

Daily bioeconomic analysis in a multispecific artisanal fishery in Yucatan, Mexico

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Abstract – We describe daily allocation patterns of fishing effort (hookah diving) of the artisanal fleet in San Felipe, Yucatan (Mexico), using catch, fishing effort, catch per unit of effort, variable costs, quasi rent and distance from port to four fishing grounds as performance variables. Two vessel categories were defined by the presence/absence of a Long Range Navigation (LORAN) system. Hookah divers caught a daily average of four species in 95% of the trips, thus precluding the quantification of effective fishing effort allocated by species. Highest catches and quasi rent were mainly obtained on Thursdays and Fridays, coinciding with the highest catches of *Octopus maya* and spiny lobster (making up 50% of the total economic revenue) on Fridays in 3 of the 5 weeks analysed. An upper ceiling of daily catch per diver occurred close to the weekend, suggesting a limited capacity in terms of handling time and diving hours, and also a catch level that fulfills daily economic expectations. Both LORAN and non-LORAN vessels preferred to work the nearest ground to port, in spite of higher yield and economic rent from more distant grounds. Nonlinear modelling of fishing effort allocation showed distance from port as the key decision factor. Generalized linear modelling (GLM) revealed significant effects of vessel type and fishing ground, with LORAN vessels having significantly higher catch rates and tending to allocate more effort to distant grounds than vessels without LORAN. GLM performed by species corroborated that Friday was the most productive day concerning spiny lobster and octopus. This day effect in the most valued species also suggests that pressure for higher economic benefits occurs before diminishing (Saturday) or ceasing (Sundays) fishing activities. © 2001 Ifremer/CNRS/Inra/IRD/Cemagref/Éditions scientifiques et médicales Elsevier SAS

fishing effort / short-term allocation / artisanal fishery / Yucatan

Resumen – **Análisis bioeconómico diario en una pesquería artesanal multiespecífica de Yucatán, México.** Se describen los patrones de asignación diaria del esfuerzo pesquero (buceo con compresor) de la flota artesanal de San Felipe, Yucatán (México), empleando la captura, esfuerzo pesquero, captura por unidad de esfuerzo, costos variables, cuasi renta y distancia del puerto base a la zona de pesca como variables de desempeño. Se definieron dos categorías de embarcaciones de acuerdo a la presencia/ausencia del sistema de posicionamiento global LORAN. Los desembarques diarios constaron de cuatro especies en el 95% de los viajes, lo cual impidió la cuantificación del esfuerzo pesquero asignado por especie. Los mayores valores de captura y cuasi renta ocurrieron en jueves y viernes, coincidiendo con las mayores capturas de pulpo y langosta espinosa (50% de los retornos económicos) durante los viernes, en tres de las cinco semanas analizadas. Un techo superior en las capturas por buzo se observó durante los fines de semana, sugiriendo una capacidad límite en término de tiempo de manipulación de la captura o bien de buceo, así como la búsqueda de cierto nivel de captura que cubriera sus ganancias diarias esperadas. Ambas categorías de embarcación (con/sin LORAN) mostraron preferencia por las zonas más cercanas a puerto, a pesar de los mayores rendimientos económicos y pesqueros obtenidos en zonas más alejadas. La modelación no lineal de la asignación del esfuerzo pesquero mostró que la distancia a puerto constituye un factor clave de decisión. El modelo lineal generalizado (MLG) sugirió que las embarcaciones con LORAN tendieron a asignar más esfuerzo pesquero a zonas alejadas de puerto que las embarcaciones sin LORAN. De igual forma, el MLG corroboró que el viernes es el día más productivo con respecto a langosta y pulpo, sugiriendo una mayor presión por beneficios económicos en cercanías del fin de semana, cuando disminuye (sábado) o cesa (domingo) la actividad pesquera. © 2001 Ifremer/CNRS/Inra/IRD/Cemagref/Éditions scientifiques et médicales Elsevier SAS

esfuerzo pesquero / asignación de corto plazo / pesquería artesanal / Yucatán

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1. INTRODUCTION

Studies on fishing effort dynamics have been mainly focused on long-term decisions of fishers, emphasizing the estimation of rates of entry and exit to the fishery and the characterization of general patterns of allocation of fishing intensity (Smith, 1969; Clark, 1979; Mangel and Clark, 1983; Emerson and Anderson, 1989). However, it is in the short-term that fishermen make their spatial decisions: after deciding to go fishing and selecting the target species, they decide where to fish (Hilborn and Ledbetter, 1979; Bockstael and Opaluch, 1983; Eales and Wilen, 1986; Defeo et al., 1991; Defeo, 1993; Sampson, 1993; Seijo and Defeo, 1994). In artisanal fisheries this is very important, because fishing effort is actually applied to a multispecific resource, and hence fishermen have to choose between areas and several target species (Smith, 1969; Seijo et al., 1993), defining what is called 'fishing tactics' (Laloë and Samba, 1991; Pelletier and Ferraris, 2000). This has management connotations, as daily observations of bioeconomic performance variables of the fishing process provide useful insights about fishermen's behaviour and spatio-temporal resource dynamics (Seijo and Defeo, 1994; Sardà and Maynou, 1998). Fishers, as generalist predators, might select a target stock according to its availability in space and time; they can also choose between species according to the economic demand. Indeed, the effect of differential fishing intensity on given fishing grounds over several days would lead to local stock depletion, especially in sedentary and high valued shellfish. Socio-economic factors might also lead to direct fishing effort to a given species according to the day of the week. This knowledge should lead to improve the viability of the exploitation system.

