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The Galápagos sea cucumber fishery: management improves as stocks decline

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SUMMARY

The Galápagos Islands, a world heritage region for the protection of the unique terrestrial and marine wildlife, are also home to a small human population, dependent on fisheries. There was a lucrative sea-cucumber (*Stichopus fuscus*) fishery in the islands, which began in 1992. After a rapid expansion in the Galápagos archipelago, the fishery has declined and now persists predominantly around the western islands. Initially, the fishery was largely illegal and uncontrollable. Subsequently, a co-management framework developed, with fisher participation. Gradually enforcement improved, apparent corruption declined, and research capacity increased. Although stock abundance surveys have been carried out annually since 1993, the paucity of background biological and fishery information does not allow rigorous stock assessment. The achievements of co-management through the participation of fishers in research and management have been: an acceptance of management controls on numbers of fishers and quotas, a reduction in conflict and increased co-operation. Persistent problems have been: weak enforcement capacity, limited funds for patrolling and research, corruption and declining stock abundance. Proposed application of precautionary principles to management, including a range of fishery indicators, may save the fishery from collapse. The principles are applicable to many other data-poor fisheries globally.

Keywords: beche-de-mer fishery, co-management, fishery conflict, fishery indicators, overfishing, precautionary approach, sea cucumber fishery, *Stichopus fuscus*

INTRODUCTION

The abundant and unique wildlife of the Galápagos Islands is almost entirely dependent on the production of the surrounding sea. As fishing intensity has increased during the last decade, driven by the needs and demands of a growing population, conservation efforts to protect marine ecosystems have also intensified, especially with increased understanding about the ecosystem roles of exploited species in the system (Okey *et al*. 2003*a*, *b*). Serious conflicts between fishers and managers frequently erupted, especially in the lucrative developing *pepino* (sea-cucumber or beche-de-mer) fishery (James & Miller 1995). This fishery commenced in 1992 and, over the next 10 years, progressed from an anarchic phase to co-management, with a continuously evolving management regime, including trials of individual property rights (Murillo *et al*. 2002*b*).

Even without conflict, pepino fisheries are difficult to manage, due to the high cost of stock assessment. The life history and ecology of most species are poorly known, and many are slow growing, with low productivity, and vulnerable to overfishing (Conand 1990, 2001). Most fisheries have exhibited boom-bust cycles, followed by prolonged collapses (Uthicke 1996; Conand 1998, 2001). S*tichopus fuscus* is no exception. A pepino fishery based on *S. fuscus* lasted only six years in Baja California (Aguilar-Ibarra & Ramirez-Soberón 2002)) and three years in continental Ecuador (De Miras *et al*. 1996). The collapse of the fishery on the continent precipitated a transfer of fishing capacity to the Galápagos and the start of a pepino fishery there (Carranza Barona & Andrade Echeverría 1996). The fishery biology of *S. fuscus* is better known in Mexico (Fajardo-León *et al*.1995; Herrero-Pérezrul *et al*.1999), than in the Galápagos, where only the reproductive cycle (Toral-Granda 1996) is described, although there are ongoing research efforts (P. Martinez). Despite many reports on the politics of the fishery, important catch and effort data since the inception of the fishery, critical for future modelling, have never been assembled, nor has a coherent historical account been compiled. A review of the fishery in its present critical stage of decline is therefore overdue.

This paper focuses on the crucial role that science must play in the management of a developing fishery in a developing country, and especially where the assertion of management control is a contentious issue. In the Galápagos, the biological issue was ensuring sustainability in a setting of uncontrolled fishing and high uncertainty about the catch (Coello 1996) and stock abundance. Management issues related to asserting control in a volatile, and often hostile, environment, while promoting dialogue with fishers and achieving their participation in management. We describe the troubled history of the fishery, and the vicissitudes of management in the prevailing social climate, from early

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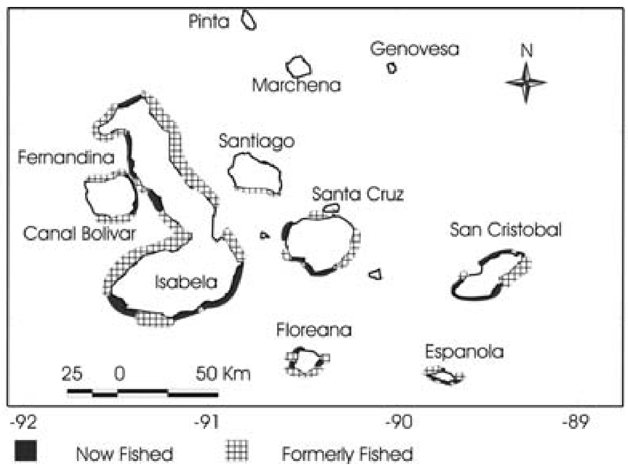

Figure 1 The Galápagos Archipelago, showing all islands except the distant northern islands, Darwin and Wolf. The three northern islands shown, Pinta, Marchena and Genovesa, were never fished. Western islands are Fernandina and Isabela. Main eastern islands are Santa Cruz, Santa Fe, Floreana, Española and San Cristóbal. Coastal areas fished in 1992–1993 are hatched, and dark shading shows those fished in 1999–2002.

attempts to stifle an illegal gold-rush industry to the present, still fragile, participatory management with fishing cooperatives. We reconstruct past catches and patterns of fishing from the limited fishery-dependent data, and from historical and anecdotal evidence. Finally, we infer the current status of the fishery from available survey data and sketch in outline the biological information required and management steps necessary for precautionary management in a now depleted fishery.

The fishery started in Canal Bolívar (western Isabela) in early 1992, with over 100 fishers (Carranza Barona & Andrade Echeverría 1996), and later spread to the eastern islands of Santa Cruz, Santa Fe, Floreana, Española and San Cristóbal (Fig. 1). Fishers set up illegal camps on National Park land, and, upon their discovery and forcible closure, the fishery became clandestine, but continued with the connivance of corrupt officials in the transport and sale of the illicit product (Powell & Gibbs 1995; Anon.1997).

