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STRENGTHENING OF A TRADITIONAL TERRITORIAL TENURE SYSTEM THROUGH PROTAGONISM IN MONITORING ACTIVITIES BY LOBSTER FISHERMEN FROM THE JUAN FERNÁNDEZ ISLANDS, CHILE

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ABSTRACT

A small-scale rock lobster [*Jasus frontalis* (Milne-Edwards, 1837)] fishery has operated for decades in the Juan Fernández Archipelago (Chile) under a traditional territorial tenure system that has put an effective cap on the size of the fishing force. Research on this fishery started in the mid 1960s, but time series of basic indicators other than annual landings have not been collected on a regular basis. Scientific input to the central administration has consisted of sporadic monitoring and assessments, the latter consisting of equilibrium models supporting total-allowable-catch recommendations, but introduction of such a system in the tightly structured but informal management system could have undesirable effects for both the social and biological sectors of the fishery. Seeing the need for improved advice, the local fishermen's organization ("syndicate") acted to develop its own spatially explicit indicators of stock status and fishery performance, which could be made available to the fisheries authority and used in fostering strategies compatible with the informal but effective management system. A collaborative effort between the syndicate and independent scientists led to the design and implementation of a cost-effective logbook-sampling program. Under this bottom-up arrangement data are shared voluntarily by individual fishermen and compiled with assistance from the syndicate. The spatially explicit information collected is used to compute and standardize a robust and precise index of relative abundance. This case is discussed in the context of the "barefoot ecologist" model for the provision of scientific support to the management of small-scale fisheries.

Provision of scientific and technical support for the management of small-scale fisheries, which sustain the livelihoods of millions of households along the coasts of developed and developing countries, from the tropics to the Arctic, has proved difficult (Berkes et al., 2001; Garcia et al., 2008). It is particularly so for benthic fisheries, where monitoring, assessment, and management must attend to spatial heterogeneity in resource structure, effort allocation, and tenure (Orensanz et al., 2005; Prince, 2010). Scarcity of appropriate information ("data poorness") often prompts the application of downgraded variants of conventional models that make questionable homogeneity or equilibrium assumptions (Ernst and Valero, 2005). Institutionally, insufficient spatial resolution of the information tends to be framed in a serious scale mismatch between centralized authorities and local-level arrangements, the latter often effective even if informal, and established by tradition rather than by bureaucratic design.

A small-scale fishery for an endemic spiny lobster species [*Jasus frontalis* (Milne-Edwards, 1837)] in the Juan Fernández Archipelago (Arana, 1987), ca. 700 km off central Chile (Fig. 1), constitutes a good example of the situation outlined above. Lobster fishing is the main source of income for a small permanent community lo-

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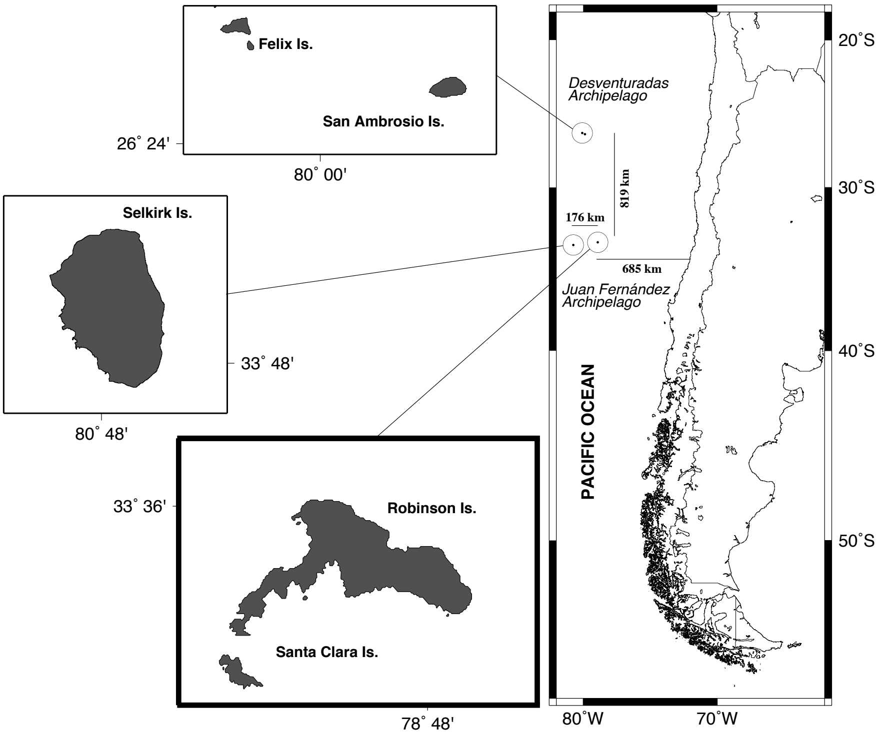

Figure 1. Geographic area of the Juan Fernández spiny lobster (*Jasus frontalis*) fishery. Box with thick border indicates the study area.

cated on Robinson Crusoe Island (San Juan Bautista, population ~630, commonly called Robinson Island) and a temporary fishing village on Selkirk Island (about 25 fishermen and their families) that is occupied only during the fishing season (October through May; Fig. 1). The fishery has been managed under a dual system, with formal and informal components. Formal regulations, established early, consist of an "SSS" strategy (Kruse, 1993): legal size, season, no egg-carrying females. Until the recent introduction of a moratorium, no formal effort controls of any sort were in force, other than gear type ("no diving"). Yet, we found that an effective but unwritten sea-tenure system had put a cap on the size of the fishing force for decades (B. Ernst et al., unpubl. data). Each fisherman or fisherman's family member may "own" a certain number of fishing spots, known as "marcas," where lobster traps are deployed, one per spot. Use and transfer of rights over marcas, which are identified by alignments of land features, are regulated by informal but well-established internal rules.

Research on the Juan Fernández lobster and its fishery started in the mid 1960s, but time series of basic fisheries data or indicators other than aggregate annual landings have not been collected regularly, allegedly because of the operational costs and logistical constrains of programs run from centralized agencies based on the mainland. Rather, scientific input to the central administration has consisted of discontinuous and costly monitoring and assessment projects, the latter consisting in recent years of equilibrium models leading to total-allowable-catch (TAC) recommendations (Arana et al., 2006). Introduction of a TAC, however, would require the

transition from an informal but tightly structured territorial tenure system to some form of quota allocation, which is likely to be socially disruptive.

Seeing the need for improved advice, the local fishermen's organization ("syndicate") acted to develop its own spatially explicit indicators of stock status and fishery performance. Fishermen perceive stock abundance through catch per trap haul or per fishing trip, so some form of catch per unit effort (CPUE) would be a natural indicator, which they can monitor and understand. Other empirical indicators to which they attend are size, sex ratio, and the fractions of commercial (legal-size lobsters not carrying eggs) and noncommercial (undersized or egg-carrying) lobsters in the catch. Monitoring and analysis of those indicators, all of which vary spatially and seasonally, require a format for the provision of scientific or technical advice that operates from the bottom up. A collaborative effort between the syndicate and independent scientists, taking advantage of technical skills available within the fishing community and with the support of conservation-oriented nongovernmental organizations, led to the design and implementation of a cost-effective logbook sampling program. The information gathered is made available to the fisheries authority and will, we hope, be used in fostering strategies compatible with the management system already effectively in place, even if informal. The indicators monitored, together with the empowerment of the fishermen's organization gained through implementation of the process, are expected to lead to management strategies based on simple, indicator-based decision rules, paralleling developments in other small-scale fisheries (Prince, 2010).

