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Remembering the Gulf: changes to the marine communities of the Sea of Cortez since the Steinbeck and Ricketts expedition of 1940

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One of the most storied biological expeditions is the 1940 trip to the Sea of Cortez (Gulf of California) by author John Steinbeck and his close friend Edward F Ricketts, a professional biologist. Steinbeck and Ricketts visited intertidal sites around the Gulf and made extensive collections, taking notes on fauna and natural history. In 2004, we retraced the Steinbeck and Ricketts' voyage, visiting the same intertidal sites during the same season and using the authors' extensive natural history notes as a baseline for comparison. Although we found many of the same species as they did, populations were, in many cases, not as geographically widespread, and individuals were fewer in number and smaller in size. In particular, echinoderms and large gastropods showed declines, as did most large pelagic vertebrate species. One of the most remarkable changes in the pelagic community is the present abundance of jumbo squid, *Dosidicus gigas*, a species not reported in 1940. Although Steinbeck and Ricketts, by their own admission, "could not yet relate the microcosm of the Gulf with the macrocosm of the sea", the changes we observed with historical perspective are in agreement with documented changes in ocean and coastal ecosystems around the world.

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Non-traditional datasets are increasingly used to document environmental degradation related to fisheries and global climate change (Sagarin and Micheli 2001; Saenz-Arroyo *et al.* 2005a). In 1940, author John Steinbeck and biologist Edward F Ricketts conducted an expedition to the Gulf of California, or Sea of Cortez, on the *Western Flyer*, a 76-foot sardine fishing vessel (Figure 1), out of Monterey, CA. Steinbeck and Ricketts visited 20 intertidal sites (15 rocky, four sandy, one coral; Figure 2; WebTable 1) and published their results in *Sea of Cortez: a leisurely journal of travel and research* (Steinbeck and Ricketts 1941), which includes both their ecological observations and a catalog of more than 550 species they encountered. Although Steinbeck and Ricketts' record lacks quantitative rigor, great value can be found in the eloquent narrative components of the *Sea of Cortez*, which reflect a naturalist's mindset (Saenz-Arroyo *et al.* 2006). Their account has helped us to understand ecological disruptions that had already affected the Gulf by 1940, and it established a baseline for understanding the accelerating human impacts that have occurred in the Gulf since their voyage. Decimation of the pearl-oyster fishery and large reductions in cetacean populations had already occurred (Saenz-Arroyo *et al.* 2006), but large-scale commercial fishing operations in the Gulf were just beginning, and major tourism development was nonexistent. The effects of global warming, which became evident in the last quarter of the 20th century (Chavez *et al.* 2003), were not yet apparent.

In 2004, a group of marine scientists, journalists, and writers attempted to assess changes to the Sea of Cortez by retracing the 1940 expedition, visiting the same intertidal sites at the same time of year as part of the Sea of Cortez Expedition and Education Project (SOCEEP; www.seaofcortez.org) from April 26–May 25, 2004, aboard the 73-foot wooden fishing vessel *Gus D* (Figure 1). We relocated Steinbeck and Ricketts's sampling sites from descriptions given in the *Sea of Cortez* and in previously

In a nutshell:

- In 2004, a group of marine scientists, journalists, and writers repeated the famous 1940 expedition of marine biologist Edward F Ricketts and author John Steinbeck to document the intertidal ecology of the Sea of Cortez, Mexico
- Using both the scientific and literary records left by Steinbeck and Ricketts, we were able to document dramatic changes to the intertidal sites and fauna, as well as the pelagic environment
- Diversity and abundance of large gastropod snails and echinoderms have declined at many intertidal sites and large pelagic species of tuna, sharks, billfish, and turtles also appear to be much less abundant
- However, vermetid gastropods (tube snails) appear to be more abundant and widespread, and jumbo squid, not documented at all by Steinbeck and Ricketts, are currently very common in the Sea of Cortez and constitute a major fishery
- Coastal development and pollution, fishing, disease, and climate change may all be drivers of the observed changes, but further studies are necessary

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Figure 1. *Vessels used for the Sea of Cortez expeditions. (a) The* Western Flyer, *chartered by Steinbeck and Ricketts in 1940. (b) The* Gus D, *chartered for the Sea of Cortez Expedition and Education Project in 2004.*

unpublished field notes made by Ricketts (Rodger 2006; Figure 2). At each intertidal station, between two and ten people sampled the fauna, carrying out intensive intertidal searches and taking photographs. At nearly all rocky intertidal sites, we sampled under boulders for organisms found on the underside and in the substratum (WebTable 1). In addition to these methods, which were also used by Steinbeck and Ricketts, we laid out two to six transect tapes from the high to low intertidal zone and recorded numbers or percent cover of intertidal organisms in 0.25-m^2 quadrats, positioned at 1-m intervals.