The fishery was reopened experimentally in October–December 1994 for 420 authorized divers, subject to a total allowable catch (TAC) of 550 000 pepinos. By mid-December *c*. 900 divers were fishing without control and with rampant violations, creating a situation 'so scandalously intolerable' (MacFarland & Cifuentes 1996) that the fishery was prematurely closed with a catch already of 8–12 million pepinos (De Miras *et al*. 1996). The fishery thereupon became illegal and continued in this manner until 1999. During this period camouflaged camps were often discovered and catches seized. Fishers retaliated often with violent protest, besieging Galápagos National Park Service (GNPS) or Charles Darwin Research Station (CDRS) offices three times, taking persons or tortoises hostage, and seizing property; while on one occasion a park ranger was shot (Stone 1995; Coello 1996; MacFarland & Cifuentes 1996; Jenkins & Mulliken 1999, Anon. 2000).

To improve management and promote reconciliation, 'The Special Law for the Galápagos' was enacted in 1998 (Heylings *et al*. 1998), and provided for a Participatory Management Board (PMB), comprising fishing, tourist, research, management and conservation interests, to manage the fishery. An Interinstitutional Management Authority (IMA), presided over by the Minister for Environment, constituted an appeal tribunal.

After an initial fisher training workshop, the fishery was opened for about two months a year around four or five islands during 1999–2002. In two years a TAC was imposed, with a quota overrun of 10% in one year, and in 2001 and 2002 there were size limits of >20 cm for fresh and >6 cm for dried pepino. In 2001, when the price fell from US$ 0.88 per pepino (2000 price) to $ 0.55, partially because the pepinos taken were generally smaller, the catch was small. However, in 2002 the catch increased more than threefold and fishers ignored the minimum length requirement, with 56% of the catch being <20 cm (Murillo *et al*. 2002*a*, *b*). Overall catches for the archipelago are given in Table 1, and for each island in Table 2; Espinoza *et al*. (2001) and Murillo *et al*. (2002*a*, *b*) give details of the fishing seasons. In 2001, the cooperatives established for the first time a form of individual quota for members.

Over these four years of a managed fishery, the number of fishers fluctuated between 597 and 1229 (Table 2), because of conflicting pressures from cooperatives to increase members and from management to reduce fishing effort (Heylings & Bravo 2001). The 2001 decline in numbers of fishers was a result of the introduction of individual quotas and a low perceived catch per fisher (Murillo *et al*. 2002*a*).

In both 2001 and 2002, the IMA adopted a precautionary adult density of 0.4 m^{-2} as a limit reference point, based on empirical threshold densities for other invertebrates (Shepherd & Partington 1995), and resolved to close fishing around those islands with pepino densities below the limit. However, in both years, under strong pressure from fishers, the decision was rescinded, although adult pepino densities were declining and below the reference level.

Illegal fishing persisted during 2000–2002, with estimates of an annual illegal take of 250 000–300 000 pepinos for 2000–2001 (J. Machuca, personal communication 2001). Enforcement capacity remained weak through much of the period, partly because the fishing grounds were remote, and few of the detected offences led to sanctions. For example, in 2002, illegal fishing in prohibited zones was detected 56 times, but only two sanctions were imposed, and neither was for size limit infractions (Murillo *et al*. 2002*a*). When offences were detected, strong political pressure was often applied or bribes offered to stifle prosecution. During the 1990s, corruption was rife among public officials and defence personnel, including the judiciary and a member of congress (Jácome & Ospina 1999, Jenkins & Mulliken 1999). Lastly, there was a lack of resources needed for rigorous stock assessment on which

Table 1 Catch estimates for the Galápagos pepino fishery from 1992–2002. Official export figures from Ecuador are given for 1992, 1995, 1999–2002 (2002 figures from Murillo *et al.* 2002*b*, where weights were not comparable with earlier years because pepinos were exported fresh, dried or in brine); only import figures from Ecuador were available for 1993. Numbers of pepinos are calculated from the number:biomass conversion rate of 50 000 pepino t^{-1} for 1992–1998, 42 557 pepino t^{-1} for 1999, and 41 276 pepino t^{-1} for 2000. Maximum estimates of numbers taken are the minimum estimates increased by the estimated amounts taken illegally. The preferred estimates for 1992–1993 are less than those (36 million) given by Aguilar *et al.* (1993); the preferred estimates are the average of the upper range in 1994, the average of the minimum and maximum estimates in 1995–1996, and the same figures for 1997–1998 as in 1996, assuming continuation of illegal fishing at the same level. CPUE (catch per unit effort) estimates for 1992–1993 are the average of the estimated range 4000–5000. nd = no data available.

Year	*Exports or imports (t)*	*Minimum estimate of numbers of pepino (10^6)*	*Maximum estimate of numbers (10^6)*	*Preferred estimate of numbers (10^6)*	*CPUE (numbers of pepino per diver per day)*
1992	29.3	1.50	48.0	25.0 ± 5.0	4500
1993	15.0	0.75	48.0	25.0 ± 5.0	4500
1994	16.6	0.83	8–12	10.0	1166
1995	60.5	3.03	3.0	3.0	nd
1996	38.0	1.90	3.0	2.5 ± 0.5	nd
1997	nd	nd	3.0	2.5 ± 0.5	nd
1998	nd	nd	3.0	2.5 ± 0.5	nd
1999	103.4	4.40	4.8	4.8	416
2000	119.9	4.95	5.2	5.2	248
2001	98.1	2.672	2.7	2.7	479
2002	176.1	8.301	8.3	8.3	125

to base quotas. Stock surveys gave estimates of relative abundance at fixed sites, but the paucity of information on growth rates, recruitment or behaviour of pepinos hampered an understanding of the fishery dynamics.