Brief Overview of the Fishery and Its History

Commercial lobster fishing in the Juan Fernández Archipelago can be traced back to the late 1890s (Arana, 1987). Throughout the first half of the 20th century, the fishery was run by fishing companies that hired the fishermen, exploited the resource, and exported the products. During the 1960s and 1970s the fishermen gradually became independent and organized themselves as a well established cooperative, which collapsed in 1980 as a result of administrative mismanagement and a political climate unfriendly to cooperatives. Since then, the lobster market has been controlled by small middlemen, but some fishermen recently organized themselves to run a marketing business.

Lobell et al. (1947) counted 41 boats operating from Robinson Island. The size of the fleet increased only slightly afterward and has been virtually stable at 50 boats since the early 1970s; about 10 of them have operated regularly from Selkirk Island for decades, and the rest from Robinson and Santa Clara Islands, making sporadic fishing trips to the Desventuradas Archipelago (Fig. 1). The fleet is composed of double-ended wooden boats, 8–10 m long, built on Robinson Island; the basic design has not changed over the last century. Motors were introduced in 1914; presently most boats are powered by outboard motors (Fig. 2A; see Arana, 1983, for description). Gear consists of rectangular wooden traps, introduced during the 1950s (Fig. 2B), and are complemented by small bait fisheries for small pelagics, whitefish, and moray eels. Trap design changed around 1980 from the so called "I" to the "L" type (see Arana, 1983, for description). According to Yañez et al. (1985: 254) the transition between trap designs occurred during the 1979–80 (~50% L design) and 1980–81 (~74% L design) seasons. The L design is said to be 30%–50% more efficient (Arana,

Figure 2. Typical Juan Fernández lobster fishing boat (A) and "L" design wooden lobster trap (B).

1983: 81). Traps are deployed individually, usually for one or two days. Boats differ in the number of traps active on a given date, which also varies during the course of the season. In general, traps tend to be deployed near shore at the beginning of the season, and active locations are gradually shifted offshore as the season progresses (Arana and Toro, 1985: 163). Motors and the improvement in trap design have increased effective effort over recent decades, but even more influential has been the gradual introduction of small hydraulic winches ("chigres") during the late 1990s. Chigres reduce handling time, allowing fishermen to visit more traps during a given trip (Henríquez et al., 1985).

Annual landing records started in the early 1930s (Fig. 3), making this the longest fishery time series in Chile, but monitoring by the fisheries authority (SERNAPESCA, http://www.sernapesca.cl) has several limitations. Fishermen are required to keep records of lobster and bait catches, reported by fishing trip; no information on number of traps is required. Records are generally filled out at home. Much of the reported information is subsequently lost during the compilation process: (1) catch information is aggregated for the entire archipelago (Robinson, Santa Clara, Selkirk, and Desventuradas Islands), (2) effort (trip) information is disregarded, (3) information is grouped by calendar year rather than fishing season, and (4) landings are converted from number of lobsters (the reporting unit) to aggregated weight by means of a constant conversion factor. The remaining information—annual aggregated landings expressed in metric tons—is of little use for the construction of indicators or for stock assessment.

Early studies of the Juan Fernández lobster and its fishery (Segerstrale, 1931; Lobell et al., 1947; Bahamonde, 1948; Canessa, 1965; Ulloa, 1968) were just descriptive snapshot accounts. Modern research started effectively in January, 1970 (Arana and Melo, 1973; Pizarro and Tiffou, 1974). Since then five research projects have been commissioned by the fisheries authority (Table 1). Data collected have been used in a series of formal assessments, based on which specific recommendations were made to the central fisheries authority. Models aside, scientists involved with this fishery have generally agreed that (1) this is a "recruitment fishery" (the catch is based mostly on recruits to legal size; Arana and Martínez, 1982; Henríquez et al., 1985), (2) maturity is reached 6–7 yrs and commercial size 8–10 yrs after settlement (Arana and Martínez, 1982; Arana et al., 1985), and (3) much of the reproductive output is contributed by females below legal size and by legal-size females that carry eggs early during the fishing season (Arana et al., 1985).

The top fisheries authority is the highly centralized Undersecretary of Fisheries (SubPesca, http://www.subpesca.cl). According to the Chilean Fisheries Act of 1991, the Juan Fernández lobster fishery falls into the "artisanal" category, which includes all boats smaller than 18 m, countrywide; no legal impediment prevents a substantial increase in boat size. In 2004 the authority introduced a 5-yr moratorium on entry of new participating fishers. The harvest has been regulated since 1934 by an "SSS" strategy: a legal size limit (115 mm carapace length), a closed season (15 May–30 September), and a prohibition on harvest of egg-carrying females. Noncompliance consists mostly of keeping sublegal-size lobsters for local consumption (Henríquez et al., 1985), but following a request from the fishermen themselves the central authority has commissioned a resident agent on San Juan Bautista since 2007, a change that has greatly improved the enforcement of size regulations.

Material and Methods

Reconstructing the History of the Fishery

We conducted a search through the scientific literature, unpublished reports, and archival sources to compile historical information on the Juan Fernández lobster and its fishery. The most informative sources were (1) historical records on fishing-boat construction and ownership, started in the mid 1970s and meticulously kept at the Chilean coastguard detachment of Juan Bautista (Robinson Island); (2) annual landing statistics collected by SERNAPESCA; and (3) catch and effort data available from a diversity of project reports, which yielded a discontinuous but informative time series of average CPUE (Table 1; Fig. 3).

Table 1. Historical summary of CPUE data (catch/trap) collection by various projects in the Juan Fernández lobster fishery, Robinson and Santa Clara Islands only. "The authority" refers to SERNAPESCA, the Chilean Servicio Nacional de Pesca.

Seasons	Source of data	Percentage of trips sampled	Documented by
1970–71, 1971–72	The cooperative	21%	Arana and Melo (1973, table 1); Pizarro and Tiffou (1974, table VIII)
1972–73 through 1980–81	The cooperative	100%	Larrain and Yañez (1983); Arana (1983, table II)
1981–82, 1982–83[a]	The cooperative	100%	Yáñez et al. (1985, table I)
Apr 1981–Mar 1982	Project contracted by the authority	Not reported	Arana and Toro (1985, tables IV, VI)
1984–85	Project contracted by the authority	Not reported	Henríquez et al. (1985, table 5)
1996–97	Project contracted by the authority	100%, number of traps estimated from monthly interviews	Arana et al. (1997, tables 4–7, 22); Arana and Vega (2000)
2004–05 through 2006–07	Marcas project	Not applicable	Our study
2005–06	Project contracted by the authority	Not reported	Arana et al. (2006)
2006–07 through 2007–08	Logbook program	50% of the fleet	Our study

[a] Data in Yañez et al. (1985, Table I) were expressed in terms of trips using the old "I" trap design. We standardized them to reflect the gradual transition during this period to the newer "L" design.