We limit direct comparisons of faunal diversity to 12 intertidal sites where we were reasonably confident that we had located and sampled as intensively as did Steinbeck and Ricketts (this excludes sites such as Cabo Pulmo, where Steinbeck and Ricketts sampled a coral reef destructively; WebTable 2). Other comparisons – for example, concerning the paucity of large gastropods – consider the overall picture of the Sea of Cortez, based on all information available from the two expeditions. Because of potential biases arising from differences in observer effort and level of taxonomic resolution, we limit our comments on changes in diversity to within-group comparisons of conspicuous species with little taxonomic ambiguity. Examination of Steinbeck and Ricketts' historical baseline leaves little doubt that major ecological changes have occurred in the Sea of Cortez over the past 65 years. Causal mechanisms for these changes can only be inferred from these observational data and we do so here on a speculative basis – with reference to similar phenomena seen in other Gulf or western Pacific studies – for the purpose of highlighting focal areas for future research.

Site differences

Cabo San Lucas provides a good example of the dramatic changes that have taken place at intertidal sites in the Gulf (Figure 3). Whereas Steinbeck and Ricketts saw not a single light after dark (Steinbeck and Ricketts 1941), the same area is now a resort town, bustling with well-illuminated human activity. Where Steinbeck and Ricketts described tide pools "ferocious with life" (Steinbeck and Ricketts 1941), we found that even the common and conspicuous species they noted were absent. Puerto Escondido, which Steinbeck and Ricketts describe as "a textbook exhibit for ecologists" (Steinbeck and Ricketts 1941), showed relatively low diversity. Both these sites have been physically altered by tourism development; as late as the 1970s, a journalist lamented seeing a single yacht in now densely anchored Puerto Escondido (Johnson 1972). These physical alterations are likely to have had secondary ecological effects on the intertidal zone, through changes in water and sand movement (due to coastal structures such as marinas and breakwaters), increases in nutrient enrichment and other pollutants, and easier access to intertidal resources. It is possible, for example, that changes in sand availability benefited the sabellariid polychaete worms (which build sand tubes) we observed at Cabo San Lucas, but negatively affected the many rocky intertidal species observed by Steinbeck and Ricketts that we did not find.

Declines in diversity and abundance of several species were also evident at relatively undeveloped sites, such as Punta Lobos on Isla Espiritu Santo, but the most remote sites with no (or extremely few) access roads and only minimal local human habitation (Punta Marcial, Punta Trinidad, and San Francisquito) appear to have retained relatively high species diversity, even among echinoderms, which have declined throughout the Gulf (see below). The most striking example of a site that appears to have greater levels of biodiversity now than in 1940 is Isolote Cayo, a rocky islet near Isla San Jose, which Steinbeck and Ricketts described as being "burned" (Steinbeck and Ricketts 1941) – a quality they ascribed to places that lacked vigor and diversity. At this site, we observed 68 species, while Steinbeck and Ricketts observed only 23.

Intertidal species changes

Differences in populations of intertidal and shallow subtidal organisms between 1940 and 2004 were apparent throughout our investigation. Echinoderms, large gastropods, and vermetid gastropods (tube snails) provide particularly striking examples of change in the Sea of Cortez. These groups are valuable for comparison because they are conspicuous and/or easily identifiable, and often play key roles in intertidal ecology.

In both species diversity and population size, echinoderms appear to have declined dramatically since 1940 (Table 1). Reductions in the numbers of asteroids (starfish), echinoids (urchins), and ophiuroids (brittle stars) are revealed by the results of species counts at most sites (Figure 4; WebTable 3), with asteroid species numbers declining across all sites (paired *t* test, $t_{11} = -6.03$, $P < 0.001$). A more dramatic shift can be seen in abundances, inferred from Steinbeck and Ricketts' repeated references to "many, many" sea stars in "great numbers" and "knots" of brittle stars. In contrast, we did not observe great numbers of individuals of either group (Table 1). Likewise, the low abundance recorded of the sea cucumber, *Holothuria lubrica*, could not be reconciled to the "literally millions" of this organism noted by Steinbeck and Ricketts. Other holothurian species could not be compared confidently, due to the difficulty of identifying and preserving specimens from the field.