METHODS

Catch and effort data

We estimated the total annual catch indirectly because of uncertainty about early catch data. Declared pepino exports from Ecuador and declared imports by major importers from Ecuador (Jenkins & Mulliken 1999) provide minimum estimates of catches up to 1996. Data from transfer certificates, required for export of pepinos, gave estimates of the legal catch for 1999–2002. Estimates of the maximum catch until 1996 were calculated from evidence given by fishers to a government enquiry (Carranza Barona & Andrade Echeverría 1996). For example, in 1992 an average of 60–100 divers each fished 2000–5000 pepino per day (for 4–5 hours fishing) for 15 days a month (CDRS and GNPS, unpublished reports 1993). Assuming that they fished eight months a year, we calculated an upper limit to the catch (~48 million). Coello (1996) reviews other estimates with more (5–6) hours per day worked and more (20) days fishing per month. Murillo *et al.* (2002*a*, *b*) summarized catch and effort data for 1999–2003, derived from port monitoring; illegal catches were estimated from diver interviews.

For conversion of export/import data in tonnes dried weight (1992–1996) to numbers of pepinos, we used a dry weight:fresh weight ratio of 1:10 (Conand 1990). Because weight estimates ranged from 37 000 dried pepino t^{-1} (Sonnenholzner 1997) to 83 000–25 000 pepino t^{-1} for pepinos seized in the Galápagos (Jenkins & Mulliken 1999), for

Table 2 Total allowable catch (TAC) in millions of pepinos for each fishing season (none means no TAC was specified), number of divers, estimated total catch of pepinos (numbers in millions) and catch per unit effort (CPUE) (numbers $diver^{-1}$ d^{-1}) by island or island group for 1999–2002. nd = no data. Closure indicates fishery closed for season on that island. CPUE data for Isabela and Fernandina in 1999–2000 were incomplete because there were no observers in some areas.

Year	*TAC*	*Divers*	*Isabela and Fernandina*		*Santa Cruz*		*Española*		*Floreana*		*San Cristóbal*	
			Catch	*CPUE*	*Catch*	*CPUE*	*Catch*	*CPUE*	*Catch*	*CPUE*	*Catch*	*CPUE*
1999	none	613	2.19	382	0.48	374	0.49	590	0.08	nd	1.16	337
2000	4.5	1229	3.11	407	0.72	342	0.26	279	0.24	261	0.62	270
2001	4	597	2.49	534	0.09	235	Closure		0.05	278	0.05	124
2002	none	778	7.23	130	Closure		0.08	92	0.24	51	Closure	

import/export data we used Castro's (1993) figure of 50 000 pepino t^{-1} for the same species in Baja California. There are slightly lower conversion figures for 1999 and 2000–2001 because some of the catch in transfer certificates was semi-dried.

In 1999–2003, CDRS personnel recorded catch and effort data (Toral-Granda *et al.* 2000; Espinoza *et al.* 2001, Murillo *et al.* 2002*a*, *b*). These data overestimated catch per unit effort (CPUE) for 1999–2000 because some unrecorded nocturnal fishing effort occurred at some islands. The changing spatial pattern of the fishery was derived from CDRS reports and diver information.

Survey data

The first pepino surveys were undertaken in Canal Bolívar in 1993, during the early illegal phase of the fishery (Aguilar *et al.* 1993; Merlen 1993; Richmond & Martínez 1993); hence the data for some sites probably represent nearly unexploited densities of pepino stocks. Bermeo-Sarmiento (1995) conducted subsequent surveys and, from 1994, Martínez and Toral-Granda conducted annual surveys (Anon. 1997; Espinoza *et al.* 2001; Toral-Granda & Oviedo 2002; Toral-Granda & Vega 2003). Here we present mean density values from 1993–2003 extracted from these sources for (1) Canal Bolívar, 1992–1998, and Fernandina and Isabela (which included the Canal Bolívar sites), 1999–2003, and (2) for all other islands combined, 1999–2003.

Average densities of harvested pepinos were crudely estimated from CPUE data as follows. Shepherd (1985) showed that, if the power of a diver (i.e. the area of bottom searched per hour) is known, then the density, D, of available animals collected can be estimated from the equation:

$$D = N/(Tr - mrN) \quad (1)$$

where N is the total number collected, T is the diving time in minutes, m is the handling time in minutes and r is the power of the diver in m^2 per min. These authors found that the power of commercial and experienced research divers was $\sim$20 m^2 min^{-1} or 1200 m^2 h^{-1}. Assuming (conservatively) a mean diver power of 1000 m^2 h^{-1}, a handling time of one second per pepino and an average diving time of 4.5 hours per day, the mean density of harvested pepinos was crudely estimated for 1992–1994, and 1999–2002.

RESULTS

The total annual catch (Table 1) declined from early estimated peaks of 20–30 million pepino in 1992–1993 to 2.7 million pepino in 2001, increasing to 8.3 million pepino in 2002. Catch data by island from 1999–2002 (Table 2) show that the proportion of the total catch from Isabela and Fernandina (the western islands) increased from 50–93% as the fishery progressively collapsed in the eastern islands.

Mean CPUE declined from an anecdotal 4000–5000 pepino $diver^{-1}$ d^{-1} in 1992–1993 to 125 pepino $diver^{-1}$ d^{-1} in 2002; the temporary increase in 2001 occurred because almost the whole catch came from the western islands (Table 1). This corresponds to a decline in mean takeable density from 1.2 pepino m^{-2} in 1993 to 0.03 pepino m^{-2} in 2002 (Fig. 2). Survey densities were remarkably consistent with these crude CPUE-derived densities. In Canal Bolívar, pristine densities ranged from 0.8–6.2 pepino m^{-2} (mean 3.1 pepino m^{-2}) in the three surveys (Aguilar *et al.*1993, Merlen 1993, Richmond & Martínez 1993), declining to 0.10 pepino m^{-2} in 1998, and to 0.35 pepino m^{-2} after the 2000–2002 increase. The latter increase was because of the first substantial recorded influx of recruits (5–10 cm size), comprising 80–90% of the total numbers (M.V. Toral-Granda, unpublished data 2002). By 2003 mean adult density (>20 cm) in the western islands was only 0.04 pepino m^{-2} (Toral-Granda & Vega 2003).