Artisanal fisheries constitute an important socio-economic component of coastal communities in Latin America and the Caribbean. Over 2200 artisanal fishing communities and at least one million people are directly engaged in this activity (Bermúdez and Agüero, 1994). Drastic short and long run increase in fishing effort was observed in almost all artisanal fisheries of this region (Castilla, 1994; Defeo and Castilla, 1998). Some key factors that promote intensification of fishing effort allocation in the short run are (Defeo, 1989; Seijo and Defeo, 1994; Defeo and Castilla, 1998): a) short-term variations in the demand in local or foreign markets and their relation with global supply (Defeo et al., 1993; Defeo and Castilla, 1998); b) individual size price variations (Anderson, 1989); c) intra-annual fluctuations in stock abundance and accessibility (Caddy, 1979; Defeo et al., 1991); d) open-access regimes, coupled with economic pressures for daily subsistence, lack of alternative employment and low operating costs (Castilla, 1979; Defeo, 1989; Defeo et al., 1993). In spite of its important management connotations, short-term allocation of fishing effort in artisanal Latin American fisheries has

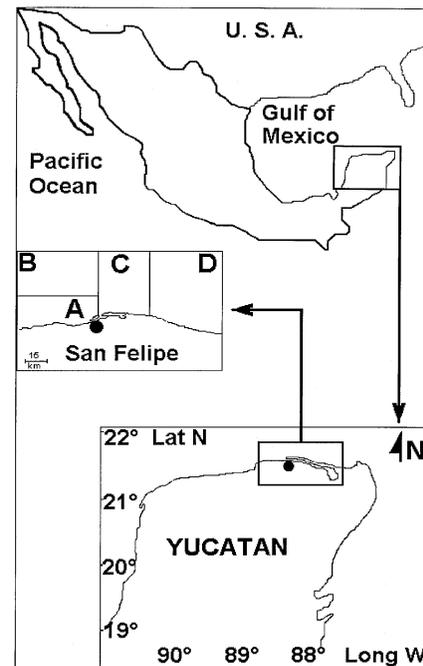


Figure 1. Study area with the 4 analysed fishing zones.

received little attention (Defeo et al., 1991; Defeo, 1993; Seijo and Defeo, 1994; Defeo and Castilla, 1998).

The above situation is becoming more common in artisanal, open access fisheries all along the coasts of Mexico. Factors regulating the short-term spatial dynamics of the fishing fleet are unknown, as well as the variables affected in this allocation. The present work evaluates the incidence of several bioeconomic variables in the short-term allocation of effort in a multi-specific artisanal fishery of San Felipe, Yucatan, Mexico. To this end, we analyze daily catch-effort and ancillary economic information, to characterize the dynamics of the fishermen in the short-term. We also propose explanations for the observed patterns.

2. MATERIAL AND METHODS

The port of San Felipe is located on the East Coast of Yucatan State, Mexico ($21^{\circ}34' N$, $88^{\circ}14' W$, *figure 1*). The fishing fleet is composed of 211 artisanal vessels of 7.5 m length, fiber glass and outboard engines; some have an electronic positional device called LORAN (LONG RANGE Navigation) that facilitates the location of the preferred fishing grounds. Hookah is the only fishing method. The vessel crew generally consists of 3 people (skipper, diver and hose operator). In this fishery, fishermen operate in cooperatives with a high organization level as a fishing community, which allows reliable information to be obtained.

Field sampling was carried out during August 1994. Fifteen fishermen were daily interviewed after returning from the fishing trip. The information gathered focused on catch, fishing effort (departure and arrival times, sailing time and effective diving time), catch per unit of effort (CPUE: catch/effective diving hours), variable costs, ex-vessels price, location and distance from port to the fishing ground. The distance was recorded after daily interviews with the fishers, who annotated the fishing location in a map and, in the case of LORAN vessels, the exact position of the fishing activity. Total daily economic revenues were obtained by summing the revenues obtained for each species; these were given by multiplying the daily catch per species (in kilograms) by its unit price per kilogram; the daily quasi rent of variable costs was obtained as the difference between total revenues and variable costs (food, beverages, oil and gas).

To evaluate differences in the performance of fishing vessels, only those with more than 16 effective days within the survey period were considered. We took into account only those fishing trips in which the entire activity consisted of diving carried out by one fisherman in order to mitigate individual variations in fishing power. Eight vessels were finally selected, 5 of which (*Aury*, *Catarinos*, *Cittlali*, *Dulita*, and *San Pablo*) had LORAN, while the remaining (*Josergio*, *Juanita* and *Nubia*) did not. Bioeconomic variables were analysed in each of four fishing grounds well known by the fishermen (figure 1), by type of vessel (i.e. LORAN) and day of the week. Data analysis was facilitated because diving was always carried out by the same fishermen, who did not switch from one ground to another during the day. Data were tested for normality and homoscedasticity and compared by ANOVA procedures (Zar, 1984).

