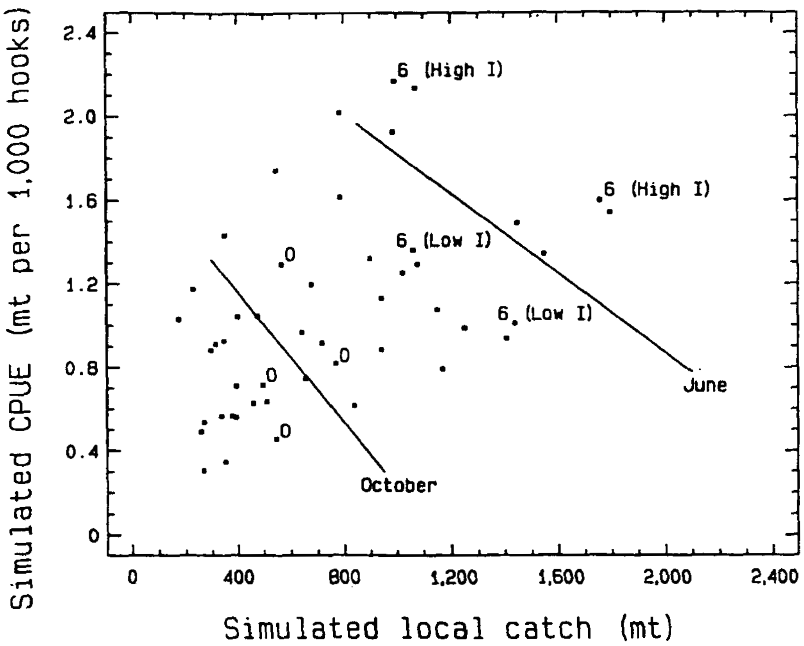

Figure 5. Simulated local catch per unit effort (CPUE) plotted versus simulated local catch in metric tons (mt) for the limited-range fishery model with immigration (I) alternating from high to low (40% less than high) in alternate years. Relationships for an average amount of immigration, calculated with the multiple regression analysis are shown for June (points labelled 6) and October (points labelled O).

In reality, local immigration is an unknown quantity, but the apparent abundance of fish over a larger area can be used as an index of immigration in a multiple regression analysis of real data. It is logical that more fish would immigrate in years when they are more abundant in the surrounding area, and this behaviour would be consistent with work showing strong correspondence between the apparent abundance of pelagic fish in local areas and abundance on a wider scale (Wetherall and Yong, 1983; Squire and Au, 1990; Skillman and Kamer, 1992). Another mechanism that would explain the correspondence in apparent abundance would be widespread changes in catchability. In contrast, changes in immigration or local catchability due to localized environmental conditions would not be consistent with the observed correspondence in apparent abundance, and thus the local environment may represent an additional source of variation.

The simulations illustrate how relationships between catch and effort within a limited area may differ seasonally and annually. The optimal level of fishing effort may be highly dynamic, making the rational management of fishing effort difficult. Analyzing CPUE data *versus* catch should at least be useful for detecting an impact of local fishing pressure on local CPUE, even when that impact differs seasonally and annually. Detecting such an impact however may require quantifying variation due to other factors.