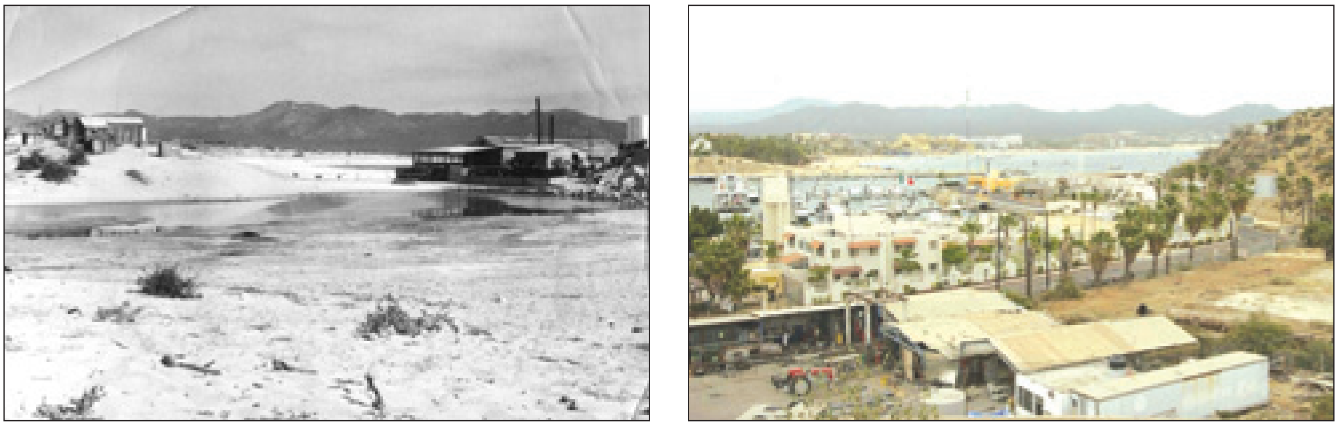
Loss of echinoderms may be due to a combination of episodic diseases and climate warming. The starfish *Heliaster kubiniji* was very abundant during the 1940 expedition and until 1978, when a disease outbreak greatly reduced its numbers throughout the Gulf (Dungan *et al.* 1982). *H kubiniji* has since recovered to some extent, and remains the most prevalent intertidal sea star, but its abundance is clearly reduced from earlier levels inferred from Steinbeck and Ricketts' observations. Echinoderm die-offs appear to be linked to anomalous warm-water periods that may affect asteroids, ophiuroids, and holothurians simultaneously (Dungan *et al.* 1982). Several strong El Niño events (1982–83 and 1997–98) in the context of a positive (warm) Pacific Decadal Oscillation (PDO) cycle (Chavez *et al.* 2003) may have hindered recovery of *H kubiniji* and echinoderm species first affected in the late 1970s. In the southern Channel Islands off the coast of California, for example, echinoderms have not fully recovered from catastrophic disease-related mortality in the late 1970s, and signs of disease re-emerge during warm seasons and years (J Engle pers comm). Warming may also disproportionately affect species that favor under-rock habitats in the intertidal zone, where even small increases in average ambient temperature may be lethal (Stillman and Somero 1996). It is noteworthy that several under-rock dwelling taxa (eg ophiuroids, holothuroids, and peanut worms) showed the greatest apparent declines in numbers.

Large snails were almost completely absent from all the sites that we investigated (Table 1; WebTable 4). Steinbeck and Ricketts encountered "huge" conchs and whelks at several sites (Steinbeck and Ricketts 1941) and great numbers of large *Turbo* snails. We found small living specimens of conchs and *Turbo* at only three and four sites, respectively, and only dead whelk (*Strombus galeatus*) shells at Isolote Cayo (presumably from a subtidal fishery). We also found few live murexes (eg *Chicoreus erythrostomus*, *Muricanthus nigritus*, *Hexaplex princeps*) at any of our sites, and none at any of the sites sampled by both our expedition and that of Steinbeck and Ricketts' (WebTable 4). By contrast,

Figure 2. Map of Baja California showing collection sites. Black circles indicate sites sampled by Steinbeck and Ricketts and relocated successfully by the Sea of Cortez Expedition and Education Project (SOCEEP). Complete data on sampling times and locations is given in WebTable 1. Gray circles indicate Steinbeck and Ricketts' sites that were visited by SOCEEP, but that were not relocated with certainty, or sites where similar sampling effort was not possible. Letters in circles refer to sites listed in WebTable 2.

Steinbeck and Ricketts found murexes at five of the 12 commonly sampled sites and at three other sites. While they reported pink murex (*Chicoreus erythrostomus*) to be "the commonest large snail in the Gulf", the greatest number of pink murex shells we observed occurred in waste piles from a gill-net fishery for subtidal murexes in San Carlos, Sonora.

Our findings of a dramatic decline in large gastropods in the Sea of Cortez since the mid-20th century are supported by the findings of other, earlier expeditions. In 1936, William Beebe found a beach just north of Bahia Concepcion to be "a conchologist's paradise", with shells "of amazing size and a host of species" (Beebe 1938). Amateur shell collecting books from the 1960s encouraged collectors to take live murex specimens for their shells and noted sites in the Sea of Cortez where "the entire Bay is alive with shells" of pink murex (Violette 1964). Older fishermen in the Gulf are more likely to



Courtesy of L Lewis

Courtesy of L Cicero, Stanford University News Service

Figure 3. *Cabo San Lucas in (a) 1947 and (b) 2004. Note armoring of inlet on left center of the 2004 photo and coastal development throughout, including hotels, marina, gas station, and paved roads.*

believe that populations of exploited snail species have been depleted than are younger fishermen (Saenz-Arroyo *et al.* 2005b), indicative of a "shifting baseline" phenomenon. In the upper Gulf, large murexes appear to have declined sharply in the 1990s, when fisheries targeted peak reproductive assemblages, although some recovery may have occurred in recent years due to better management practices (R Cudney Bueno pers comm).