A multiple standardization of CPUE (Hilborn and Walters, 1992) was made through a generalized linear model (GLM; McCullagh and Nelder, 1989), using (a) the 2 vessel categories, (b) the 4 fishing grounds, and (c) the 6 working days of the week (no fishing was ever observed on Sundays) as explanatory variables, and the CPUE (in kilograms per effective diving hours) as the response variable:

$$CPUE_{ijk} = G^{-1} (CPUE_{111} + \alpha_i + \beta_j + \delta_k + \alpha_i \beta_j + \alpha_i \delta_k) + \varepsilon_{ijk} \quad (1)$$

where *i*, *j* and *k* refer, respectively, to vessel type, fishing grounds and days of the week, $CPUE_{111}$ is the catch per unit of effort obtained by vessels with LORAN in ground A during Monday (considered as standard); α_i is the efficiency of vessels without LORAN when compared with vessels with LORAN; β_j represents the average abundance on ground *k* when compared with ground A; δ_k is a factor that accounts for the relative abundance in Monday relative to the other 5 days, and ε_{ijk} is the deviation between the expected and observed CPUE for vessel class, ground and time. The terms $\alpha_i \beta_j$ and $\alpha_i \delta_k$ accounted respec-

tively for the interactions vessel type–fishing ground and vessel type–day of the week, in order to answer whether some particular vessel class is able to fish in specific areas or days. G^{-1} is the inverse of the logarithmic link function used to relate the expected catch rates to the categorical predictors. We used the GLM routine contained in STATISTICA program (StatSoft, 1999) to estimate the parameters by maximum likelihood and test the significance of the main effects via the likelihood ratio test. The observed CPUE frequency distribution was skewed to the left and followed a gamma distribution function ($\chi^2 = 8.03$, $df = 11$, $P = 0.71$), which was used explicitly in the GLM. The GLM was also performed by species in order to observe the effect of the same factors (device, fishing ground and day of the week) in each of the main species. Since San Felipe’s artisanal fishery is multispecies, it was impossible to discriminate between the effort effectively applied by each diver to each resource. To circumvent this, the CPUE estimated to perform the GLM per species was the daily catch per species per fishing trip. In this case also, a gamma distribution and a log-link function were used to carry out the GLM.

The spatial allocation of effort (SAE) of vessels with and without LORAN was analysed over the short run. The incidence of distance from port in fishing effort allocation was estimated by vessel category, using the following model (Seijo et al., 1993, 1998):

$$SAE_k = \frac{P_k \cdot \tau_k \cdot \left(\frac{1}{D_k^\psi} \right)}{\sum_k \left[P_k \cdot \tau_k \cdot \left(\frac{1}{D_k^\psi} \right) \right]} \quad (2)$$

where SAE_k is a (0,1) distribution function of fishing intensity that evaluates the optimal allocation of fishing effort applied on each ground from the base port among the *k* (= 4) grounds; P_k is the probability of finding the target species at profitable levels in alternative fishing grounds *k*; τ_k is the quasi rent of variable costs received by the fishermen on ground *k*; D_k is the estimated average distance to fishing ground *k* from port incurred by each vessel category; and ψ is the parameter to be estimated, i.e., a weighing factor called ‘friction of distance’ (Issard and Liossatos, 1979; Seijo et al., 1993, 1998; Caddy and Carocci, 1999). Since the value of ψ was unknown, we evaluated the behaviour of the model by nonlinear iteration (Quasi-Newton). The optimum ψ value minimized the sum of squares (SS) of the deviations between observed and predicted values of SAE_k . Since D_k is raised to ψ in equation (2), $\psi = 0$ indicates no friction and means no restrictions in the selection of fishing grounds in relation to their distance from port, whereas ψ values > 0 indicate a high incidence of distance as a decision factor in the allocation of fishing effort. P_k was calculated as the ratio between the number of trips

where total revenues were greater or equal to variable costs of fishing effort and total fishing trips per ground.

3. RESULTS

3.1. Daily trends in catch composition and magnitude

The San Felipe artisanal fleet did not show preference for a single target, and thus 99% of the daily landings were composed of more than one species. Four species were landed in 97% of the fishing trips: *Octopus maya* represented 38% of the total catch, the red grouper *Epinephelus morio* was 35%, the spanish hogfish *Bodianus rufus* 13% and the spiny lobster *Panulirus argus* 11%. The remaining 3% corre-

sponded to 11 species. Concerning total daily revenues, the spiny lobster accounted for 53%, octopus 23%, red grouper 17%, *Bodianus rufus* 6% and the remaining 11 species 1%. Individual prices of these four species remained constant throughout the period: the highest valued species was the spiny lobster (22 US\$.kg⁻¹), followed by octopus (2.84 US\$.kg⁻¹), the red grouper (2.53 US\$.kg⁻¹) and the spanish hogfish (2.09 US\$.kg⁻¹).

Catch showed marked short-term temporal trends (figure 2a): a) highest catches and highest quasi rent were mainly obtained previous to the weekend, on Fridays; b) spiny lobster catch showed a marked single peak that occurred on Fridays in 3 of the 5 analysed weeks; c) catch of *Octopus maya* also increased towards the end of the week, mainly on Thursdays (2) and Fridays (3); and d) no fishing activities were ever observed on Sundays.

Analysis of 159 individual observations showed that highest catches of shellfish (lobster + octopus) were never coincident with highest fish catches, and vice versa (figure 2b). Solid circles in figure 2b define the upper limits of the relationship, which represents maximum shellfish catches for varying levels of maximum fish catch. With the exception of one datum, this upper limit always corresponded to fishing activities from Thursdays to Saturdays; the values within this 'envelope', well below the upper ceiling, represent a wide range of suboptimal fishing performance. An inverse relationship ($R^2 = 0.90$; $P < 0.0001$) of the form $SHELLFISH = 81.79 - 0.72 \times FISH$ was fitted to the points close to the upper bound slope of the bivariate plot (figure 2b), suggesting an estimated maximum daily catch per diver of 82 kg of shellfish or an equivalent of 114 kg of fish.