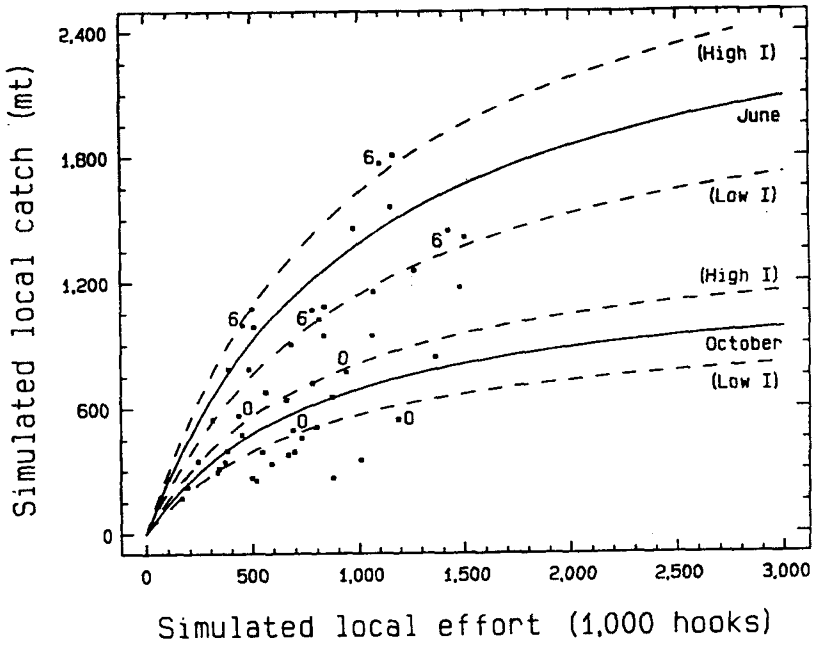

Figure 6. Asymptotic catch relationships for monthly local catches in metric tons (mt) as a function of monthly local effort in a limited-range fishery from the analysis of simulated data shown in Figure 5. The relationships for high and low immigration (I) years (dashed lines) differ from the average relationship (solid lines) for each month (June data labelled 6; October data labelled O).

5. YELLOWFIN TUNA CPUE IN HAWAII

In a preliminary study (Boggs, 1991), troll and handline CPUE data (pounds per trip) were plotted *versus* longline catch to determine whether relationships appeared that might be indicative of fishery interactions. This graphical inspection of the CPUE *versus* catch data was applied to yellowfin tuna, bigeye tuna (*Thunnus obesus*), blue and striped marlins, mahimahi, and wahoo. In the preliminary study (Boggs, 1991), the analyses covered data for January 1987-June 1990. The present study extends the analysis through the end of 1990 for yellowfin tuna troll CPUE (pounds per trip) and compares troll CPUE with the total catch (by all fisheries) rather than just the longline catch.

The data used to calculate troll catch per trip (CPUE) were provided by the Hawaii Division of Aquatic Resources (HDAR) as summaries of commercial catch (pounds of fish) by year (1983-90) and month (1987-90) along with summaries of the total number of fishing trips per year or month, respectively. Annual and monthly catch rates were calculated as the ratio of total catch (in pounds) to the number of trips. No geographic categorization of the data was used, but most of the troll fishing was conducted within 50 miles of shore around the eight main Hawaiian Islands. The HDAR catch data did not contain reports of trips; rather, each date for each vessel in the records was counted as a trip if any PMUS or tuna was reported caught. The assumption of 1-day trips is fairly realistic for the small-vessel troll and handline fisheries.

Catch per trip may not be a good measure of yellowfin tuna abundance since important operational changes and improvements in trolling methods have undoubtedly occurred over the years. The catch per trip index contains no data from trips with zero catches, no standardization of trips as a unit of effort, no estimate or correction for underreporting, and no estimate or correction for changes in reporting over time. Any of these factors could bias trends or relationships in the data, or give the appearance of a trend or relationship where none exists.

Despite these potential problems, catch per trip as an abundance index can provide some indication of changes in the local abundance or availability of fish to trollers and handliners in Hawaii. Catch per trip indices based on HDAR data often mirror patterns seen in more sophisticated CPUE indices, such as catch per hook or catch per set, from nearby fisheries (Wetherall and Yong, 1983; Skillman and Kamer, 1992). When the data from several different sources show a similar pattern, those data probably indicate a true pattern of apparent abundance unless some unknown bias affects several sources of data similarly. In any case, catch per trip is the only available measure of CPUE for Hawaii's troll and handline fisheries. More definitive examinations of trends in CPUE will require data that more accurately specify fishing effort.

