# Evaluation of ghost fishing in the Hawaiian lobster fishery

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**Abstract.**–Mortality due to retention of lobsters in derelict traps was evaluated over a 2-year period using two approaches. First, a string of eight empty, single-chamber, plastic traps was deployed at 40 m depth off Oahu, Hawaii, and monitored periodically by scuba during a 6-month period in 1990. The traps were stable and remained intact despite adverse oceanic conditions. Numerous entries and exits of lobsters were recorded. For the second test, the ability of lobsters to exit traps was tested in a series of field and laboratory trials of trap strings stocked with Hawaiian spiny lobster *Panulirus marginatus* and slipper lobster *Scyllarides squammosus*. The number of lobsters that died in stocked traps was less than 4% of the test population and differed significantly from zero only in the laboratory evaluation ($\chi^2$ 5.42, $P$ 0.02). The two species exited similarly; however, the pattern of exits in laboratory and field tests differed significantly ($\chi^2$ 23.889, $P$ 0.03). All lobsters exited within 56 days in a pattern generally approximating an exponential decline. Our evidence suggests that little direct mortality of lobsters is due to the inability to exit traps, and consequently ghost fishing by these traps is not considered a problem for spiny and slipper lobsters.

Manuscript accepted 14 August 1992.
Fishery Bulletin, U.S. 90:720–725 (1992).

Continued fishing by lost traps has become the focus of increasing concern by both fishery managers and scientists. The recent trend for trap fisheries to replace their degradable traps with designs made from more persistent synthetic materials has heightened the seriousness of possible ghost fishing by such unrecovered traps. Ghost fishing has been defined as the continued fishing of irretrievable gear (Smolowitz 1978). Such a definition fails to distinguish between permanent entrapment and temporary occupation of a trap (e.g., for feeding or shelter). Mortality occurring in abandoned traps should be measured to assess the impact of ghost fishing on a particular fishery.

The phenomenon of ghost fishing has been observed in a wide range of trap fisheries with diverse trap designs (e.g., High 1976, Pecci et al. 1978, Smolowitz 1978, Paul 1983). Despite this attention, few studies have effectively assessed the ghost fishing problem for any species. The more rigorous evaluations rely on continued underwater field observations of simulated lost traps (Breen 1990). With this method, mortalities have been clearly demonstrated in temperate fisheries in which animals were unable to exit traps fitted with nonreturn entrance devices. Features such as spring-loaded doors and slick plastic entrance chutes effectively reduce the ability of some animals to exit actual and simulated lost traps, resulting in reported mortalities of 26–55% (High 1976, Miller 1977, Breen 1987). Conventional wooden, two-chamber or "parlor-type" traps designed for the American lobster *Homarus americanus* have produced mortalities of 12–25% (Sheldon and Dow 1975, Pecci et al. 1978, Smolowitz 1978).

Ghost fishing poses a potential risk to at least some trap fisheries, and such a risk requires assessment for each species and trap configuration. Tropical lobsters have been largely neglected in the controlled evaluation of mortality by ghost traps. Isolated anecdotal reports of tropical lobsters found in lost traps (Sutherland et al. 1983) and tank studies made to date (Paul 1983) do little to predict realistic, long-term effects of lobsters interacting with modern traps in the field.

Hawaii's lobster fishery targets two species, Hawaiian spiny lobster *Panulirus marginatus* and slipper lobster *Scyllarides squammosus*. A laboratory study by Paul (1983) used California parlor-type traps made of wire to determine the effectiveness of escape vents in releasing undersized Hawaiian spiny lobster. Paul (1983) suggested that ghost fishing might occur in these traps and recommended that the Hawaiian fishery consider incorporating degradable escape panels to facilitate the escape of adult lobsters. By 1985 the fishery had adopted a more cost-effective molded-plastic trap design as the standard gear. Degradable panels have not been included.

In 1989 the Hawaiian lobster industry reported that more than 1 million traps were set in the Northwestern

Hawaiian Islands (NWHI); an estimated 2000 of these traps were unrecovered (Landgraf et al. 1989). The annual accumulation of lost plastic traps on the banks where commercial trapping occurs must be considered a potential hazard to the lobster stocks. No field studies have been done on the interactions between lost traps and the adults of the two target lobster species. The objectives of this study were to (1) evaluate the persistence of lost commercial traps under field conditions, (2) estimate retention of target species in plastic traps with bait depleted, and (3) assess mortality of lobsters unable to exit traps.