The frequency distribution resulting from the above 159 observations (figure 3) showed increasing fishing activity from Mondays (9%) to Fridays (21%). Not

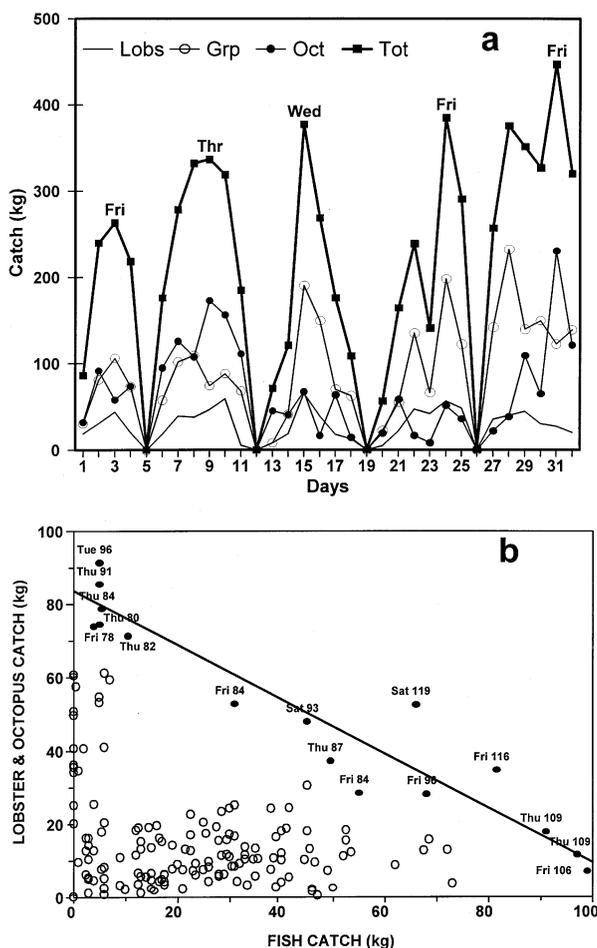


Figure 2. (a) Daily variations in total catch (—■—) in the 8 San Felipe vessels, also highlighting the three most important species. Lobs: lobster; Grp: red grouper; Oct: octopus; (b) scatter diagram of total daily catch of shellfish (lobster plus octopus) plotted against the total daily catch of fish caught per diver. The upper boundary of the relationship and the points included in this estimation (●), labelled with the day of the week and the total catch, are highlighted.

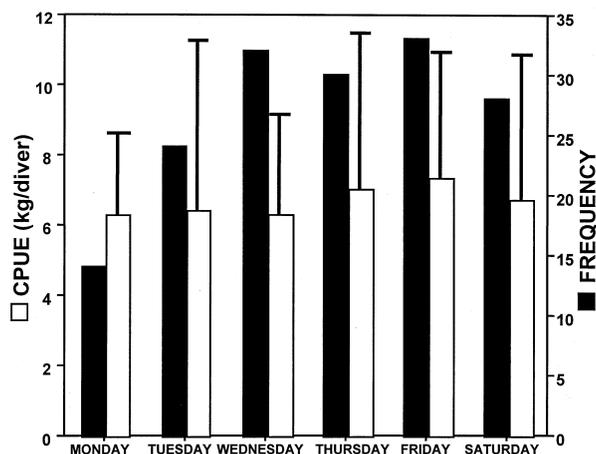


Figure 3. Frequency distribution of the number of working days for the 8 San Felipe vessels, discriminated by day of the week (■), together with the corresponding mean (± SD) CPUE (□).

only the frequency of fishing increased at the end of the week, but also the resulting catch rates (figure 3). The daily CPUE (mean \pm SD) followed the same pattern, being lowest on Mondays (6.27 ± 2.36) and highest on Fridays (7.33 ± 3.57); however, the high within and between vessel variability precluded the detection of statistical differences between days, either for LORAN and non-LORAN vessels (ANOVA: $P > 0.05$). A 2-way ANOVA did not also found differences between frequentation of fishing grounds according to the day of the week.

3.2. Daily selection patterns of fishing grounds

Individual vessels showed a wide short-term variability in the selection of fishing grounds that did not correspond to a single optimisation of economic performance. The following trends were observed:

– Continuous shift of fishing grounds. The absence of fishing activities, combined with the lack of economic revenues in the following days, caused a continuous change of fishing grounds, as shown by the vessel *Aury* during the first fortnight (figure 4a). Vessel *Cittlali* (figure 4b) showed a continuous shift of fishing grounds in response to low quasi rent, changing e.g., from ground C to A (days 4 and 7), from ground A to D (days 8 and 9), and from ground D to A (day 10). In this case, low or negative quasi rent values generated an inactivity of 7 consecutive days.

– Continuous permanence in a fishing ground. Some vessels consistently selected the nearest ground to port (A), independently of the quasi rent levels obtained in previous days (*Juanita*: figure 4c). This risk aversion behaviour was also noted for *San Pablo* (figure 4d), which remained at ground A from days 1 to 10 at lower quasi rent values. The permanence on a fishing ground also responded to economic considerations. For example, *San Pablo* systematically allocated fishing effort to ground C from days 29 to 32, in response to high quasi rent values (figure 4d).