Annual troll CPUE (pounds per trip) for yellowfin tuna declined from a relatively high level in 1979 to low levels in 1982-84 (WPRFMC, 1991). Troll CPUE for yellowfin tuna returned to high levels in 1987, dropped again and remained low through 1989, and showed some recovery in 1990 (Boggs, 1991). The decline in troll CPUE for yellowfin tuna in 1987-1989 corresponded with a period of dramatic expansion of Hawaii's domestic longline fishery (Boggs, 1991; Ito, 1991; WPRFMC, 1991), suggesting that some fishery interactions may be occurring. The low troll CPUE seen in 1982-84, however, occurred before the domestic longline fishery expanded and after the foreign longliners ceased fishing in Hawaii's EEZ, suggesting that periods of low troll CPUE may be unrelated to longline fishing effort.

The total longline catch, as estimated by the National Marine Fisheries Service (NMFS) shoreside monitoring programme, showed increasing monthly variation and an upward trend from 1987 through 1989, levelling off somewhat (annual average) in 1990 (Figure 7). The longline catch estimates were for the entire range of the longline fishery, mostly within the Hawaii EEZ but extending beyond it. The range of the troll and handline fisheries is much smaller and is roughly centred within the area fished by the longline fishery (these data precede the establishment of nearshore area closures for longline fishing).

The NMFS data rather than the HDAR data were used to estimate longline catch because they cover most of the longline catch in Hawaii, whereas the HDAR data cover only a small fraction of that catch. Conversely, the NMFS market sample data cover only a fraction of the troll and handline catch and do not distinguish between these two gear types, which have markedly different catch rates. Therefore to obtain total catch, the HDAR data on the catch by gear other than longline (mostly troll and handline) were combined with NMFS estimates of the longline catch. A potentially large component of

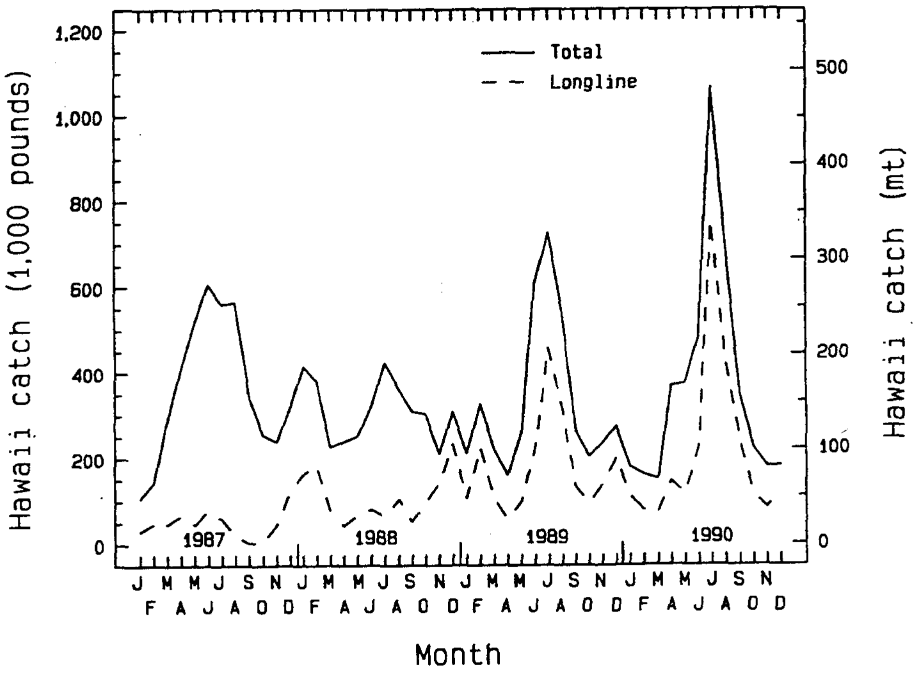

Figure 7. Total catch (all gear types combined, in pounds and metric tons) and longline catch of yellowfin tuna in Hawaii each month in 1987-90. Longline catch is estimated from the shoreside monitoring programme of the National Marine Fisheries Service, and the remainder of the total is from the non-longline catches in the commercial catch reports of the Hawaii Division of Aquatic Resources. The recreational catch is not known.

the total catch, namely the recreational catch, remains unquantified, and there are no good estimates of under-reporting by commercial troll and handline fishermen. Thus, total catch is known with less certainty than longline catch, which was one reason Boggs (1991) used only longline catch.