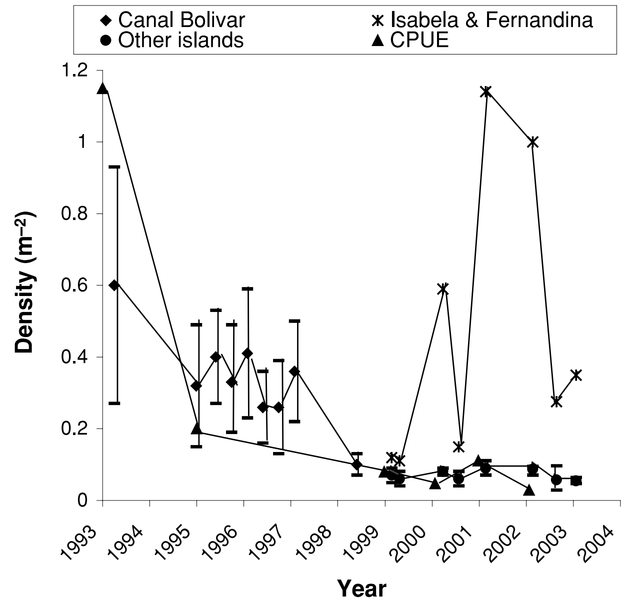

Figure 2 Trends in pepino abundance from January 1993–2003. Canal Bolívar 1993–1998 with added sites on Isabela and Fernandina for 1999–2003; all eastern islands combined; and CPUE-derived density data for the whole fishery for 1993, 1994 and 1999–2002. Data pairs in 1999, 2000 and 2002 are before and after fishing, respectively.

On the eastern islands mean survey densities slowly declined during 1999–2003, reaching an all time low of 0.055 pepino m^{-2}, with no evidence of significant recruitment (Fig. 2).

The high estimated annual catches of 20–30 million pepinos in 1992 and 1993 are consistent with data on the area of the fishery originally exploited and the survey data. The total length of coastline fished in 1992–1993, derived from diver surveys, was calculated to be $\sim$1130 km, excluding the inhospitable west coast of Fernandina (Fig. 1). Assuming a mean width of exploitable habitat of 30 m searched by divers and an annual capture of 25 million pepinos in 1992 and 1993, this gives a mean removal rate of 0.94 pepino m^{-2} yr^{-1}.

The fished areas have shown some spatial decline since 1992 (Fig. 1). In 1992 divers fished the coasts of all the islands except the subtropical northern ones (Fig. 1). Coasts without commercial quantities of pepinos were sandy bays on eastern Isabela and Española, and parts of the north coasts of Floreana, Santa Cruz and Santiago. By 1993 the east coast of Isabela and southern Santiago were practically fished out, and by 2003 all the eastern islands had low densities. In terms of coastline length there has been a range decline of ~30%. Size frequency catch data from 1999–2002 (Murillo *et al.* 2002*a*) show that fishers exploited the size range of accessible pepinos from 14–36 cm length, with the mean size declining from *c.* 24.5 cm in 1999 to *c.* 22.5 cm in 2002, when 56% were <20 cm and 74% were below the mean size of sexual maturity (*c.* 22 cm).

DISCUSSION

The declines in abundance of pepinos in the eastern islands suggest a failing fishery, not due to overt open access policies (Scott 1993), but because fishers, driven by high indebtedness and high expectations, maintained strong pressure to fish despite falling densities and against their own long-term interest. First, we review the evidence for overfishing, and then discuss how science-based criteria for management need to be firmly embedded in the decision-making process for a sustainable fishery.

Evidence for overfishing

Stichopus fuscus forms intense aggregates at a scale of metres, and, during surveys measuring spatial dispersion, the mean number of pepinos per occupied 10 m^2 segment of transect fell from five to two below a mean density of *c.* 0.1 pepino m^{-2} (Shepherd *et al.* 2003), suggesting a threshold mean density of *c.* 0.1 m^{-2} below which spawning aggregations were unlikely. Mean within-patch densities to achieve 50% fertilization success were estimated to be 1.2 pepino m^{-2} (R Babcock, personal communication 2001), from the model of Babcock & Keesing (1999) applied to data on this holothurian's reproductive output and egg size (Toral-Granda 1996). Hence, the mean adult densities of pepinos on the eastern islands have been so low since 1999 that the effect of low density on fertilization success (Allee effect) is probably sufficient to have caused widespread recruitment failure. This conclusion, however, is tentative, and we acknowledge that many species occur at lower densities (Uthicke 1996). In the western islands, only the strong recruitments of 2000–2002, possibly associated with the El Niño of 1997–1998 (Murillo *et al.* 2002*a*), maintained the fishery, albeit mainly on immature individuals. However, later intense fishing has largely fished out this cohort (Fig. 2). Recent reports (Espinoza *et al.* 2001; Toral-Granda & Vega 2003) reiterated the parlous state of the fishery and considered that only a complete closure could avoid collapse.

Although range contraction is inevitable when a virgin stock is exploited, the present virtual absence of pepinos around some islands (Fig. 1) is additional evidence of a stock in serious decline. Range contraction is an important component of fishery collapse though it is seldom reported or modelled (see MacCall 1990; Shepherd & Rodda 2001). MacCall (1990) proposed a basin model to explain the spatial pathology of fishery decline for sedentary meroplanktonic species, such as this pepino. According to this model, recruitment varies spatially due to hydrodynamic mechanisms determining larval dispersal, and spatial collapse occurs in those areas with weakest recruitment. In this fishery overfishing was initially driven by the steep increase in price from the equivalent of US$ 0.06 per pepino paid to fishers in 1992 (De Paco *et al.* 1993) to US$ 0.80–1.00 per pepino in 2000. Although in global terms the price was low, in local terms it was still high enough to maintain fishing pressure. Thus, the economic threshold density, below which it is not economic to fish, was still below the biological threshold density for fertilization success in 2002. This was a major force driving recruitment overfishing.