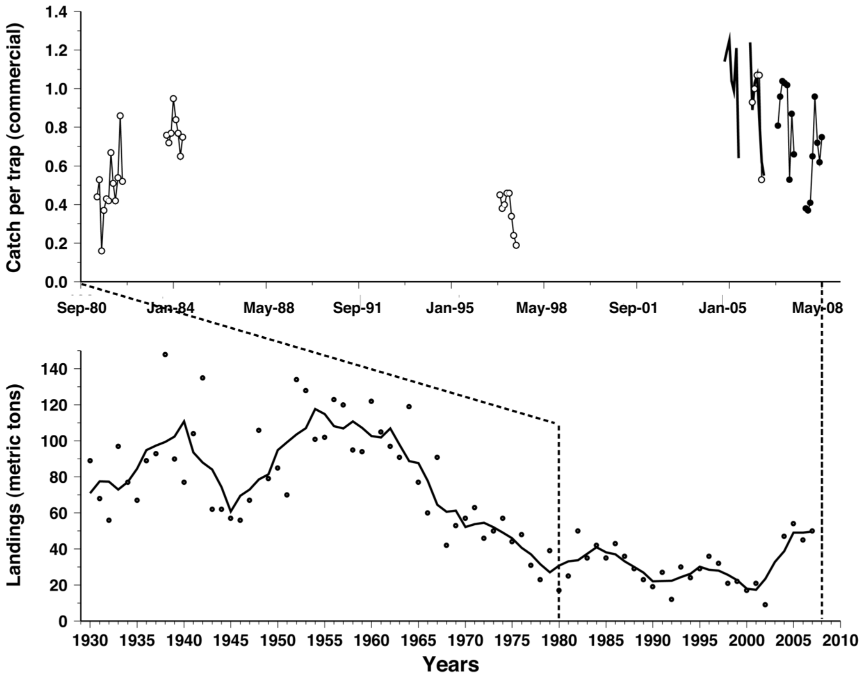

Figure 3. Time series of total catch (bottom) and average catch per trap of commercial-size lobsters (top). Total catch figures are from Chilean National Fisheries Service (SERNAPESCA). Open circles: Projects funded by the fisheries authority (see Table 1); thick lines: marcas project; filled circles connected by thin line: logbook program.

The Marcas Project, 2004–2007

In February–March 2004, we conducted a preliminary survey of the marcas system as part of a general in situ assessment of the fishery. On 4 March 2004, one of us (B.E.) accompanied the late Mr. Hugo Arredondo (then president of the Juan Fernández syndicate) during a fishing trip to the vicinity of Santa Clara Island. That area was selected because fishing intensity (traps deployed per unit area) seemed to be highest there. A GPS unit was used to record the positions of the points where 26 traps were lifted and redeployed. On the basis of that preliminary work, a survey strategy was designed for the 2004–05, 2005–06, and 2006–07 fishing seasons. The information recorded consisted of a pretrip interview and field data. The latter included the geographical coordinates of each trap lifted and redeployed and of locations where bait was procured, obtained with Magellan 320 and 315 GPS recorders (precision 10 m). Also recorded were the number of lobsters (legal and sublegal size, egg-carrying females) caught per trap haul and the type of bait used. During the 2004–05, 2005–06, and 2006–07 fishing seasons, 58, 60, and 50 trips were covered, respectively.

In conjunction with the geographical information on the marcas, we created a complete catalog of more than 350 toponyms used by the fishermen, expanding greatly the list from a previous survey (Arana and Toro, 1985, their fig. 2). The results allowed us to georeference verbal or anecdotal information on catch and effort, particularly in a historical perspective.

The Logbook Program

The convenience of initiating a voluntary logbook program was discussed at meetings of the syndicate held during September 2006, attended by their prospective partner scientists. This possibility implied a major innovation in the role of fishermen in monitoring; some of

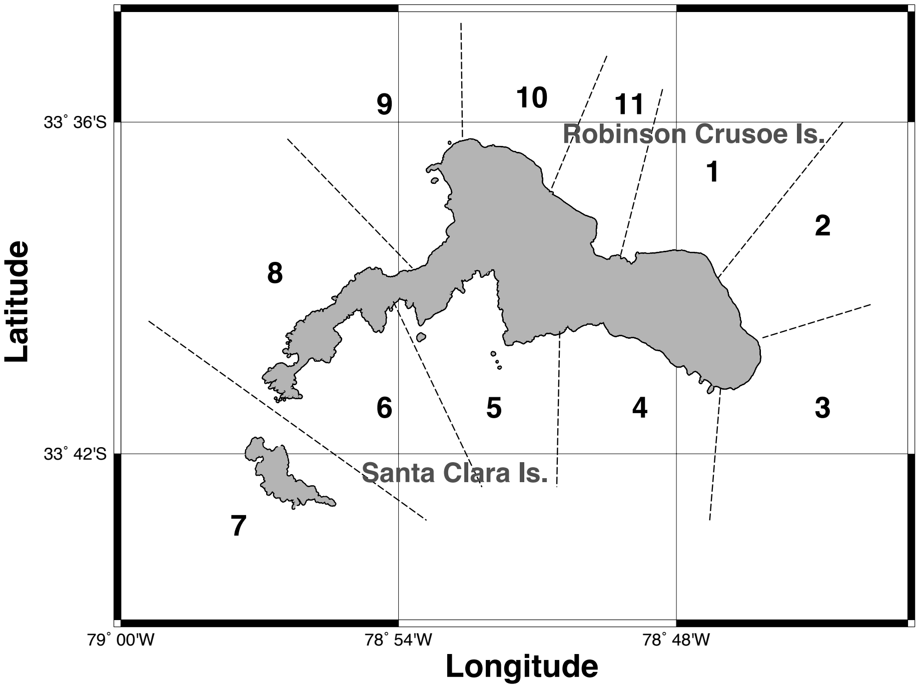

Figure 4. Areas defined for data compilation as part of the logbook program in which fishermen participated.

them were reluctant to collaborate because of the expected burden. Half of the fleet joined in. One incentive was that, with consent from the central authority, mandatory information required from individual fishermen (daily catch of bait and lobsters) was to be transcribed on their behalf by project team members, from the logbooks. A significant factor behind strong participation was that the information was to be collected and preprocessed by a highly trusted and well trained member of the island fishing community.

On the basis of inspection of the pattern of spatial distribution of the marcas and marca ownership, fishing grounds around Robinson and Santa Clara Islands were partitioned into 11 statistical areas (Fig. 4). Initially fishermen were asked to complete the information by fishing zones, but the practice soon proved ineffective because of the mismatch between printed charts and the detailed cognitive maps of the fishermen. Consequently they were asked to give information on trap location based on toponyms. Fishing locations were then stratified on the basis of the toponym directory compiled as part of the marcas project.

Definitive logbooks were designed that incorporated feedback from fishermen about size, font, and amount of information that could be reasonably expected to be completed given the time constrains imposed by fishing operations. Data to be recorded included date, boat, number of traps in the water, number of commercial and noncommercial lobsters per trap, and vernacular names of marca locations and alignments.

Modeling Catch per Trap

Because all the traps are basically of the same size and design and are serviced in a similar way, the trap haul forms a convenient basic unit of fishing effort. The numbers of commercial and noncommercial lobsters found in a trap (the response variables) were modeled as Poisson random variables. Assuming that the response variables included no overdispersion, we fit a Poisson regression (Clayton and Hills, 1993) using generalized linear models. The link func-

tion was therefore formulated with a linear structure. If X is defined as a random variable that represents the total number of lobsters caught in a trap, and x as one realization of X, then

$$f(x) = \frac{e^{-\lambda}\lambda^{x}}{x!}, \tag{1}$$

where λ is the expected number of lobsters in a trap. In the full model we expect the response variable to depend on boat, area, month, and fishing season:

$$\log(\lambda) = \log(1) + \beta_0 + \beta_1 u + \beta_2 v + \beta_3 w + \beta_4 z \tag{2}$$

$$\lambda = e^{\beta_0 + \beta_1 u + \beta_2 v + \beta_3 w + \beta_4 z} \tag{3}$$

where the offset (log(1)) is zero because the count is performed on each trap and u, v, w, and z represent, respectively, fishing season, month, zone, and boat; β_i are coefficients and β_0 is the overall intercept. We fitted the models shown in Table 2 using the *glm* function of the R statistical package (Faraway, 2006). These models are of different complexity; some incorporate interactions. Model comparison was performed by means of the Akaike information criterion (Burnham and Anderson, 1998).