The total catch of yellowfin tuna by all gear types (Figure 7) varied monthly in 1987-90 but did not show much of an annual trend. As catch by the longline fishery increased, catch by the other fisheries decreased. Fishermen have suggested that increased longline catch might be causing the decline in troll and handline catch; this is why troll and handline CPUE was plotted *versus* longline catch in Boggs (1991). However, examination of CPUE in relation to total catch is more appropriate since the catch by trollers and handliners would also be expected to contribute to any local reduction in biomass.

Hawaii's trollers, handliners, and longliners depend on the same size range of fish to provide the bulk of their yellowfin tuna catch, so interactions of these fisheries are possible. Even though the troll and handline size-frequency distribution (combined) includes more small (<50 lb) fish than the longline size-frequency distribution (Ito, 1991), the small fish add relatively little to the weight of troll and handline landings (Figure 8). The combined troll and handline data (Figure 8) are mostly from Oahu where trolling predominates. Handline-caught fish tend to be even more similar in size to longline-caught fish. The reason for the decreasing catch of small fish (Figure 8) is not known.

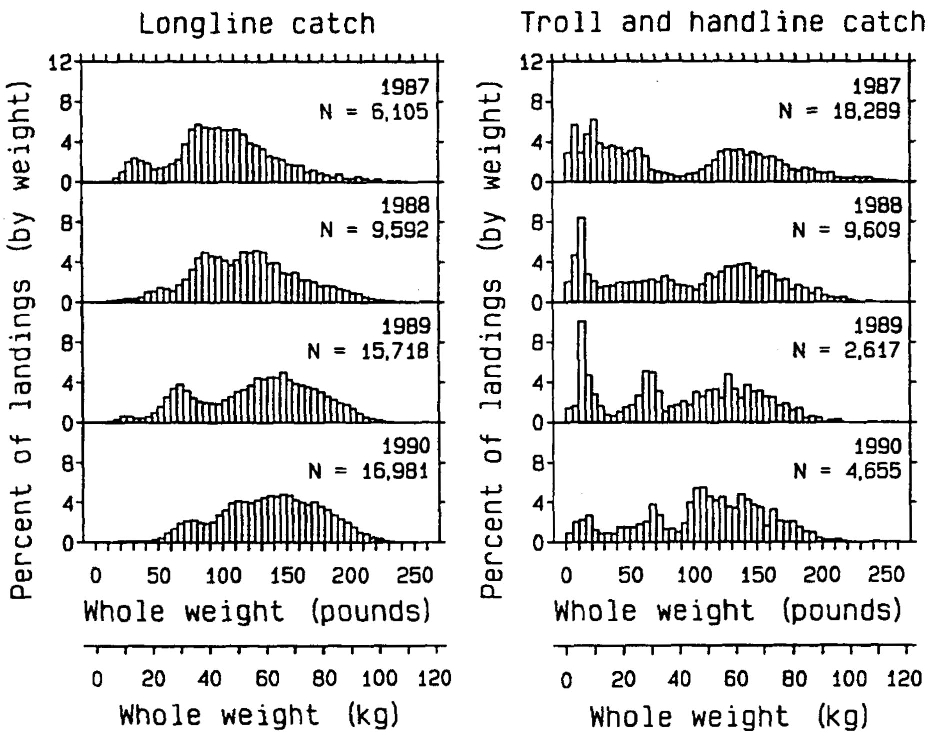

Figure 8. The proportional landings (percent of total weight landed) by weight category (pounds and kg) in Hawaii's longline and combined troll and handline fisheries. Weights of fish were obtained by the National Marine Fisheries Service shoreside monitoring programme (N = number of fish). The combined troll and handline samples are from Oahu, where trolling is the predominant small-vessel pelagic fishing method.

Changing operational characteristics in recent years make longline trips a poor measure of effective effort. For the same reason, longline-catch per trip is a poor measure of yellowfin tuna abundance and thus has not been examined. Troll and handline trips differ from each other and from longline trips in their relative effectiveness, making total effective effort difficult to estimate. Thus, total catch, rather than effort, was used as a more convenient estimate of fishing pressure.