The loss of large gastropod predators may have favored smaller snails due to release from predation, competition, or both. We found smaller predatory muricids to be more diverse, common, and widely distributed than did Steinbeck and Ricketts. We commonly encountered the smallest of these species, *Morula ferrunginosa*, at ten of our 12 sites, whereas Steinbeck and Ricketts report them from only four sites, and describe the species as abundant at only two sites (Figure 5; WebTable 4).

Sessile vermetid gastropods, which were given scant attention by Steinbeck and Ricketts, were consistently found in a conspicuous zonation band at most sites, mirroring Myra Keen's observations from the late 1950s (Keen 1960). It is possible that the largely Panamic (ie of a biogeographic region with its northern boundary in the Sea of Cortez) group of vermetid gastropods now in the Sea of Cortez may, since Steinbeck and Ricketts' expedition, have shifted their ranges northward or increased in abundance due to long-term warming. This pattern was also observed in the vermetid *Serpulorbis squamigerus*, near its northern range limit in central California, during a period of climatic warming in the 20th century (Sagarin *et al.* 1999). Alternatively, the relatively vulnerable vermetids may have increased in number following losses of large predatory snails. Given vermetids' dominance in most intertidal sites and their ability to alter habitat structure with their hard, convoluted shell reefs, Keen was prescient in stating that "they may prove to be much more significant than we have realized" (Keen 1960).

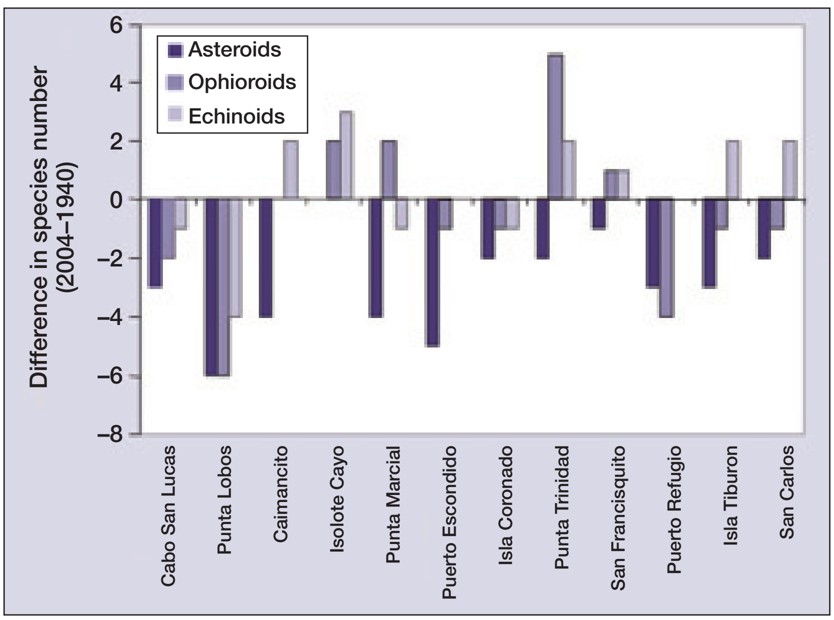


Figure 4. *Number of echinoderm species observed at 12 sites by Steinbeck and Ricketts' 1940 expedition and the Sea of Cortez Expedition and Education Project 2004 expedition.*

Pelagic changes

Although we traveled at the same time of year for about the same amount of time as Steinbeck and Ricketts, we witnessed a greatly changed pelagic community in the Gulf. Our assessment was conducted using visual observations from the deck of the boat and sampling with trolling lines, which, as in Steinbeck and Ricketts' expedition, remained deployed for most of the time that we were at sea. Steinbeck and Ricketts wrote, "we could see the splashing of great schools of tuna in the distance, where they beat the water to spray in their millions" (Steinbeck and Ricketts 1941), and there are repeated observations in the *Sea of Cortez* of enormous schools of tuna (presumably yellowfin and skipjack) and many "swordfish" (probably referring to several species of billfish), as well as observations of turtles and large

Table 1. A comparison of observed marine species from *The Sea of Cortez* (Steinbeck and Ricketts 1941) and from a 2004 expedition to the same sites