Results

Time Series of Indicators

Five fisheries research projects sponsored by the central fisheries authority have been conducted in the Robinson/Santa Clara Islands (Table 1), each consisting of close monitoring of catch (including sex and size of lobsters) and effort (trips and trap hauls) over one or two seasons (and in one case also during the closed period between two seasons). During the first of those projects, conducted in 1971–72 (Arana and Melo, 1973), the cooperative collaborated in the collection of catch and effort records. After the end of that project, the cooperative continued collecting information through 1980, when its activities were terminated; the local police detachment kept collecting the same information through 1983. The result is the longest existing time series of catch and effort (trips) data for the fishery (Arana, 1983; Larrain and Yañez, 1983; Yañez et al., 1985), but despite its unquestionable historical value, this series has a number of problems. First, Henríquez et al. (1985: 45; their fig. 9) showed that, for a given period, the relationship between the number of trips and the number of hauls is very variable. Second, catch per trip shows a sudden decrease between the 1975–76 and 1976–77 seasons, noticed earlier by Yañez et al. (1985: 258). Interviews with a number of participants from that period did not identify any corresponding phenomenon, which could not have gone unnoticed. The decrease may have resulted from a change in the recording protocol or other artifact. Third, trap design changed around 1980, with implications that are difficult to account for. Published and reliable CPUE (catch/trap) information is therefore available only for the four discontinuous projects conducted in 1981–82, 1984–85, 1996–97, and 2005–06 (Table 1, Fig. 3).

Table 2. Model selection for CPUE of commercial-size and noncommercial lobsters. Number of model parameters (np) and the Akaike information criterion statistic (AIC) are shown for each model. Degrees of freedom (df), deviance, and P-value correspond to the difference between the current and the previous model.

Model	Model components	np	AIC	df	Deviance	P (> |χ|)
1	Constant	1	139297			
2	Intercept + Season	2	137004	1	2295	0
3	Intercept + Season + Month	9	135740	7	1278	1.02E-271
4	Intercept + Season + Month + Season×Month	16	134140	7	1614	0
5	Intercept + Season + Month + Zone	13	134809	–7	–1670	0
6	Intercept + Season + Month + Zone + Season×Month	26	133153	10	1007	6.14E-210
7	Intercept + Season + Month + Zone + Boat	40	133576	21	1274	6.90E-257
8	Intercept + Season + Month + Zone + Boat + Season×Month	47	131908	7	1682	0
Noncommercial lobsters						
1	Constant	1	526141			
2	Intercept + Season	2	525302	1	841	6.42E-185
3	Intercept + Season + Month	9	474975	7	50342	0
4	Intercept + Season + Month + Season×Month	16	470593	7	4395	0
5	Intercept + Season + Month + Zone	13	459519	–7	11080	0
6	Intercept + Season + Month + Zone + Season×Month	26	455150	10	4384	0
7	Intercept + Season + Month + Zone + Boat	40	434696	21	20482	0
8	Intercept + Season + Month + Zone + Boat + Season×Month	47	430733	7	3976	0

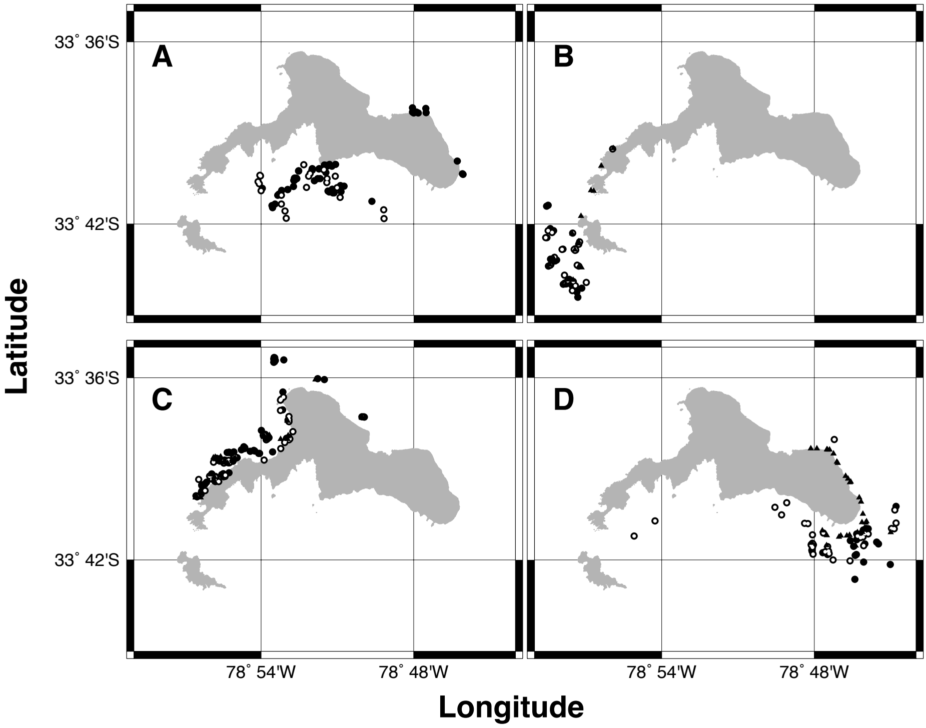

Figure 5. Spatial distribution of the marcas (traditionally designated fishing spots) of four lobster boats (A–D) occupied during three consecutive fishing seasons. Filled circles, 2004–05; open circles, 2005–06; triangles, 2006–07.

The Informal Management System

Although the existence of fixed locations where traps are deployed has been documented before (Arana et al., 1997; Arana and Vega, 2000, their fig. 2), the nature and significance of the informal "marcas" tenure system has not. A complete description of the system, the subject of a forthcoming contribution, is beyond the scope of this article. Marcas are not sold but can be transferred with a boat if the latter is sold, can be inherited by family members, and are often lent to other users under a variety of arrangements. The total number of marcas we recorded near the Robinson and Santa Clara Islands was 3762. This traditional tenure system is complex and highly structured and enjoys high compliance. The spatial distribution of the marcas and the temporal component associated with their use suggest that (a) most suitable sites have been already located, (b) a conservative clustering pattern is maintained across seasons, and (c) fidelity of individual fishermen to their sites is high (Fig. 5). Some crews can operate up to 200 marcas, but on average they tend to operate about 80. Only a subset of that total (30 on average) is active at any given time.