Management of the pepino fishery

Co-management of fisheries resources has emerged in the last two decades as a response to declining fish stocks, and/or ineffective management (Pinkerton 1989; Jentoft *et al.* 1998). Experiences with co-management vary between regions (Jentoft 1989; Sen & Raakjer-Nielsen 1996; Pitcher *et al.*1998*a*), and on the north-south axis (Bailey 1988; Hollup 2000) according to differences in history, development and culture. In developing countries pressures for development are high, and for conservation low, leading to a weak capacity for management (Bailey 1988). The majority of Latin American benthic resources are depleted and few are managed sustainably (Painter & Durham 1995; Castilla & Defeo 2001). The Galápagos are no exception. While their outstanding conservation values are recognized and international pressure is strong for sustainable management, the Galápagos still suffer from being in a poor developing country, subject to strong development pressure from impoverished fishers (Coello 1996).

In this fishery, two phases in management are in stark contrast. The anarchic initial phase was characterized by conflict, sabotage and social disruption. Interaction between management authorities and fishers was noted for the asymmetry of power, lack of cooperation and mutual distrust. In a sociological analysis, Coello (1996) considered that the influx of many poor immigrant Ecuadorian fishers without cultural roots to the Galápagos in the early 1990s explained the absence of community control or management (Hollup 2000).

Enforcement of the law by conventional surveillance was largely ineffective. Corruption and conniving officials facilitated an illegal fishery, and complaints were rare through fear of reprisal. Control by unscrupulous buyers (Carranza Barona & Andrade Echeverría 1996) kept the fishers impoverished, dependent and alienated, with little incentive to accept conservationist restraints, seemingly driven by foreign agendas (Christy 1995). From the start, fishers incurred large debts to buy boats and equipment, and in 1996 it was estimated that 37% of fishers' incomes were used to repay such debts (Anon. 1997). In this climate, civil disobedience and intimidatory tactics by marginalized stakeholders were effective weapons to achieve the desired ends, a view which has persisted, as shown by the public statement of a cooperative chief that 'even if there is no fishing season fishers will have to fish illegally to pay their debts' (*Le Monde* 31 March 2001). Thus, up to 1998, the troubled fishery possessed almost every negative feature considered by Charles (1992) to generate conflict, and reflected, in Charles' typology, a basic paradigm conflict between conservation objectives and those of fishers.

After 1998 the PMB and IMA became the main arenas for debate, political lobbying and establishing influence (Heylings & Bravo 2001). In this second phase, the achievements of co-management were notable and ongoing. We can summarize them as: (1) provision of a forum (PMB) for debate among stakeholders, and increased cooperation among them, (2) trials of individual quotas, (3) involvement of fishers in fishery surveys and reporting, (4) limited entry to the fishery, and (5) reduction in apparent corruption. Weaknesses in management were: (1) early failure to control the number of fishers, (2) weak enforcement capacity, (3) activity of lawless fishers in cooperatives, and (4) lack of rigorous stock assessments. The achievements of co-management became possible because they favoured the individual, long-term self-interest of fishers (Hart & Pitcher 1998). Alternatively, they suggest a social learning process in which the cooperatives enhanced their capacity for modern management (Dale 1989). However, the issues considered by the PMB still reflected the basic tension between conservation objectives based on a scientific analysis of fishery data and fishers' short-term self-interests. As emphasized by Freire & García-Allut (2000), when the knowledge base is weak, politics rather than science drives management. Hence, pressures for a fishery, assisted by infrequent eruptions of violence from fishers, have prevailed over precaution, and the fishery has continued to decline.

Charles (2001) saw sustainability of a fishery as the simultaneous achievement of ecological, socioeconomic, community and institutional objectives. The overall sustainability of a fishery could be assessed by the use of indicators, suitably weighted in favour of the ecological component to avoid the anomaly of a high index value for a collapsing stock. Clearly, conservation-based management is critical and a science-based assessment process must be firmly embedded in decision-making to ensure that resource conservation remains the overriding objective. Yet the conservation objective has too often been submerged, while other objectives have been vigorously and successfully pursued. At least until 2000, two factors, the high debt burden of fishers and the continuing illegal fishery, underlay the strong pressure for a continuing fishery despite declining stocks. But, even in 2001–2002, with better control of illegal fishing, pressure to continue fishing persisted despite lower prices. How can a precautionary approach, required under the Special Law of the Galápagos, become embedded in decision-making to ensure primacy of the conservation paradigm?

Precaution first

Because of the vulnerability of sea-cucumber fisheries to overfishing, management guidance must be sought from the few well-managed pepino fisheries, such as those in Alaska. There, TACs are fixed at 5–10% of the exploitable biomass, regional quotas are fixed in a rotational manner (Bradbury & Conand 1991, Woodby & Larson 1997) and mean overall abundance kept constant. The Galápagos, with a similar coastal topography to Alaska, could be similarly managed. In addition, simple fishery indicators derived from broad-scale surveys (Shepherd *et al.* 2003; Toral-Granda & Vega 2003), with some refinements, could be used to continuously evaluate the state of the stocks. Useful indicators are total biomass, recruitment strength, and aggregation sizes and frequency (Shepherd & Rodda 2001), in addition to traditional catch and effort data and spatial information.

The precautionary approach (Garcia 1996, reviewed by Foster *et al.* 2000) could be reinforced by application of the following principles (Charles 2001).

(1) Assume a positive spawner-recruit relation and fix a conservative threshold spawning density as a limit reference point (for example 0.4 pepino m^{-2}). Other fishery indicators could be used in a thermostat approach (Caddy 1998) to assess the status of stocks.
(2) Assume that each island stock is self-recruiting (i.e. manage each island stock as an independent unit; see Freire & García-Allut 2000) and apply the 'management of the weakest stock' principle (Morrell 1989).
(3) Impose fishing closures until threshold densities are exceeded, enforce size limits and re-establish quotas based on weight rather than numbers.