3.3. Fishery performance variables by vessel category

Effective fishing days (root–root transformed to fulfill ANOVA assumptions) varied significantly among grounds ($P < 0.001$), reflecting a consistent preference for both vessel categories, mostly by those without LORAN, to fish on fishing ground A, the closest to port (figure 5a). This ground duplicated the number of days with respect to ground B, the second most important, and was selected in 85 of the 159 effective fishing activities of the 8 analysed vessels over the entire month. No significant differences between vessel categories were observed (table 1), even though vessels without LORAN had a higher number of days fishing on grounds A, B and C (figure 5a).

Both travel distance and diving time fulfilled homoscedasticity (Cochran test: $P > 0.50$) and normality (K–S test: $P > 0.20$) assumptions. Travel distance was

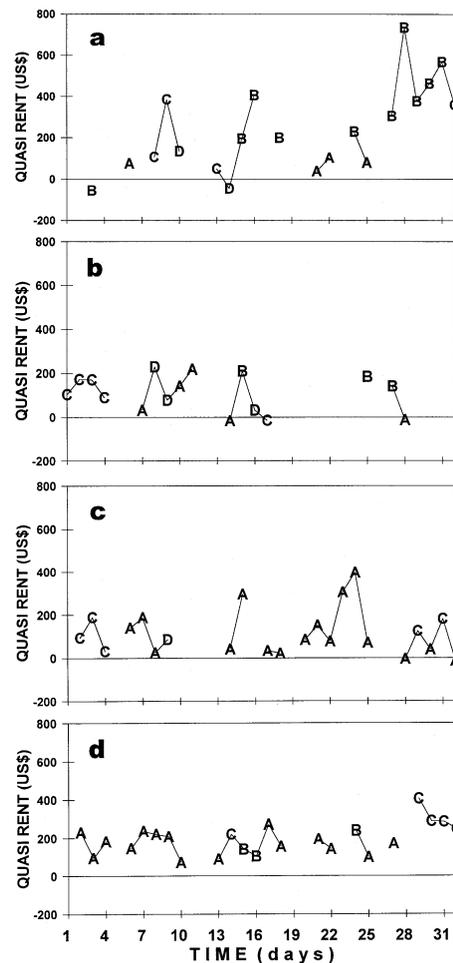


Figure 4. Daily variations in the quasi rent (US\$) for 4 selected vessels. The upper case letters show the fishing grounds chosen each day. (a) *Aury*; (b) *Cittlali*; (c) *Juanita*; (d) *San Pablo*.

significantly higher for ground D, far from port, and lower for ground A, the closest (Tukey test: $P < 0.01$). Diving time did not differ either between vessels or fishing grounds (table 1), varying mainly in the range of 6–7 hours per day. However, a decreasing trend in time spent diving was observed for both vessel categories on ground D (figure 5b). Travel time did not differ between vessel classes ($P = 0.88$), but between grounds ($P < 0.001$), following the same trend as travel distance.

Mean daily catch and CPUE (root–root transformed) differed between grounds (table 1), being significantly higher (Tukey test: $P < 0.01$) on grounds A, B and C than on ground D for both vessel categories (figures 5c,d). LORAN vessels always had higher CPUE and catch (table 1, $P < 0.001$) on each of the 4 fishing grounds. No interaction between vessel category and fishing ground were ever observed (table 1).

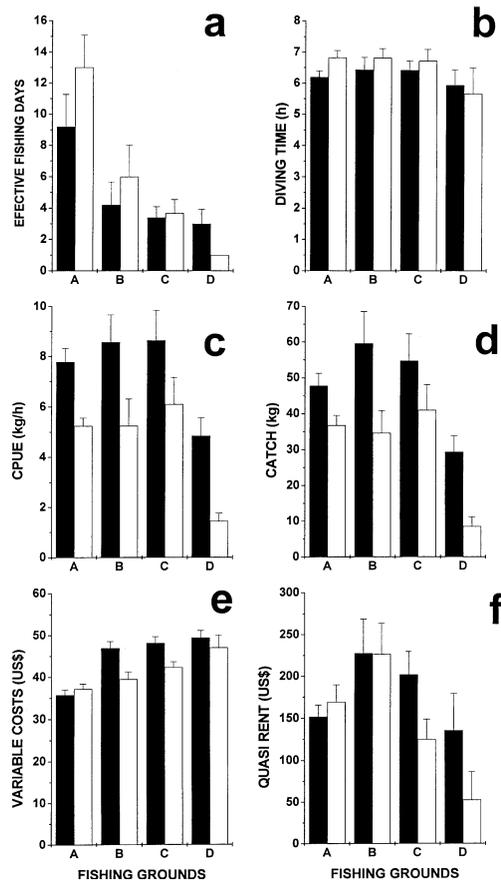


Figure 5. Daily mean (\pm SE) values of: (a) effective fishing days; (b) diving time; (c) CPUE; (d) catch; (e) variable costs; and (f) quasi rent, discriminated by fishing ground and vessel type (■ with LORAN, □ without LORAN).