The Logbook Data

During the 2006–07 fishing season, 29 boats (out of 39) participated in the program, but not all of them complied throughout the season. During the 2007–08 fishing season, 20 boats participated, representing about half of the fishing fleet of Robinson and Santa Clara islands. During the two seasons combined, 57,347 trap

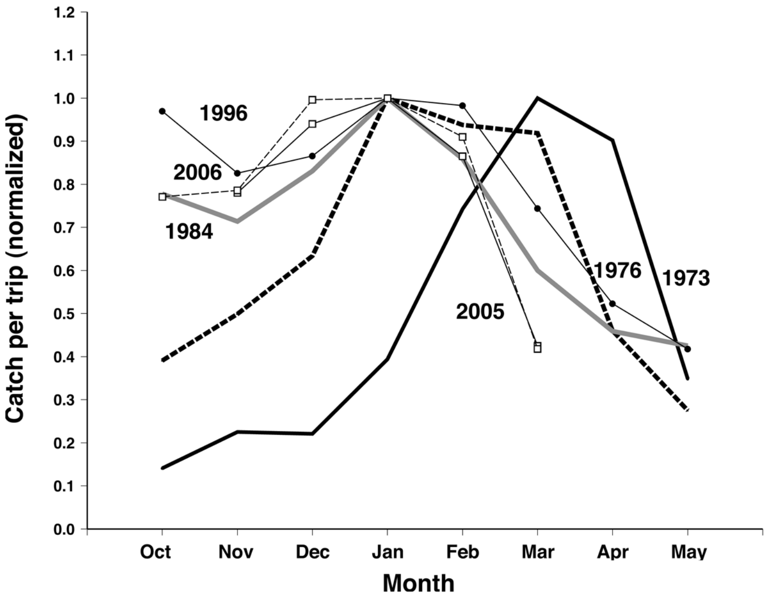

Figure 6. Seasonal trends of normalized CPUE (catch per trip); seasons differed in the timing of maximum CPUE.

hauls were recorded. Some boats that had limited participation in the first season were excluded from the analyses, leaving a total of 21 for the first season and 20 for the second and a final overall total of 55,658 trap-haul records after trimming.

Variation of CPUE

Data generated by the logbook program demonstrated the value of the latter for capturing patterns of seasonal and spatial variation of CPUE, the indicator regarded as most informative by the fishermen.

Seasonal Variation.—Intraseasonal variation in CPUE had been well documented in earlier studies; CPUE peaks midway through the season and shows significant interannual variation (Fig. 6). Biological phenomena possibly governing this pattern have been discussed by Larrain and Yañez (1983). In our study, CPUE of commercial-size lobsters also showed remarkable intraseasonal variation (Fig. 7A). During the 2006–07 season it was high at the onset, reached a maximum in December, and declined thereafter. In contrast, during the 2007–08 season, CPUE started off at a historical low level of about 0.4 lobsters/trap, reaching a maximum in February and declining through the rest of the season. CPUE of noncommercial lobsters showed a different pattern (Fig. 7B). In both seasons it started at a low level of 4 lobsters/trap, increased steadily, reached a maximum of about 12 lobsters/trap in February, and declined afterward, except in May 2008 (probably an artifact due to small sample size). Interseason variation in CPUE was lower for noncommercial than for commercial-size lobsters. The ratio of commercial to noncommercial lobsters was about 1–10.

Spatial Variation.—The highest cumulative catch of observed commercial and noncommercial lobsters occurred in both seasons in area 7 (Santa Clara Island), followed by areas 8, 3, and 9 (Fig. 8A–B). The fishing grounds around Santa Clara Island concentrated about 53% of the overall fishing effort (Fig. 8C–D) and 65% of the cu-

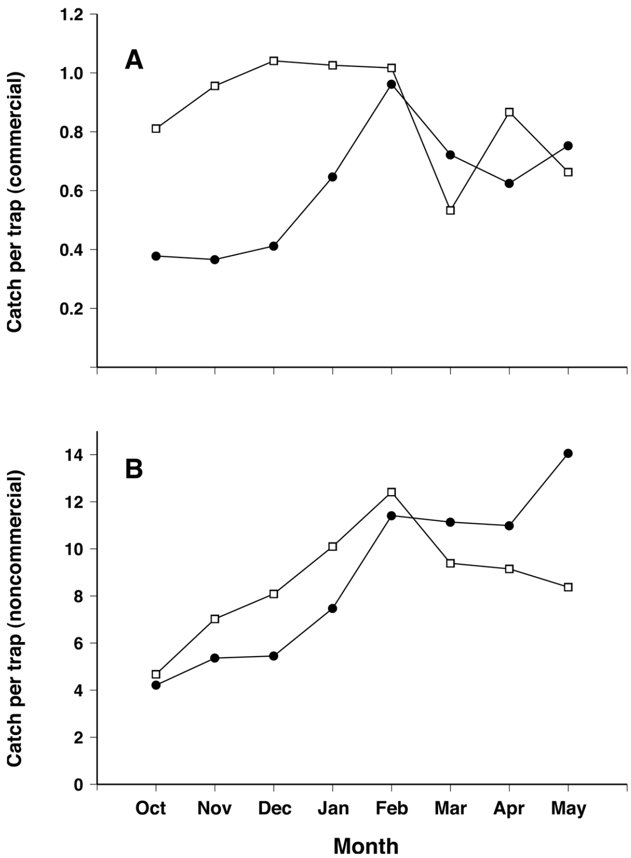

Figure 7. Intraseason variation in average catch per trap. (A) commercial-size lobsters; (B) noncommercial lobsters. Open symbols, 2006–07 season; filled symbols, 2007–08 season.

mulative catch (Fig. 8A–B). Areas 1, 2, 4, 5, 6, and 11 received little effort and yielded relatively small catches. During the 2007–08 season, areas 7, 8, 9, and 10 (Fig. 8D) received an important increase in fishing effort (number of hauled traps), probably in response to a decrease in CPUE (Fig. 8E–F). Commercial CPUE dropped in all areas except area 2 (Fig. 8F). The largest average commercial CPUE value was recorded in area 6 (2006—07 season), and areas 7, 8, 9, and 10 had similar CPUEs in the two years (Fig. 8F).

Variation among Boats.—Average CPUEs of boats differed by as much as 64% during the 2006–07 season (Fig. 9), but differences were less conspicuous during the 2007–08 season. Between seasons, average CPUE decreased for all but two monitored boats.

Model Selection

Figure 10 shows the empirical distribution of the CPUE random variable for commercial and noncommercial lobsters (the two seasons combined). The Poisson statistical model shows a good fit to the response random variables. The zero value was