The assumptions implicit in the above principles effectively achieve a reversal of the burden of proof, as advocated by FAO (1995) and Dayton (1998), until further research reduces uncertainty about the level of risk.

How is success in management to be judged, given the multi-faceted goals of conservation, social equity and efficient wealth generation? Most authors have emphasized sustainability as the prime measure of success (Bailey 1988, Pitcher *et al.* 1998*a*). Others have variously argued that simultaneous achievement of all goals is a prerequisite of success (Charles 1992, 2001, Sen & Raakjer-Nielsen 1996), that social equity would lead to sustainability in the other dimensions (Worster 1993), or that the extent of compliance (Hollup 2000), or the acceptance of responsibility by fishers to rebuild collapsed stocks (Harris 1998), was the most important. All aspects are important, and, in our view, success can best be measured by a broadly based 'sustainability assessment' (Charles 1992, 2001), possibly using multi-criteria decision analysis (Pitcher *et al.* 1998*b*). Co-management may continue to be a long and painful learning process in the Galápagos, but it may also become a creative one, as stakeholders accept responsibility for rebuilding the fishery.

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References

Aguilar, F., Chalén, X., Castro, F., Sonnenholzner, J. & Herrera, M. (1993) Evaluación del recurso pepino de mar, Holothuroidea, al este de la Isla de Fernandina de la Provincia de Galápagos. Unpublished report, Instituto Nacional Pesquera, Guayaquil: 22 pp.

Aguilar-Ibarra, A. & Ramirez-Soberón, G. (2002) Economic reasons, ecological actions and social consequences in the Mexican sea cucumber fishery. *Beche-de-Mer Information Bulletin* **17**: 33–35.

Anon. (1997) El cuidado de los ecosistemas. In: *Informe Galápagos 1996–1997. Volume I*, pp. 19–32. Quito, Ecuador: Fundación Natura y el Fondo Mundial para la Naturaleza (WWF).

Anon. (2000) Galápagos Station survives latest attack by fishers. *Science* **290**: 259–261.

Babcock, R. & Keesing, J. (1999) Fertilization biology of the abalone *Haliotis laevigata*: laboratory and field studies. *Canadian Journal Fisheries Aquatic Science* **56**: 1668–1778.

Bailey, C. (1988) Optimal development of third world fisheries. In: *North South Perspectives on Marine Policy*, ed. M. Morris, pp. 105–118. Boulder, CO, USA: Westview Press.

Bermeo-Sarmiento, J.D. (1995) Informe sobre la evaluación del recurso pepinos de mar *Isostichopus fuscus* (Ludwig, 1875) en áreas interiores del Canal Bolívar en las Islas Galápagos. Unpublished report, Instituto Nacional de Pesca: 11 pp.

Bradbury, A. & Conand, C. (1991) The dive fishery for sea-cucumbers in Washington State. *Beche-de-Mer Information Bulletin* **3**: 2–3.

Caddy, J. (1998) A short review of precautionary reference points and some proposals for their use in data-poor situations. *FAO Fisheries Technical Paper 379*. Rome, Italy: FAO: 29 pp.

Carranza Barona, C.C. & Andrade Echeverría, M. (1996) Retrospectiva de la pesca del pepino de mar a nivel continental. Unpublished report, Comisión Permanente para las Islas Galápagos, Fundación Charles Darwin and ORSTOM, Quito, Ecuador: 53 pp.

Castilla, J.C. & Defeo, O. (2001) Latin American benthic shellfisheries: emphasis on co-management and experimental practices. *Reviews in Fish Biology and Fisheries* **11**: 1–30.

Castro, L.R.S. (1993) Pesquerías de pepino del Pacifico (*Parastichopus parvinenis*) y *Parastichopus californicus* y *Isostichopus fuscus* del Golfo de California. Unpublished report, Instituto Nacional de Pesca, Ensenada: 114 pp.

Charles, A.T. (1992) Fishery conflicts: a unified framework. *Marine Policy* **16**: 379–393.

Charles, A.T. (2001) *Sustainable Fishery Systems*. Oxford, UK: Blackwell Science: 370 pp.

Christy, F.T. (1995) The development and management of marine fisheries in Latin America and the Caribbean: issues and options for the Inter-American Development Bank. Unpublished report, Inter-American Development Bank, Washington, DC, USA: 80 pp.

Coello, S. (1996) Situación y opciones de manejo de las pesquerías de Galápagos: perspectivas para la implantación del plan de manejo de la reserva de recursos marinos. Unpublished report, Estación Charles Darwin: 133 pp.

Conand, C. (1990) The fishery resources of Pacific Island countries. Part 2. Holothurians. *FAO Fisheries Technical Paper 272.2*. Rome, Italy: FAO: 143 pp.

Conand, C. (1998) Are holothurian fisheries sustainable? In: *8th International Coral Reef Symposium, Panama Volume 2*, ed. H. Lessios & I.G. MacIntyre pp. 2021–6. Panama: Smithsonian Tropical Research Institute.

Conand, C. (2001) Overview of sea cucumber fisheries over the last decade – what possibilities for a durable management? In: *Echinoderm 2000*, ed. M. Barker, pp. 339–344. Lisse, the Netherlands: Balkema.

Dale, N. (1989) Getting to co-management: social learning in the redesign of fisheries management. In *Co-operative Management of Local Fisheries*, ed. E. Pinkerton, pp.49–72. Vancouver, Canada: University British Columbia Press.

Dayton, P.K. (1998) Reversal of the burden of proof in fisheries management. *Science* **279**: 979–980.

De Miras, C., Andrade, M. & Carranza, C. (1996) Evaluación socio-económica de la pesca experimental de pepino de mar Galápagos. Unpublished report, FCD and ORSTOM: 45 pp.

De Paco, C., Hurtado, M., MacFarland, C., Martínez, P., Reck, G. & Richmond, R. (1993) Evaluación de la pesquería de pepinos de mar en las Islas Galápagos, Ecuador. Unpublished report, Unión mundiale para la Naturaleza, Quito, Ecuador: 25 pp.