Site	*Observed in 1940*	*Observed in 2004*
Cabo San Lucas	• "The exposed rocks…were ferocious with life" • "A gorgeous fauna of bryozoa, brachiopods, polyclad worms, flat crabs, large *Cucumaria*-type of holothurian, some anemones, many sponges of three types… many snails, including cones and murex, two or three species of limpets, a nudibranch or shell-less tectibranch, hydroids, a few annelid worms, a red pentagonal starfish"	• One anemone species • The snail *Stamonita biseralis* • Two limpet species • Littorines • Barnacle *Tetraclita confinis* • Large masses of sabellariid polychaete worm tubes, not observed in 1940
Punta Lobos	• Six asteroids (sea stars) • Five urchins • Five to seven ophiuroids (brittle stars) • Five holothurians (sea cucumbers) • Ten crabs • Four shrimps • Several nudibranchs and tectibranchs (sea slugs) • A "good number" of sipunculids (peanut worms)	• One asteroid • One urchin • Two ophiuroids • Two holothurians • Four crabs • No shrimps • Two nudibranchs • Occasional sipunculids
Puerto Escondido	• "A textbook exhibit for ecologists" • Many anemones (*Cerianthus* sp) • Synaptids (*Euapta godeffroyi*) • Ruffled clams (*Carditamera affins*) • Stinging worms (*Eurythoe*) • Particularly high diversity and abundance of echinoderms • "We dropped the fishing lines and immediately hooked several hammer-head sharks and a large red snapper"	• Few of these forms, and none in great numbers • We dropped the fishing lines and immediately hooked ten small (< 35 cm) spotted bay bass (*Paralabrax maculatofasciatus*), four small red snappers (*Lutjanus peru*), and a Pacific porgy (*Calamus brachysomus*)
Isolote Cayo	• "Even in the distance it had a quality which we call 'burned'. One knows there will be few animals on a 'burned' coast" • "We found, as we knew we would, a sparse and unhappy fauna"	• One of the more diverse sites visited
Taxon	*Observed in 1940*	*Observed in 2004*
Gastropods (snails)	• A "great many", "huge stalked eyed conchs" • "A great number of giant snails (*Turbo fluctuosus*), of which we collected many hundreds" • Pink murex, "the commonest large snail in the Gulf", being "most abundant just below the low tide level" • "The beach was beautiful with the pink and white shells of the murex. Sparky found them so beautiful he filled a washtub full of them"	• Only small living conchs at three sites • *Turbo* never commonly found. Highest density = 1 snail m^{-2} • Few live murexes • No murexes at 12 rocky sites commonly sampled by both expeditions • Smaller muricids, especially *Morula ferrunginosa*, more common across commonly sampled sites
Vermetids (tube snails)	• Described from five of 12 sites • Maximum of one species per site	• Cursory descriptions of potentially ten different species from all 12 commonly sampled sites • Four or more species at four sites
Asteroids (starfish)	• "Many many" and "great numbers" at Cabo San Lucas, Pulmo Reef, Punta Lobos, Puerto Escondido • Six species at Punta Lobos and Puerto Escondidio	• Fewer species at 11 of 12 sites • Only one species at Punta Lobos and Puerto Escondido
Ophiuroids (brittle stars)	• "We had read of their numbers in the Gulf and here they were, mats and clusters of them, giants under the rocks. It was simple to pick up a hundred at a time in black, twisting, squirming knots"	• Fewer species at seven of 12 sites • Never more than eight individuals clustered
Holothuroids (sea cucumbers)	• "Literally millions" of individuals of *Holothuria lubrica* "in clusters and piles between the rocks and under the rocks"	• Average density of *H lubrica* = < 0.5 per boulder, < 7 individuals m^{-2}

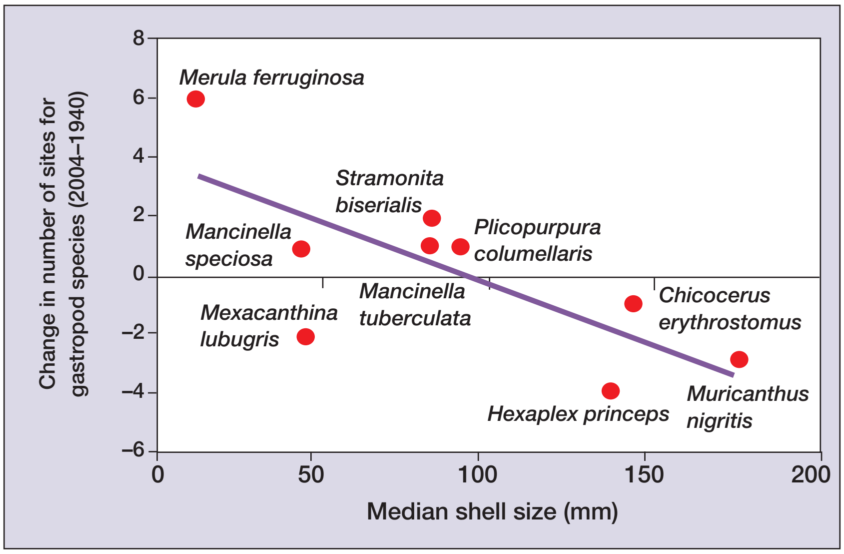


Figure 5. *Change in presence of muricid gastropod species between 1940 and 2004. Vertical axis indicates the difference in the number of common sites in which the indicated species of muricid snails were observed in 2004 versus 1940. Horizontal axis gives median shell length (mm) for each species, as taken from Skoglund (2002) and Brusca (1980). Heavy blue line is a linear least squares regression:* $y = -0.0413x + 3.8442$ ($r^2 = 0.53$).

manta rays. In contrast, we encountered no schools of tuna and sighted no billfish or turtles and only one (unidentified) shark (WebTable 5). Our crew was not composed of professional fishermen, and trolling in the manner of Steinbeck and Ricketts brought us no yellowfin tuna or even skipjacks, but we did catch the Sierra mackerel mentioned by Steinbeck and Ricketts. We also caught yellowtail and jack crevalle, neither of which was reported by Steinbeck and Ricketts. Where Steinbeck and Ricketts observed enormous manta rays, we observed many small manta-like rays (probably *Mobula munkiana*, distinguishable by their small size and frequent jumping).