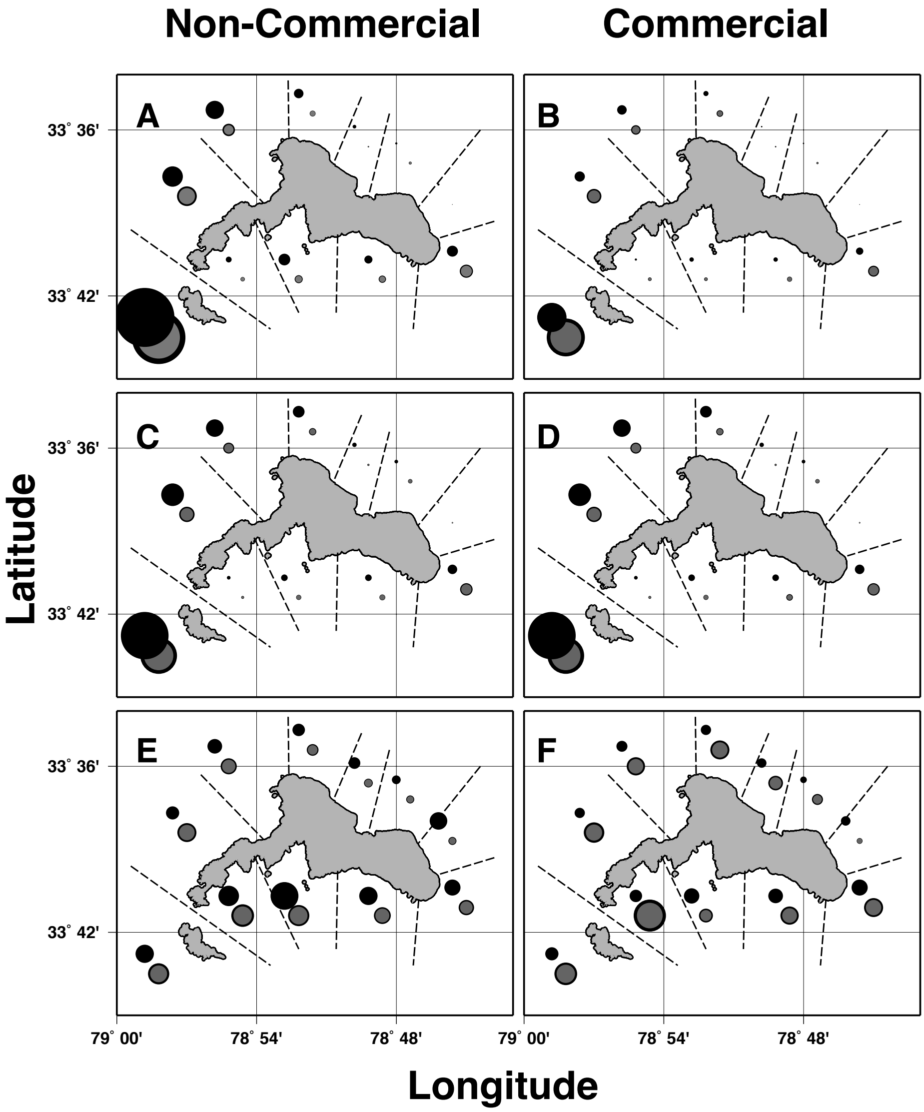

Figure 8. Cumulative catch (A–B), total effort (C–D), and average catch per trap (E–F) by statistical area and season, commercial and noncommercial lobsters. Light circles, 2006–07 season; dark circles 2007–08 season.

present 58% of the time for commercial and 12% for noncommercial lobsters (Fig. 10A,B).

Eight different models were selected on the basis of the Akaike information criterion for commercial and noncommercial lobster CPUE. Number of model parameters, degrees of freedom, deviance, p-values, model components, and interaction terms are summarized in Table 2. For both commercial and noncommercial lobsters, the optimal model incorporated season, month, zone, boat, and the interaction of season with month (Table 2).

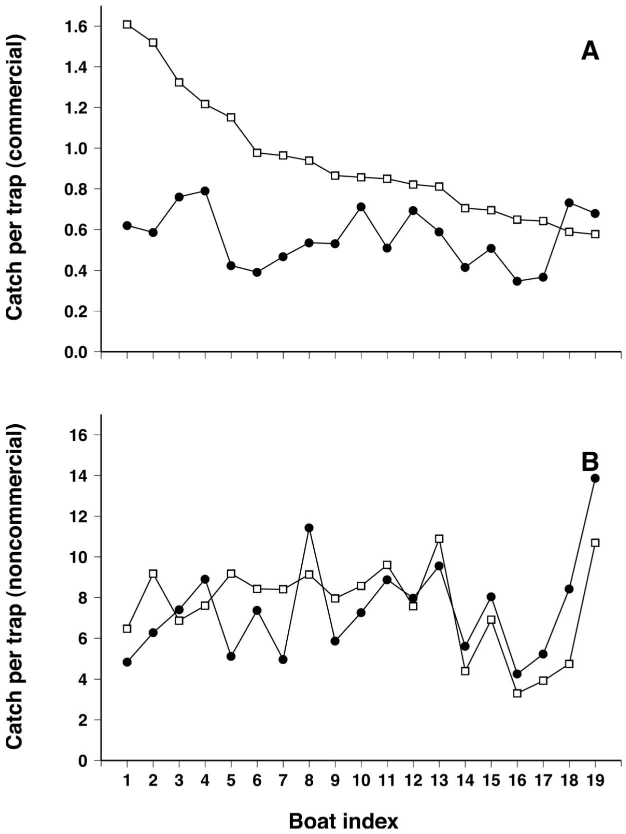

Figure 9. Average catch per trap by season for boats participating in the logbook program. (A) commercial-size lobsters, (B) noncommercial lobsters. Open symbols, 2006–07 season; filled symbols, 2007–08 season.

For commercial lobsters, season strongly affected the response variable—the 2006–07 value was higher than that for 2007–08—whereas for the noncommercial lobsters, it did not (Fig. 11A,B). For commercial lobsters, month strongly affected the response variable for all months except month 6, during which the effect was much smaller (Fig. 11C). For noncommercial lobsters, a dome-shape curve was observed; the effect on the response variable grew progressively to a peak in month 6 (Fig. 11D). For both commercial and noncommercial lobsters the spatial component, zone, strongly affected the response variable. For the commercial lobsters, the effect was stronger in southern areas (3–7) than in northern ones (Fig. 11E). Noncommercial lobsters showed a revealing pattern, in which the negative effect on the response variable was strongest in areas 1, 10, and 11 and the positive effects were strongest in areas 6 and 7 (Fig. 11F). This result indicated that areas adjacent to Cumberland Bay showed low relative abundance of noncommercial lobsters and that areas 6 and 7 showed the highest relative abundance of small lobsters. Other zones presented almost no difference in overall average value. The boat effect showed the highest interlevel variability of all factors, in both cases (Fig. 11G,H). Season had a marked effect on standardized CPUE. The standardized CPUE of commercial and noncommercial lobsters was higher in the 2006–07 season than in the 2007–08 season (Fig. 12).

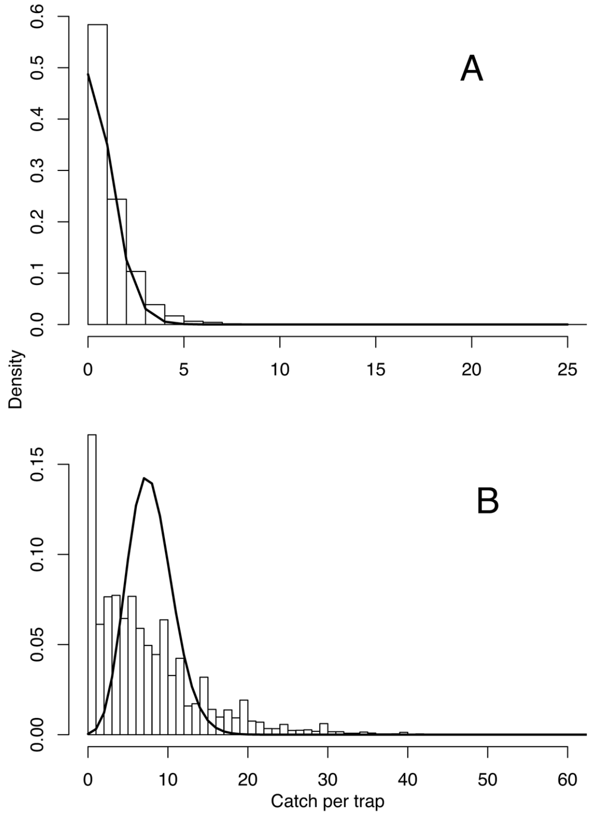

Figure 10. Frequency distribution of all catch-per-trap observations (bars) and fitted Poisson model (line); (A) commercial-size lobsters, (B) noncommercial lobsters.