Espinoza, E., Murillo, J.C., Toral-Granda, M.V., Bustamante, R.H., Nicolaides, F., Edgar, G.J., Moreno, J., Chasiluisa, C., Yépez, M., Barreno, J.C., Shepherd, S.A., Viscaino, J., Villalta, M., An drade, R., Born, A., Figueroa, L., Guerrero, P. & Piu, M. (2001) Fisheries in the Galapagos: a summary of the main indicators for 2000. In: *Galapagos Report. 2000–2001*. Quito, Ecuador: Fundación Natura y el Fondo Mundial para la Naturaleza (WWF).

Fajardo-León, M.C., Michel, E.G., Singli-Cavamillas, J., Veléz, B.J.A. & Massó, J.A. (1995) Estructura poblacional y ciclo reproductor del pepino de mar (*Isostichopus fuscus*) en Santa Rosalia, BCS, México. *Ciencia Pesquera* **11**: 45–56.

FAO (1995) Precautionary approach to fisheries. Part 1. Guidelines on the precautionary approach to capture fisheries and species introductions. *FAO Fisheries Technical Papers, 350/1*. Rome, Italy: FAO.

Foster, K.R., Vecchia, P. & Rapacholi, M.H. (2000) Science and the precautionary principle. *Science* **288**: 979–980.

Freire, J. & García-Allut, A. (2000) Socioeconomic and biological causes of management failures in European artisanal fisheries: the case of Galicia (NW Spain). *Marine Policy* **24**: 375–384.

Garcia, S.M. (1996) Precautionary approach to capture fisheries and species introductions. *FAO Fisheries Technical Papers, 350/2*. Rome, Italy: FAO: 54 pp.

Harris, C.K. (1998) Social regime formation and community participation in fisheries management. In: *Reinventing Fisheries Management*, ed. T.J. Pitcher, P.J.B. Hart & D. Pauly, pp. 261–276. London, UK: Kluwer.

Hart, P.J.B. & Pitcher, T.J. (1998) Conflict, consent and co-operation: an evolutionary perspective on individual human behaviour in fisheries management. In: *Reinventing Fisheries Management*, ed. T.J. Pitcher, P.J.B. Hart & D. Pauly, pp. 215–226. London, UK: Kluwer.

Herrero-Pérezrul, M.D., Reyes Bonilla, H., Garcia-Dominguez, F. & Cintoa Buenrostro, C.E. (1999) Reproduction and growth of *Isostichopus fuscus* in the southern Gulf of California, Mexico. *Marine Biology* **135**: 521–532.

Heylings, P. & Bravo, M. (2001) Survival of the fittest? Challenges facing the co-management model for the Galápagos marine reserve. CM News. *Newsletter of the IUCN* **5**: 10–13.

Heylings, P., Cruz, F., Bustamante, R., Cruz, D., Escarabay, M., Granja, A., Martínez, W., Hernández, J., Jaramilla, C., Martínez, P., Piú, M., Proaña, P., Valverde, F. & Zapata, C. (1998) La reserva marina de Galápagos. In: *Informe Galápagos 1997–1998*, pp. 14–19. Quito, Ecuador: Fundacíon Natura y el Fondo Mundial para la Naturaleza (WWF).

Hollup, O. (2000) Structural and sociological constraints for user-group participation in fisheries management in Mauritius. *Marine Policy* **24**: 407–421.

Jácome, R. & Ospina, P. (1999) La reserva marina de Galápagos: un primer año dificil. In: *Informe Galápagos 1998–1999*, pp. 35–42. Quito, Ecuador: Fundación Natura y el Fondo Mundial para la Naturaleza (WWF).

James, M. & Miller, M. (1995) The pepinero wars: the challenges of conservation in the Galapagos. Unpublished report, California Academy of Sciences, San Francisco, USA: 7 pp.

Jenkins, M. & Mulliken, T.A. (1999) Evolution of exploitation in the Galapagos Islands: Ecuador's sea cucumber trade. *Traffic Bulletin* **17**: 107–118.

Jentoft, S. (1989) Fisheries co-management: delegating government responsibility to fishermen's organizations. *Marine Policy* **13**: 137–154.

Jentoft, S., McCay, B.M. & Wilson, D.C. (1998) Social theory and fisheries co-management. *Marine Policy* **22**: 423–436.

MacCall, A.D. (1990) *Dynamic Geography of Marine Fish Populations*. Seattle, USA: Washington Sea Grant Program.

MacFarland, C. & Cifuentes, M. (1996) Case study: Ecuador. In: *Human Population, Biodiversity and Protected Areas: Science and Policy Issues. Report of a Workshop April 21–25, 1995. Washington, DC*, ed. V. Dompka, pp. 135–188. Washington, DC, USA: American Association for the Advancement of Science.

Merlen, G. (1993) Censo de pepino de mar, *Isostichopus fuscus*, durante un viaje a la parte norte del Archipiélago de la lancha Ratty. Unpublished report, Estación Cientifica Charles Darwin: 5 pp.

Morrell, M. (1989) The struggle to integrate traditional Indian systems and state management in the salmon fisheries of the Skeena River, British Columbia. In: *Co-operative Management of Local Fisheries: New Directions or Improved Management and Community Development*, ed. E Pinkerton, pp. 231–248. Vancouver, Canada: University of British Columbia Press.

Murillo, J.C., Andrade, R., Vizcaíno, J., Hearn, A., Chasiluisa, C., Molina, L. & Moreno, J. (2002*a*) Monitoreo de la pesquería del pepino de mar (*Stichopus fuscus*) en las islas Galápagos, 2002. Unpublished report, Fundación Charles Darwin, Puerto Ayora, Galápagos: 46 pp.