Variable costs were significantly higher for LORAN vessels ($P < 0.03$; *table I*), increasing markedly from ground A to D ($P < 0.0001$; *figure 5e*). The interaction effect vessel category \times fishing ground was also significant ($P < 0.02$, *table I*), reflected in the much sharper increase in costs of vessels without LORAN on more distant grounds to port when compared with LORAN vessels.

Even though catch, CPUE and total economic revenues were higher for LORAN vessels, the also higher variable costs did not lead to significant differences in the quasi rent between vessel categories ($P = 0.11$). Vessels with LORAN presented higher mean daily quasi rent on grounds B (US\$ 226), C (US\$ 201) and D (US\$ 135), while vessels without LORAN had higher quasi rent on ground A (US\$ 169). The quasi rent differed between grounds ($P < 0.012$): it was significantly higher on ground B for both kind of vessels, followed by grounds C, A and D (*figure 5f*).

3.4. Standardization of fishing power

A clear effect of type of vessel and fishing ground was detected through the global GLM. The base catch rate, defined for LORAN vessels operating on fishing ground A during Monday, was estimated at $6.92 \text{ kg-trip}^{-1}$ (*table II*). Four main results could be highlighted from GLM analysis: 1) vessels without LORAN had 83% of the CPUE achieved by LORAN vessels; 2) fishing grounds B and C were 1.16 and 1.09 more productive than ground A, whereas ground D was 34% less productive than ground A; 3) Fridays, followed in decreasing order by Thursdays and Saturdays, were the most productive days for San Felipe fishers, with catch rates 1.20, 1.18 and 1.16 times higher than in Mondays; 4) the significant vessel-fishing ground D interaction suggests that vessels without LORAN were particularly inefficient in ground D (60% of the standard catch rate, *table II*). Statistical significance of parameters estimates gave special emphasis to the low fishing performance of vessels without LORAN ($P < 0.01$), the lowest catch rates in the ground more distant from port, especially for non-LORAN vessels ($P < 0.01$) and the highest catch rates during Fridays ($P < 0.10$).

GLM analyses discriminated by species differed between shellfish and finfish (*table III*). In the case of spiny lobster, fishing ground B was 2.18 times more productive than ground A, and Fridays were the most productive day for San Felipe fishers, with catch rates 1.97 times higher than in Mondays. The significant vessel/fishing ground interaction suggests that vessels without LORAN were particularly inefficient in grounds C and D (*table III*). Concerning *Octopus maya*, non-LORAN vessels were 64% less efficient than LORAN vessels, and grounds B and D were 65% and 87% less productive than ground A. The effect of the day of the week was also clear in this case, with Fridays as the most productive day of the week. The GLM concerning finfish showed no effect of the day of the week. In both cases, the significant vessel-fishing ground interactions demonstrated again that non-LORAN vessels were particularly inefficient working in fishing grounds far from port (*table III*).

3.5. Spatial allocation of fishing effort

The major intensity of fishing effort allocated to ground A (nearest to port) for both vessel categories, determined high values of friction of distance parameter ψ (*figure 6*). The nonlinear optimization of ψ clear converged at values $\psi = 2.8$ and 7.9 , which best explained, respectively, the spatial allocation of fishing effort for vessels with and without LORAN (*figure 6*). The fact that parameter ψ was almost three times greater for vessels without LORAN clearly suggests a higher effect of the friction of distance for this category. As individual examples, the LORAN vessel *Aury* allocated fishing effort more evenly among grounds, resulting in $\psi = 0.4$. On the other hand, the

Table I. Two-way ANOVA results on the selected fishery response variables*.

Response variable	Factor	df	F value	P value
Effective fishing days**	vessel type	24	0.07	0.800308
	ground	24	5.35	0.005774
	vessel type × ground	24	0.61	0.612304
Travel distance (km)	vessel type	153	3.29	0.071584
	ground	153	27.02	0.000000
	vessel type × ground	153	1.56	0.201038
Diving time (h)	vessel type	153	0.20	0.656185
	ground	153	0.95	0.416994
	vessel type × ground	153	0.78	0.507840
Travel time (h)**	vessel type	153	0.24	0.877571
	ground	153	16.15	0.000000
	vessel type × ground	153	0.23	0.881709
Catch (kg)**	vessel type	153	18.91	0.000025
	ground	153	5.76	0.000935
	vessel type × ground	153	1.89	0.132870
CPUE (kg·h ⁻¹)**	vessel type	153	25.93	0.000001
	ground	153	5.53	0.001257
	vessel type × ground	153	1.50	0.215792
Variable costs (US\$)	vessel type	153	4.94	0.027669
	ground	153	16.45	0.000000
	vessel type × ground	153	3.26	0.023399
Quasi rent (US\$)**	vessel type	153	2.58	0.110617
	ground	153	3.76	0.012133
	vessel type × ground	153	1.39	0.249080

* Significant differences are highlighted. **: root–root transformed to fulfill ANOVA requirements.

vessel without LORAN *Nubia* had $\psi = 2.4$, as a result of an uneven allocation of fishing effort in ground A (figure 7).

4. DISCUSSION

Fishers showed a generalist behaviour at San Felipe. Four species were landed on 97% of the fishing trips, denoting the multispecific nature of the fishery. Recent fishery investigations do not integrate humans as highly specialized predators but rather they consider their generalist behaviour, as closed seasons/areas and other regulatory measures are being imposed to the primary targeted resources (Smith and McKelvey, 1986). Prey switching at San Felipe could be a response to short-term fluctuations in abundance of highly valued species (lobster, octopus). The wide variations in catch composition suggest that fishermen tended to select the magnitude of those aggregations and individual sizes of preys (one or several species) that fulfill their daily expectations of economic revenues. This multispecific nature of the fishery has important stock assessment and management connotations, as it precludes the quantification of the effective fishing effort allocated to each species.