Discussion

A major finding of our inquiry into the Juan Fernández lobster fishery was that the regulation of access and spatial effort by informal but tightly structured local practices is quite effective. The syndicate, wary of the possibly disruptive consequences of management measures emanating from a distant central fisheries authority, took the initiative to monitor catch and effort and develop indicators of the state of stock. The logbook program we designed and subsequently tested during two annual fishing seasons strengthened the standing of the fishermen's organization, which is now pursuing the creation of a protected area around the islands and promoting their product among conservation-conscious consumers. Consolidation of this bottom-up process required an arrangement for the provision of technical and scientific support and the development and exploration of appropriate indicators. The latter could be incorporated in the future into an indicator-driven management approach, under which action would respond to simple indicators that can be monitored, understood, and trusted by fishermen (González et al., 2006; Prince, 2010).

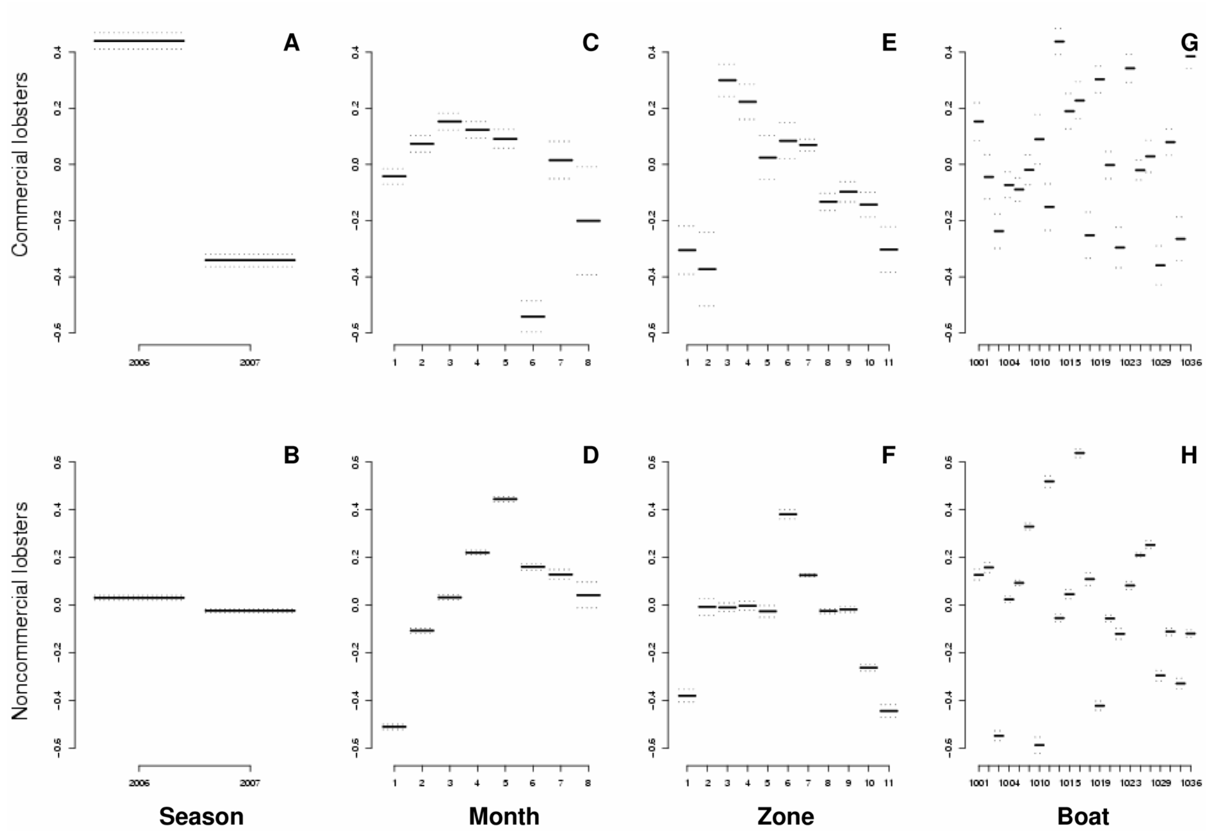

Figure 11. Coefficients of the Poisson generalized linear model (Table 2, model 8). Top row: commercial-size lobsters; bottom row: noncommercial lobsters.

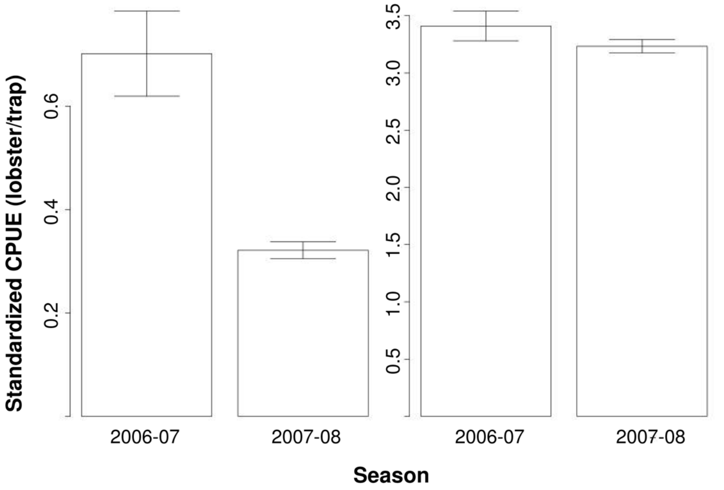

Figure 12. Seasonal coefficients (in the original units) for commercial (left) and noncommercial (right) lobsters.

Arrangements for the provision of technical and scientific support have received comparatively little attention and are variously configured (Garcia et al., 2008). In the case of commercial benthic fisheries, these include (1) fisheries research agencies' directly informing the management authority in traditional top-down management systems, the most common case; (2) reporting by providers of advice to a comanagement body that typically incorporates fishermen, managers, and scientists, as is the case in the Galápagos (Shepherd et al., 2004), the Chilean urchin fishery (Moreno et al., 2007) and the San José Gulf scallop fishery from Argentine Patagonia (Orensanz et al., 2007); (3) hired consultants, like those in the Canadian geoduck fishery (Heizer, 2000) and the Chilean TURF system (González et al., 2006); (4) collaboration of fishers with scientists in academia, usually involving one or a few cases of demonstrational value (Castilla and Defeo, 2001); and (5) providers that work within communities or fishermen's organizations and inform the latter directly, including "fisheries advisors" of cofrarías from Galicia (Molares and Freire, 2003) and RARE's "fisheries fellows" in the Gulf of California (RARE, 2005). The last category matches what Prince (2003) has popularized as "the barefoot ecologist" (see also http://www.recursosmarinos.net/?p=177). The Juan Fernández experience, where the providers of technical and scientific support were trained members of the fishing community, exemplifies an incipient but growing trend in that direction. "Barefoot ecologists" have been promoted from the top down in some cases (e.g., in Galicia) and developed from the bottom up in others (e.g., Juan Fernández). The success of the providers depends proximally on the success of the fishery, and for that reason they are committed to sustainability. In other terms, usually reserved to fishermen but applicable to other stakeholders as well, they are motivated by "the right incentives."