In the preliminary analysis by Boggs (1991) of the monthly data from 1987 to June 1990, six species were examined, but only yellowfin tuna had CPUE values that appeared to be negatively related to longline catch. The relationship was clearest when monthly CPUE was plotted *versus* longline catch for the 3-month period ending the same month. Months were categorized by Boggs (1991) as "in-season" and "nonseason" to account for seasonal effects, whereas the present study used multiple regression analysis of seasonally-adjusted CPUE data on catch with interaction terms for each month.

The apparent relationship found in the preliminary study may have been due to chance, since very low troll and handline catch rates were also observed in 1982-84, well before the longline fishery expanded. Unfortunately, good estimates of total catches for the earlier period are not yet available. Estimates for this earlier period may be developed if market data from this period can be obtained from fish dealers.

When the troll CPUE data for the 48-month period from 1987 to 1990 were analyzed in relation to total monthly yellowfin tuna catch in the present study, no relationship was apparent (Figure 9). An analysis of handline CPUE gave similar results. As in Boggs (1991), the CPUE data for each month were also analyzed in relation to longline catch, and longline catch for the 3-month period ending that month, but still no relationship was found. This was due to the addition of 6 months of new data from 1990, wherein the CPUE increased over 1989 levels despite continued high levels of longline catch (Figure 10).

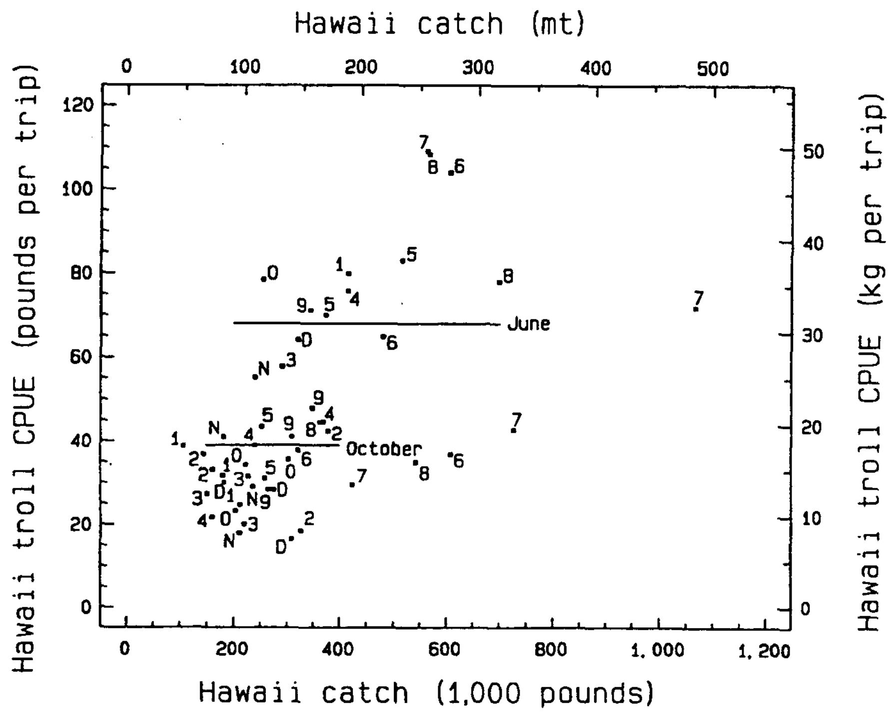

Figure 9. Observed monthly yellowfin tuna catch per unit effort (CPUE) (pounds per trip and kg per trip) in Hawaii's troll fishery, versus total monthly yellowfin tuna catch by all fishing gears (labelled as in Figure 4) for 1987-90. The lack of any CPUE versus catch relationships (slopes ≈ 0) based on multiple regression analysis is shown for June and October.