Catches peaked at the middle end of the week, mainly from Thursdays to Fridays. This might be a function of economic (supply/demand, prices) and social (human behaviour) forces that are beyond the simple explanation of effort allocation as a function of

Table II. Coefficients and associated statistics from generalized linear model (GLM), incorporating a logarithmic link function and a gamma distribution for catch per unit for effort (CPUE).

Parameter	Value	Standard error	Estimate	P
CPUE ₁₁₁	1.93	0.18	6.92	0.0000
α	-0.19	0.27	0.83	0.0000
β_B	0.15	0.13	1.16	0.2896
β_C	0.08	0.14	1.09	<u>0.0950</u>
β_D	-0.41	0.17	0.66	0.0006
δ_{TU}	0.13	0.22	1.14	0.7217
δ_{WE}	0.04	0.20	1.04	0.2430
δ_{TH}	0.16	0.21	1.18	0.7365
δ_{FR}	0.19	0.20	1.20	<u>0.0991</u>
δ_{SA}	0.15	0.21	1.16	<u>0.8737</u>
$\alpha \beta_B$	-0.11	0.21	0.89	0.6625
$\alpha \beta_C$	0.10	0.22	1.11	0.5768
$\alpha \beta_D$	-0.90	0.34	0.40	0.0186
$\alpha \delta_{TU}$	-0.16	0.33	0.85	0.7381
$\alpha \delta_{WE}$	-0.29	0.32	0.75	0.8053
$\alpha \delta_{TH}$	-0.31	0.33	0.73	0.6117
$\alpha \delta_{FR}$	-0.10	0.32	0.90	0.4203
$\alpha \delta_{SA}$	-0.43	0.33	0.65	0.1969

CPUE₁₁₁: catch per unit of effort of LORAN vessels in fishing ground A during Monday; α : efficiency of vessels without long range navigation (LORAN) relative to LORAN vessels; β_B , β_C , β_D : catch efficiency in areas B, C, and D relative to area A; δ_{TU} – δ_{SA} relative abundance from Tuesday to Saturday relative to Monday. Interactions between vessel type and fishing ground ($\alpha_i \beta_j$) and vessel type and day of the week ($\alpha_i \delta_k$) are also shown. P: likelihood ratio test probability of estimates.

Table III. Coefficients and associated statistics from GLM*.

Species	Parameter	Value	Standard error	Estimate	P
Spiny lobster	CPUE ₁₁₁₁	0.96	0.35	2.62	0.0059
	β_B	0.78	0.23	2.18	0.0059
	δ_{FR}	0.68	0.39	1.97	0.0475
	$\alpha \beta_C$	-1.09	0.39	0.34	0.0144
	$\alpha \beta_D$	-1.28	0.59	0.27	<u>0.0805</u>
Octopus	CPUE ₁₁₁₁	3.60	0.30	36.68	0.0000
	α	-1.03	0.17	0.36	0.0000
	β_B	-1.05	0.22	0.35	0.0001
	β_D	-2.07	0.39	0.13	0.0002
	δ_{WE}	-0.58	0.35	0.56	<u>0.0723</u>
	δ_{FR}	0.11	0.34	1.11	0.0489
	δ_{SA}	-0.60	0.35	0.55	<u>0.0900</u>
	CPUE ₁₁₁₁	2.70	0.37	14.90	0.0000
Red grouper	β_B	0.86	0.21	2.37	0.0086
	β_D	0.04	0.25	1.04	<u>0.0685</u>
	$\alpha \beta_B$	-0.98	0.32	0.37	<u>0.0600</u>
	$\alpha \beta_C$	-0.76	0.33	0.47	0.0440
	$\alpha \beta_D$	-2.34	0.50	0.10	0.0002
Spanish hogfish	CPUE ₁₁₁₁	1.88	0.41	6.57	0.0000
	α	-0.45	0.53	0.64	0.0009
	β_C	0.31	0.25	1.37	0.0021
	$\alpha \beta_D$	-1.49	0.64	0.22	0.0203
	$\alpha \delta_{TU}$	-0.83	0.62	0.44	0.0237

* Values are discriminated by species, incorporating a logarithmic link function and a gamma distribution for CPUE expressed as catch per fishing trip. Symbols defined as in table II. Only likelihood ratio test probability of estimates < 0.10 are shown.

resource abundance. The sharp increase in octopus and lobster catches at the end of the week was a response to increasing demand of high-valued species (economic incentive), when fishermen want to earn money

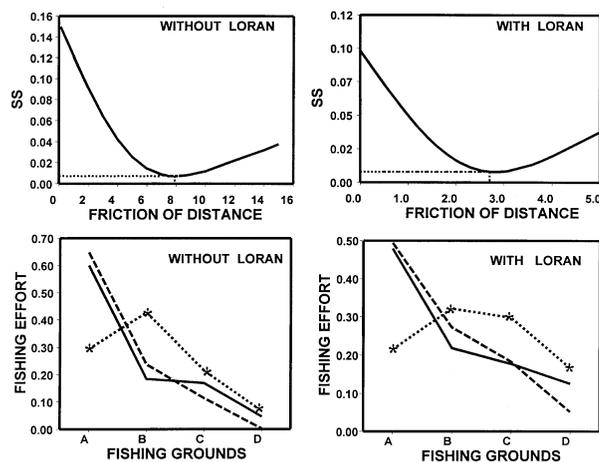


Figure 6. Top: nonlinear estimation of the friction of distance parameter (ψ) by vessel type. Bottom: observed (solid line) and estimated (dashed line) spatial allocation of fishing effort by vessel type, with the optimized ψ values. The fishing effort distribution with $\psi = 0$ (-*-) is shown for comparative purposes.