To some extent, Steinbeck and Ricketts foresaw the decline of these pelagic species when they boarded a shrimp trawler off Guaymas and witnessed the prodigous bycatch of both demersal and pelagic fish, as well as invertebrates. Today, shrimp trawling is recognized as the single most ecologically damaging activity in the Gulf (Packard Foundation nd). Recent and historical work documents overexploitation of many commercially fished species (Sala *et al.* 2004; Saenz-Arroyo *et al.* 2005b) and precipitous declines in diversity of fishes and in the size of hammerhead shark schools since the 1980s (Klimley *et al.* 2005). In parts of the Gulf, a rapid decline in sea turtles occurred following discovery of their winter dormancy sites by fishermen in the early 1970s (Felger *et al.* 1976). By the 1970s, declines in the size and number of billfish were also documented, apparently a result of Japanese long-line fishing (Talbot and Wares 1975). The apparent replacement of large mantas, *Manta birostris*, with the smaller *Mobula munkiana* that we observed is consistent with other recent observations of small elasmobranchs replacing larger species, a phenomenon that has been associated with harvesting of large pelagic predators (Baum *et al.* 2003; Ward and Myers 2005).

The large pelagic predator we most regularly encountered was not mentioned at all by Steinbeck and Ricketts. *Dosidicus gigas* (jumbo or Humboldt squid) was observed at the surface between Santa Rosalia and San Francisquito every night, and in large numbers in the daytime off Punta Trinidad. We found small juveniles and mating adults in the San Pedro Martir basin (Gilly *et al.* 2006). This species currently supports a large year-round commercial fishery in the Guaymas Basin (Markaida *et al.* 2005). Steinbeck and Ricketts passed through this same area and regularly sampled organisms at night, using night-light observation from deck and dip-netting. They noted several other species of squid, and Ricketts was familiar with *D gigas* from specimens he obtained in Monterey in 1936 (Gilly 2005; Clarke and Phillips 1936). If jumbo squid had been as abundant in 1940 as they are at present, it seems inconceivable that they could have been missed by Steinbeck and Ricketts.

Scattered observations of what may have been jumbo squid do appear in the scientific and popular literature from as early as 1938 (Beebe 1938; Linsday 1964; Cannon 1966), but there are no reports of large numbers of these squid before commercial fishing commenced in the Gulf in the late 1970s (Markaida *et al.* 2005). Jumbo squid are not mentioned in observations that Colnett (1968) made in 1793–94 in the area south of Cabo San Lucas to the Socorros Islands, though he did describe squid "of 4 or 5 feet in length" shoaling at the surface off the Galapagos Islands. Finally, jumbo squid are absent in the excellent natural histories of the Gulf written by early Jesuit missionaries (del Barco 1980; Clavigero 1937).

Although the number of *Dosidicus gigas* is known to be spatially and temporally variable (Gilly 2005), it seems that this major predator must have been far less abundant in 1940 (and before) than it is today. Although an extremely strong El Niño–Southern Oscillation (ENSO) event can lead to a temporary decrease in the abundance of jumbo squid in the Gulf (eg the 1997–98 ENSO event caused a collapse in the fishery; Markaida 2006), no such anomaly occurred in 1940. Longer-term variations in sea temperatures due to PDO have had profound effects on the composition of pelagic fish species in the northeast Pacific (Chavez *et al.* 2003), but the extent to which PDO alters species composition in the Sea of Cortez is currently unclear. In 1940, large schools of yellowfin tuna were abundant in the Guaymas Basin, as indicated by Steinbeck and Ricketts's log and by recollections of commercial fishermen active in the 1950s (L Lewis pers comm). Perhaps the most telling personal history comes from Ramon Ramos Vejan, a retired shrimp fisherman in Guaymas, who started trawling in 1941 but never caught a single *Dosidicus* until 1976 (R Ramos Vejan pers comm). Fishing pressure on tuna, a warming climate, and increased agricultural runoff from the Yaqui Valley in Sonora (Beman *et al.* 2005) may have acted in concert to alter pelagic food webs in the Gulf in ways that favor jumbo squid over competitors, such as yellowfin tuna.