Discussions about the participation of fishermen in the provision of knowledge support for the management of small-scale fisheries often focuses on traditional ecological knowledge (Johannes et al., 2000). Although this source of information and its role in empowerment of fishermen are unquestionably significant, fishing communities struggling to survive in the current economical and political climate face

a number of challenges: knowledge (whatever its origin) must be formalized, indicators compiled and understood, and management options evaluated and contested in multistakeholder forums. Fishermen, and their communities and organizations, must resolve conflicts of use with other—often well informed—stakeholders, capture commercial opportunities, and expand their portfolios with access to processing, ecolabeling, denominations of origin, ecotourism, etc. These challenges require adequate provision of scientific and technical support and the skills to put it to work. The Juan Fernández lobster fishery is a case in point. Until recently fishermen were passive participants, suppliers of lobsters to mainland middlemen (who set prices) and of landing figures for the central authority, but the situation has now changed. Several fishermen have formed a marketing cooperative, the fishery was selected by the Marine Stewardship Council (MSC, http://www.msc.org) to test a protocol for the certification of "data-poor" fisheries, Slow-Food (http://www.slowfood.com) promotes Juan Fernández lobsters, and the syndicate is pressing for the creation of a marine reserve around the islands (10 nmi) with the ultimate goal of excluding mainland-based fleets.

The monitoring program described here is a main element in the "tool kit" (sensu Prince, 2003, 2010) of the providers of technical and scientific support for the Juan Fernández lobster fishery. CPUE has been, traditionally, the main indicator of stock condition perceived by the fishermen. A major achievement of the monitoring program has been upgrading the status of CPUE from an indicator assessed subjectively by each individual fisherman to one that is objectively estimated. This change required the formal analysis of several sources of variation: spatial, intraseasonal, and among-boat. The program is expected to improve the information available to the fisheries authority to support management, which presently has two major limitations: lack of spatial resolution and temporal discontinuity. Attention to the spatial dimension is essential, as lobster behavior, the fishing process, and the tenure system are structured by the template of benthic bottomscapes and spatial gradients. The only piece of information that has been regularly monitored by the fisheries authority is annual catch, but spatial information is lost during the compilation process. Information on effort and CPUE has been collected only sporadically, and the scarce data available cannot be standardized because appropriate covariates are lacking.

The growing protagonism of the organized fishermen is timely, as the sustainability of the fishery faces impending threats that, paradoxically, originate from regulations intended to protect artisanal fleets and from scientific advice. The Chilean Fisheries Act establishes a size limit of 18 m for artisanal boats. Because the Juan Fernández fishery is classified as artisanal, no legal impediment prevents eventual replacement of traditional boats in the relatively homogeneous fleet (8–10 m long) with larger ones, with a consequent increase in fishing power and effective fishing effort. Larger boats could service more traps in a single fishing trip; boats currently used typically service only a fraction of their available marcas at any given time. Introduction of larger boats by one fisherman would disrupt an unwritten rule that is perceived to contribute to equity.

Sporadic recommendations of a TAC constitute another threat. The scientific support received by the centralized fisheries authority (Table 3) fits the requirements of the classical "stock-assessment driven" approach to industrial fisheries management, which resorts to downgraded versions of conventional models (Mahon, 1997: 2210). Ultimately, inappropriate support sidetracks management and distorts objectives.

Table 3. Historical summary of stock assessments and the recommendations that they supported for the Juan Fernández lobster fishery, Robinson and Santa Clara Islands only. SFD, size-frequency distribution.

Data	Model	Source	Conclusions and recommendations
Average catch-per-trip data collected by the cooperative between 1972–73 and 1978–79	Generalized stock-production model	Larrain and Yañez (1983)	The fishery was in a bioeconomic equilibrium. Effort was 59%–136% above optimal (depending on the specific model fitted). Recommended effort reduction (with due caveats regarding social consequences) or redirection to lightly exploited regions (Selkirk and Desventurada Islands). Equilibrium MSY would be between 32 and 38.3 thousand lobsters
Series extended to the 1980–81 season	Generalized stock-production model	Arana (1983)	Effort was 32%–36% above optimum. Equilibrium MSY would be between 31 and 32 thousand lobsters. TAC of 25 thousand lobsters recommended.
Series extended to the 1981–82 season	Generalized stock-production model	Yañez et al. (1985)	Equilibrium MSY would be between 43 and 48 thousand lobsters. “The stock may be showing a resistance to extinction.”
Series extended to the 1984–85 season.	Stock-production model	Henríquez et al. (1985)	Effort was 54% above optimum. Equilibrium MSY would be between 43 and 44.6 thousand lobsters.
SFDs; growth and mortality parameters	Yield per recruit	Yañez et al. (1985)	TAC recommended.
SFDs; growth and mortality parameters, 1996–97 season data	Equilibrium length based model	Yañez et al. (2000)	Keep current legal size. Slight effort reduction recommended. High harvest rate may compromise biomass level in the midterm.. Catch of 32.9 thousand lobsters recommended under a $F_{0.1}$ strategy.
SFDs; growth and mortality parameters, 2005–06 season data	Equilibrium length based model	Arana et al. (2006)	Relative abundance at highest level in 30 yrs, contradicting previous expectations. Standard reference points indicate that annual catch for the archipelago should 54.7 thousand lobsters. A TAC or effort regulations recommended as alternatives to reduce current harvest rates (but see text for discussion)

Past assessments of the Juan Fernández lobster stock (Table 3) have concluded that effort was above optimal and recommended TACs, ignoring the territorial use privileges effectively established by tradition. Fortunately, however, a TAC has not been implemented; introduction of catch quotas would disrupt a management system that has made this fishery sustainable for decades through a combination of informal traditional tenure and formal but simple regulations (size, season, no egg-carrying females). The presumably suboptimal bioeconomic equilibrium that has been a matter of concern to assessment scientists in the past is a minor problem compared to the disruptive consequences to be expected were quotas or other top-down drastic measures ever introduced without attention to the tenure system. As Beddington et al. (2007) have cogently argued, some form of suboptimal bioeconomic equilibrium is likely to be reached in small, lightly regulated fisheries, but in such cases the management priorities may be different from the optimality goals of industrial fisheries. In a situation with little or no formal management capacity but where social sustainability has been achieved with relatively modest economic rent, a suboptimal bioeconomic equilibrium may be a perfectly legitimate management goal as long as it is compatible with the sustainability of the resource. Beddington et al. (2007) pointed, specifically, to the case of territorial use rights within local communities. In a similar vein, Larrain and Yañez (1983) advised caution in the eventual introduction of measures to reduce harvest rates.

An alternative to the stock-assessment driven approach is to place the emphasis of research on monitoring interpretable indicators with participation of fishermen, developing simple decision rules, providing contexts for consultation and feedback, and ultimately, testing the system in a management-procedures framework (González et al., 2006; Prince, 2010). This course of action is being explored in other participatory research projects, like California's Collaborative Lobster and Fishery Research Project (Abramson et al., 2005; Wilson et al., in press; see http://www.calobster.org for further information). Realistically, information collected at the scale required for understanding of the fishing process and construction of reliable indicators of abundance cannot be collected without the active participation of the fishermen themselves. The central authority does not have the means to handle the financial, logistical, and technical burden of collecting, processing, and analyzing the spatially explicit information without that participation. The participation of 50% of the boats during two consecutive seasons, and now during the current one, is highly encouraging.

The results of the latest project supported by the central fisheries authority (2005–06) were discussed at workshops conducted at the mainland headquarters of the fisheries authority and on Robinson Island, with participation of the fishermen (Arana et al., 2006: 214). Scientists there agreed on the failure of previous stock assessments and traditional models. The recommendations placed emphasis, instead, on improving the quality of the indicators (e.g., catch per trap haul). Fishermen themselves insisted on the need for a regular presence of the fisheries authority on the islands (e.g., through a permanent agent) to improve the quality of landing statistics and the enforcement of size regulations. Agreement was reached that any regulatory innovation should be arrived at in consultation with the fishermen. This event highlighted the strengthened standing of the fishing community and demonstrated its commitment to biological, social, and institutional sustainability.

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