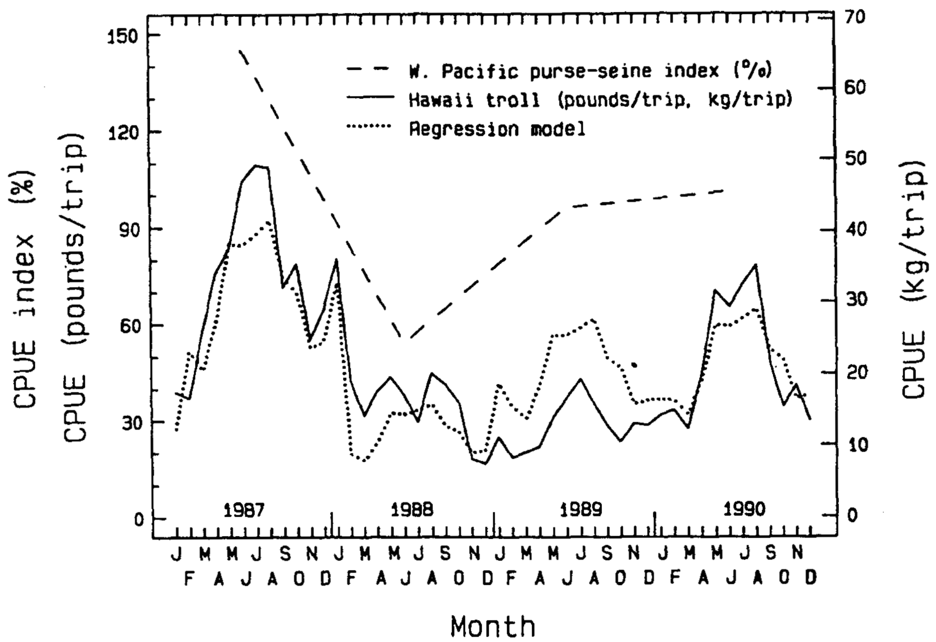

Figure 10. Observed catch per unit effort (CPUE) (pounds per trip and kg per trip) for yellowfin tuna by Hawaii's troll fishery for each month in 1987-90, and the annual index of wide-scale abundance of yellowfin tuna from the USA and Japan purse-seine fisheries (percent of average CPUE). Predicted local CPUE from a regression of seasonally-adjusted CPUE on the purse-seine index is also shown.

An index of wide-scale surface yellowfin tuna abundance from purse-seine fisheries in the western Pacific (Figure 10) was added to the regression analysis to see whether removing some of the interannual variation in immigration would reveal an underlying relationship between local CPUE and fishing intensity. The purse-seine index was calculated as the geometric mean of CPUE from the USA (Coan, 1993) and Japan (Suzuki, 1992) purse-seine fisheries in the western Pacific, expressed as a percent of mean CPUE (Figure 10). This index was the most significant factor ($P < 0.0001$) in a multiple regression of seasonally-adjusted local CPUE on total catch, the purse-seine index, and first order interactions by month.

Catch was not a significant factor (slope ≈ 0, Figure 9). The predicted CPUE, based on the seasonal adjustment and regression analysis, followed the pattern of observed CPUE fairly well (Figure 10). It seems that seasonality and the exogenous supply (*i.e.*, the immigration rate) of yellowfin tuna are the dominant factors affecting local CPUE, and the available evidence suggests that local CPUE was independent of local levels of exploitation in 1987-90.

It should also be noted that the purse-seine index may not necessarily represent increases in wide-scale biomass or increased local immigration. Instead it may reflect a widespread change in catchability caused by environmentally-induced changes in behaviour and vulnerability to fishing gear.

There is clearly a need for more research on the local distribution dynamics of tropical pelagic species. Simulation models could be much more helpful if more was known about true abundance and fish-movement dynamics. Tagging studies would be a good way to get such information, if they coincide with improved fisheries data collection emphasizing the geographic distribution of fishing effort and catch. The results of previous studies make it clear that local fisheries data alone may not provide evidence of existing fisheries interactions, because of the important effects of exogenous factors such as changes in stock-wide abundance and catchability. Environmental influences on fish movements and catchability may also play an important role that must be investigated.

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