The future of the Sea of Cortez

Even those who have documented declines in Sea of Cortez populations acknowledge that it remains an ecologically remarkable place, where marine megafauna still congregate (Saenz-Arroyo *et al.* 2005b), human population density remains relatively low, and marine diversity high (Enriquez-Andrade *et al.* 2005). If this diversity and abundance is to be preserved or restored to an earlier condition, immediate steps must be taken. To this end, cooperative fisheries on the Pacific coast and among Seri Indian populations in the Gulf have achieved recognition for developing sustainable management practices (Basurto 2005). Local organizations modeled, to some extent, on the Pacific cooperatives are beginning to emerge in the squid fishery (WFG pers obs). In recent years, an improved understanding of the ecology of the Sea of Cortez has provided opportunities to propose ecosystem-based management strategies that consider non-conventional fishery variables, such as seabird abundance and El Niño anomalies (Velarde *et al.* 2004). This approach is in keeping with the philosophy of Steinbeck and Ricketts, who stressed a holistic view of nature in *The Sea of Cortez* and their subsequent writings.

Acknowledgements

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WebTable 1. Rocky shore and cobble-field sites sampled by Steinbeck and Ricketts (1941) and the Sea of Cortez Expedition and Education Project (SOCEEP 2004) where direct comparisons could be made, with alternate names used by Steinbeck and Ricketts given in parentheses

Site	*Steinbeck and Ricketts date*	*SOCEEP date*	*Longtitude* (˚W)*	*Latitude* (˚N)*	*SOCEEP samples***
Cabo San Lucas	17-Mar-40	6-Apr-04	109.903	22.880	T
Punta Lobos, Isla Espiritu Santo	20-Mar-40	9-Apr-04	110.293	24.459	T, B
Caimancito (east of La Paz)	21-Mar-40	11-Apr-04	110.300	24.207	T, B
Isolote Cayo (Amatorajada)	23-Mar-40	13-Apr-04	110.604	24.876	T, B
Punta Marcial	24,25-Mar-40	17-Apr-04	111.014	25.505	T, B
Puerto Escondido	25,27-Mar-40	18-Apr-04	111.306	25.813	B
Isla Coronado	27-Mar-40	20-Apr-04	111.281	26.110	B
Punta Trinidad (Bahia San Carlos)	30-Mar-40	25-Apr-04	112.720	27.824	T, B
San Francisquito	31-Mar, 1-Apr-40	27-Apr-04	112.880	28.451	T, B
Puerto Refugio	2-Apr-40	29,30-Apr-04	113.535	29.542	T, B
Isla Tiburon	3-Apr-40	4-May-04	112.354	28.763	T
San Carlos, Sonora	22-Apr-40	8-May-04	111.063	27.941	T, B

Notes: *Longitude and latitude taken by SOCEEP with hand-held GPS (Garmin Map12); **T = sampled using transects perpendicular to shore line; B = sampled using boulder rolling

WebTable 2. Sites for which only limited comparisons between the Steinbeck and Ricketts (1941) and SOCEEP (2004) expeditions were possible

Site	*Type*	*Limitations to resampling*
Cabo Pulmo (A)	Coral reef, sandy beach	Non-destructive sampling only by snorkel, no rocky intertidal
El Mogote (B)	Sand bar, mangroves	Not quantitatively sampled, no rocky intertidal
Bahia Concepcion (C)	Sandy beach, limited rocky outcrops	Could not relocate precisely; limited by tide
San Lucas Cove (D)	Sand bar	Not quantitatively sampled, no rocky intertidal
Bahia de Los Angeles (E)	Small boulder fields, mostly sandy gravel	Could not relocate precisely; sampling limited by tide
Estero de la Luna (F)	Lagoon, mangroves	Not visited in 2004 due to wind conditions
Estero Agiabampo (G)	Lagoon, sand flats, and mangroves	Could not relocate precisely; not quantitatively sampled, no rocky intertidal
Bahia San Gabriel – Isla Espirltu Santo (H)	Sandy beach, limited rocky intertidal	Time constraint

Notes: Letters in parentheses refer to locations on map (Figure 1).

WebTable 3. Number of echinoderm species at the 12 sites surveyed both in 1940 (bold) and 2004 (not bold)

Site	*Cabo San Lucas*	*Punta Lobos*	*Caimancito*	*Isolote Cayo*	*Punta Marcial*	*Puerto Escondido*	*Isla Coronado*	*Punta Trinidad*	*San Francisquito*	*Puerto Refugio*	*Isla Tiburon*	*San Carlos*
Asteroids	**3** 0	**7** 1	**5** 1	**4** 4	**5** 1	**6** 1	**3** 1	**3** 1	**3** 2	**5** 2	**4** 1	**3** 1
Ophiuroids	**2** 0	**8** 2	**4** 4	**1** 3	**1** 3	**3** 2	**5** 4	**1** 6	**2** 3	**5** 1	**3** 2	**1** 0
Echinoids	**2** 1	**5** 1	**1** 3	**1** 4	**4** 3	**1** 1	**1** 0	**1** 3	**1** 2	**3** 3	**2** 4	**1** 3
Total	**8** 1	**25** 6	**12** 10	**6** 14	**10** 10	**17** 7	**10** 7	**5** 16	**6** 9	**16** 9	**10** 8	**6** 7