Murillo, J.C., Vizcaino, J., Nicolaides, F., Moreno, J., Espinoza, E., Chasiluisa, C., Andrade, R., Born, A., Villalta, M., Yépez, M. & Molina, M. (2002*b*) Informe técnico final de la pesquería del pepino de mar (*Stichopus fuscus*) en las islas Galápagos 2001: análisis comparativo con las pesquerías de 1999 y 2000. Unpublished report, Estación Cientifica de Charles Darwin, Puerto Ayora, Galápagos: 27 pp.

Okey, T.A., Banks, S., Born, A.F., Bustamante, R.H., Calvopiña, M., Edgar, G.J., Espinoza, E., Fariña, J.M., Garske, L.E., Reck, G.K., Salazar, S., Shepherd, S.A., Toral-Granda, V. & Wallem, P. (2003*a*) A trophic model of a Galápagos subtidal rocky reef for evaluating fisheries and conservation strategies. *Ecological Modelling* (in press).

Okey, T.A., Shepherd, S.A. & Martinez, P. (2003*b*) A new record of anemone barrens in the Galápagos. *Noticias de Galápagos* **62**: 17–20.

Painter, M. & Durham, W.H. (1995) *The Social Causes of Environmental Destruction in Latin America*. Ann Arbor, USA: University of Michigan Press: 274 pp.

Pinkerton, E., ed. (1989) *Co-operative Management of Local Fisheries: New Directions or Improved Management and Community Development*. Vancouver, Canada: University of British Columbia Press: 299 pp.

Pitcher, T.J., Hart, P.J.B. & Pauly, D., eds. (1998*a*) *Reinventing Fisheries Management*. London, UK: Kluwer: 435 pp.

Pitcher, T.J., Bundy, A., Preikshot, D., Hutton, T. & Pauly, D. (1998*b*) Measuring the unmeasurable: a multivariate and interdisciplinary method for rapid appraisal of the health of fisheries. In: *Reinventing Fisheries Management*, ed. T.J. Pitcher, P.J.B. Hart & D. Pauly, pp. 31–54. London, UK: Kluwer.

Powell, J.R. & Gibbs, J.P. (1995) A report from Galapagos. *Trends in Ecology and Evolution* **10**(9): 351–354.

Richmond, R.H. & Martínez, P.C. (1993) Sea cucumber fisheries in the Galápagos Islands. Biological aspects, impacts and concerns. World Conservation Union (IUCN) Technical Report: 18 pp.

Scott, A. (1993) Obstacles to fishery self-government. *Marine Resource Economics* **8**: 187–199.

Sen, S. & Raakjer-Nielsen, J. (1996) Fisheries co-management: a comparative analysis. *Marine Policy* **20**: 405–418.

Shepherd, S.A. (1985) Power and efficiency of a research diver, with description of a rapid underwater measuring gauge: their use in measuring recruitment and density of an abalone population. In: *Diving for Science*, ed. C.T. Mitchell, pp. 263–272. La Jolla, USA: American Academy of Underwater Science.

Shepherd, S.A. & Partington, D. (1995) Studies on southern Australian abalone. XVI. Recruitment, habitat and stock relations. *Marine and Freshwater Research* **46**: 669–680.

Shepherd, S.A. & Rodda, K.R. (2001). Sustainability demands vigilance: evidence for serial decline of the greenlip abalone fishery and a review of management. *Journal of Shellfish Research* **20**: 829–841.

Shepherd, S.A., Toral-Granda, V. & Edgar, G.J. (2003) Estimating the abundance of clustered or cryptic marine macro-invertebrates with particular reference to pepinos. *Noticias de Galapagos* **62**: 36–39.

Sonnenholzner, J. (1997) A brief survey of the commercial sea cucumber *Isostichopus fuscus* (Ludwig 1875) of the Galápagos Islands, Ecuador. Unpublished report, Instituto Nacional de Pesca, Guayaquil: 11 pp.

Stone, R. (1995) Fishermen threaten Galápagos. *Beche-de-Mer Information Bulletin* **7**: 22.

Toral-Granda, M.V. (1996) Biología reproductiva del pepino de mar, *Isostichopus fuscus*, en la Isla Caamaño, Santa Cruz, Galápagos. Tesis de Licenciatura, Universidad del Azuay, Cuenca, Ecuador.

Toral-Granda, M.V. & Oviedo, M. (2002) Análisis de la densidad poblacional y estructura de tallas del pepino de mar, *Stichopus fuscus*, post-pesquería 2002. Unpublished report, Fundación Charles Darwin, Puerto Ayora, Galápagos: 14 pp.

Toral-Granda, M.V. & Vega, S. (2003) Análisis de la densidad poblacional y estructura de tallas del pepino de mar, *Stichopus fuscus*, pre-pesquería 2003. Unpublished report, Fundación Charles Darwin, Puerto Ayora, Galápagos: 25 pp.

Toral-Granda, M.V., Bustamante, R.H., Murillo, J.C., Espinoza, E., Nicolaides, F.,Martínez, P.C., Cedeno, I., Ruttemberg, B., Moreno, J., Chassiluisa, C., Torres, S., Yépez, M., Barreno, J.C., Andrade, R., Figueroa, L. & Piú, M. (2000) La pesca artesanal en Galapagos 1999–2000. In: *Informe Galápagos 1999–2000*, pp.53–59. Quito, Ecuador: Fundación Natura y el Fondo Mundial para la Naturaleza (WWF).

Uthicke, S. (1996) Beche-de-mer: a literature review on holothurian fishery and ecology. Unpublished report, Australian Institute of Marine Science, Townsville, Australia: 44 pp.

Woodby, D.A. & Larson, R.C. (1997) Conservative fishery management: simplistic methods for avoiding undesirable ecosystem effects in a developing sea cucumber fishery. Regional Information Report No. 1J97–17. Alaska Department of Fish and Game, Juneau, Alaska, USA: 16 pp.

Worster, D. (1993) The shaky ground of sustainability. In: *Global Ecology: a New Arena of Political Conflicts*, ed. W. Sachs, pp.132–145. London, UK: Zed Books.