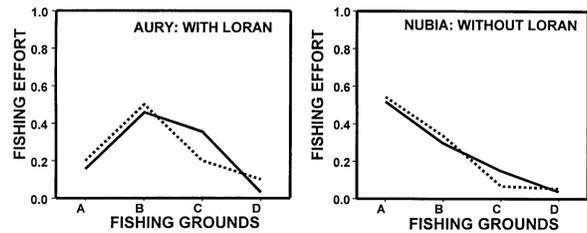


Figure 7. Spatial allocation of the observed (solid line) and estimated (dashed line) fishing effort: vessel with LORAN *Aury* ($\psi = 0.4$) and vessel without LORAN *Nubia* ($\psi = 2.4$).

for the weekend (social behaviour). This was in accordance with the inactivity observed during Sundays.

The analysis of boundaries (see Maller, 1990; Blackburn et al., 1992 for applications in ecology) of the mean daily catch per diver suggested an upper ceiling of daily catch per diver of 82 kg of shellfish, or an equivalent of 114 kg of fish per fishing day (figure 2b). The arbitrary limit, linear in this case, which always occurred between Thursdays and Saturdays, might be related to a maximum capacity of divers in terms of handling time and diving hours, both essential components of fishing effort. The 36 kg difference in the upper ceiling between both groups of species might be the result of differential behaviour of the resource and the fishers. Fish has higher unit weight than shellfish, thus providing higher biomass levels but at a lower economic value. This upper ceiling could then be related to a catch level that fulfills the daily economic expectations of the fishers, especially before the weekend because of the social behaviour mentioned above. Handling and searching times also differ between resources: fishes have higher swimming ability and could escape of being caught more easily than shellfish. Local variations in abundance and experience in locating the best fishing grounds could explain fishing success.

More than 50% of effective fishing days were allocated to ground A, the nearest to port, both by LORAN and non-LORAN vessels. Ground A was selected despite higher catch and economic benefit on grounds B and C. Thus, the amount of catch and economic rent on a previous day might not always be a good indicator of the future location of fishing effort, as stated by Eales and Wilen (1986). Within certain margins of economic rent, the selection of a site was conditioned by the preference of the fishermen to fish close to port, and thus, as in many artisanal fisheries, the friction of distance could be the most significant explanatory variable of the SAE (Seijo and Defeo, 1994). Artisanal boats with limited autonomy give substantial weight to non-monetary costs assigned to distance derived from e.g. adverse climatic factors, insecurity associated with fishing far from port, as well as other environmental and cultural factors (Defeo et al., 1991; Seijo et al., 1998). This could explain a risk

aversion behaviour of San Felipe fishermen to fishing grounds far from port, in spite of higher yields and revenues.

A strong influence of the friction of distance was also evidenced by high ψ values. The lower ψ values in vessels with LORAN suggest lower friction and means lower restrictions in the selection of fishing places in relation to their distance from port than for vessels without LORAN. The LORAN system facilitated the location of a priori successful fishing sites and could explain the higher catch rates on all grounds for LORAN vessels. On the other hand, higher ψ values in non-LORAN vessels indicate that distance could be a decision factor in effort allocation. Unfavourable weather conditions should affect the decision to go to the more distant fishing grounds, mainly in the case of non-LORAN vessels.

The GLM analysis highlighted the differences of catching power by vessel class and fishing ground. LORAN vessels were more successful and specialized in allocating fishing effort, obtaining higher catch rates on all grounds. Vessels without LORAN were particularly inefficient in grounds distant from port, and this was also reflected in the ANOVA's of bioeconomic variables (e.g., variable costs) and in the higher ψ values. The effect of the day of the week was only marginally statistical significant when considering total CPUE, due to the high individual variability of catches between and within-days and species. However, the GLM discriminated by species showed a clear day effect in catch rates in spiny lobster and octopus, with Friday as the most productive day of the week. This confirms the trend observed by the boundary analysis, i.e., catching power tended to be higher at the end of the week, especially during Fridays. The existence of a clear day effect in the species more valued in the market before the end of the week, together with the lack of effect on a global context, suggests that each fishing trip's catch is directed to fulfill some threshold in terms of quasi rent, and that pressure for higher economic benefits are still higher towards the weekend, when fishermen tended to diminish (Saturday) or completely cease (Sundays) their activity.

An annual analysis should be better to examine temporal variations in the ranking of explanatory variables in the spatial allocation of effort. The non-linear estimation of ψ provided an effective tool to objectively evaluate friction of distance issues. The incidence of ψ in different fisheries is recommended as a rich field of investigation. We highlight the importance of conducting such kind of analysis in artisanal fisheries, in order to understand factors influencing the dynamics of the stock and the fishery, and thus to provide useful management guidelines.

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