Notes: Paired *t*-test comparing number of species across sites, by group: Asteroids t_{11} = -6.027, $P <$ 0.001; Ophiuroids t_{11} = –0.60, P = 0.56; Echinoids t_{11} = 0.73, P = 0.48

WebTable 4. Occurrence, by number of sites, of predatory muricid gastropods (ordered by size) in 1940 versus 2004

	Phyletic catalog #	*Size in mm*	*Common sites 1940*	*Common sites 2004*	*Other sites 1940*	*Other sites 2004*
Muricanthus nigritus	S360	200 (150)	3	0	3	0
Hexaplex princeps	S361	170 (120)	1	0	1	1
Chicoreus (P) *erythrostomus*	S358	173 (100)	4	0	1	0
Plicopurpura columellaris[*]	S357	84 (100)	1	2	0	6
Mancinella tuberculata	S367	114 (50)	4	5	1	3
Stramonita biserialis	S362	89 (75)	3	5	0	4
Mancinella speciosa	S363	55 (35)	4	2	1	3
Mexacanthina lugubris angelica	S351	47 (40)	4	5	1	2
Morula ferruginosa	S339	(12)	4	10	0	6

Notes: *Phyletic catalog number* refers to Steinbeck and Ricketts (1941). Published sizes (in parentheses) are lengths as reported by Skoglund (2002) or Brusca (1980). Species are ordered from largest to smallest, based on the average of these measures. *Common site number* refers to the 12 sites sampled in both 1940 and 2004. *Other site number* refers to sites not shared between the two expeditions. A total of eight additional sites were studied in 1940 and 14 additional sites were studied in 2004. [*]Specimens observed by SOCEEP were generally in the 30–40 mm size range, with none as large as the sizes reported by either source here. Photograph of this species in Steinbeck and Ricketts (1941) also shows an individual in the 30–40 mm size range.

WebTable 5. Observations of manta rays, sharks, swordfish, tuna, sea turtles, and other pelagic species from *Sea of Cortez* (Steinbeck and Ricketts 1941)

Type	*Approximate location*	*Quote*	*Page*
Billfish	North of Coronado Island, south of Bahia Concepcion	"The swordfish in great numbers jumped and played about us... The helmsman changed course again and again to try to bring the bow over a resting fish."	183–4
Billfish	Near Mulege	"Tiny's and Sparky's work at the wheel had improved, and except when they chased a swordfish (which was fairly often) we were not off course more than two or three times during their watch."	195
Billfish	San Francisquito Bay	"A playful swordfish, jumping and spinning, absorbed us completely"	211
Billfish	Cabo San Lucas	"The swordfish jumped in the afternoon light, flashing like heliographs in the distance"	268
Manta ray	Between Cabo Pulmo and Pescadero Point	"We saw the first specimens of the great manta ray"	82
Manta ray	South end of Espiritu Santo Island	"There were many manta rays cruising slowly near the surface, with only the tips of their 'wings' protruding above the water."	91
Manta ray	General	"At this reading, there are many manta rays in the Gulf cruising about with our harpoons in their hides"	121
Manta ray	Puerto Escondido	"We heard him shout, and looked up to see a giant manta ray headed for him, the tips of the wings more than ten feet apart. It was rare to see them in such shallow water."	158
Manta ray	Shallow sea between Cape Arco and Punta Lobos, north of Estero de la Luna	"It was Tiny who noticed the great numbers of manta rays and suggested that we hunt them. They were monsters, sometimes twelve feet between the 'wing' tips."	251
Manta ray	North of Agiabampo	"Again we saw manta rays, but not on the surface this day, and the hunt had gone out of us."	259
Shark	Cabo San Lucas	"But now in the back of the Friars on the beach there is a great pile of decaying hammer-head sharks, the livers torn out and the fish left to rot"	55
Shark	Puerto Escondido	"We dropped the fishing lines and immediately hooked several hammer-head sharks and a large red snapper"	156
Shark	San Lucas Cove	"As we dropped anchor a large shark cruised about us, his fin high above the water. We shot at him with a pistol and one shot went through his fin."	196
Shark	Agiabampo	"The sea was sterile, or populated with sharks and rays"	259
Tuna	North of Marcial Reef	"We could see the splashing of great schools of tuna in the distance, where they beat the water to spray in their millions"	154
Tuna	North of Coronado Island, south of Bahia Concepcion	"We could see schools of leaping tuna all about us and whenever we crossed the path of a school, our lines jumped and snapped under the strikes, and we brought the beautiful fish in."	184
Tuna	East coast of Angel de la Guarda Island	"The great schools of tuna, so evident in the Lower Gulf, were not seen here."	230
Sea turtle	Magdalena Bay, Pacific	"Now the sea-turtles began to appear in numbers."	44
Sea turtle	Isolote Cayo	"Piled about the fireplaces, some old and some fresh, were not only thousands of clam-shells but turtle-shells also… A heap of fairly fresh diced turtle-meat lay beside one of the fireplaces"	128
Jumbo squid	na	No observations were made by Steinbeck and Ricketts	na