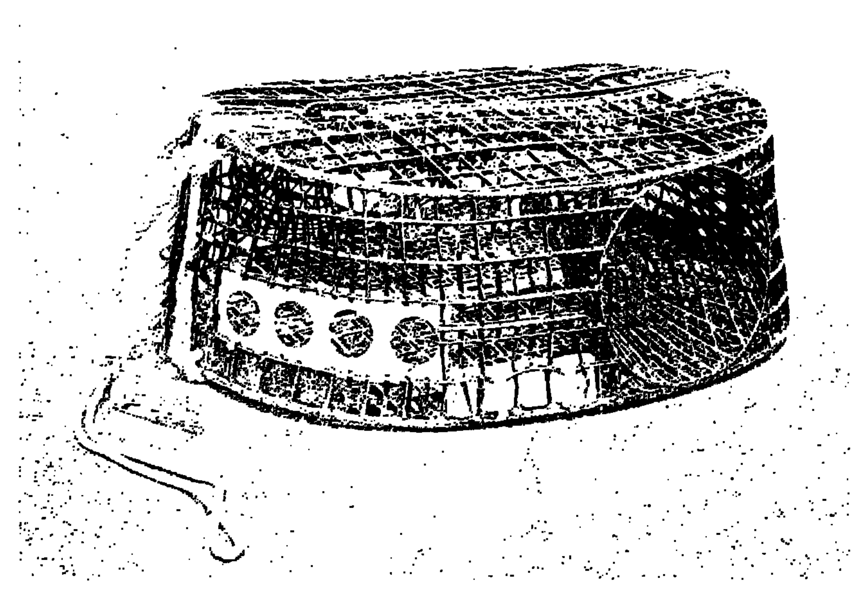

**Figure 1**
Plastic trap used in the Hawaiian commercial lobster fishery.

## Methods

### Study sites

The prohibitive cost of prolonged, ship-supported diving operations in the NWHI dictated that all field experiments be conducted at Oahu. Sites close to the windward shore of Oahu provided appropriate depths (30–40 m) and habitat consistent with the NWHI commercial banks. The area is known to harbor exploitable numbers of the lobster fishery's target species. Its heavy seas, strong bottom surge, and swift currents (Bathen 1978) might mimic NWHI conditions and thus could test the stability of lost traps. Traps placed in such rough conditions, without surface markers, were unlikely to be disturbed by fishermen and other recreational users.

### Trap stability and faunal interactions

A string of eight empty traps was deployed in a linear orientation from February to July 1990. The selected area afforded two types of adjacent habitat—high-relief rugose bottom, and hard relatively-flat bottom—allowing comparisons of trap stability and use by lobsters in the different environments. Individual traps were set 10 m apart, four on high-relief bottom and four on adjacent even bottom. The molded-plastic traps (Fig. 1) used in the study were a standard commercial model employed throughout the commercial fishery in Hawaii (Fathoms Plus Marine Implementation, P.O. Box 6307, San Diego, CA 92106). Each trap consisted of a single chamber with two side entrances and was weighted with about 10 kg of lead, as is conventional in the fishery. Traps remained in place over a 6-month period. They were observed monthly by scuba divers during three dives conducted at 48-hour intervals. Physical condition, movement, and contents of the traps were noted on each dive, along with general observations of the surrounding area. The monthly censuses recorded the initial presence of lobsters from the surrounding study site and any exits or entries over the following 4 days. The area in and under the traps was examined for exoskeleton remnants that might indicate molting or mortality. One additional trap with its hinge pins removed was deployed on flat bottom near the trap string to mimic a trap with corrodible hinge pins that had deteriorated.

### Trap stocking experiment

In the summers of 1990 and 1991, traps of the same type (Fig. 1) were deployed in the field and laboratory, and stocked with spiny and slipper lobsters from the NWHI to evaluate their ability to exit and the extent of mortality. Prior to the traps being stocked, lobsters had spent 3–8 days in transit in continuously-flushing shaded bait wells where they were fed daily. Mean carapace lengths were 87.6 mm (*N* 96, range 67.4–121.7 mm) for spiny lobster, and 83.3 mm (*N* 96, range 50.1–99.7 mm) for slipper lobster. Antennae were tagged with color-coded, plastic, self-locking, electrical ties to permit visual identification of individuals without their being handled during the experiment. Molt stage of lobsters prior to their deployment in traps was determined using Lyle's (1982) adaptation of Drach's (1939) staging technique.

In the field test, 128 tagged lobsters were placed by divers in 4 strings of 8 unbaited traps each (2 spiny and 2 slipper lobsters per trap). Two strings were placed on and around high-relief substrate, one in summer 1990 and the other in summer 1991; two strings were placed on relatively-flat hardbottom, at least 300 m from any relief that could provide lobsters shelter, in summer 1991. The contents of the traps were checked every 48 hours until all tagged lobsters had exited or died.

In the laboratory trials, 64 additional tagged lobsters were placed in 16 traps (2 spiny and 2 slipper lobsters per trap) in a large, shaded, outdoor concrete tank. Throughout the tank, food and other suitable shelter were provided outside the traps to encourage exiting. Contents of the traps were monitored daily, and any lobsters found outside the trap in which they were originally stocked were removed from the tank. Lobster death totals in the laboratory (where predation could not occur) and in the field were compared in an attempt to separate losses by predation from other mortality (e.g., starvation, conspecific aggression) in the field.

This study employed a modified experimental cohort design to examine the effects of multiple categories (replicate, habitat type, species) on exiting by lobsters. The design permits cross-classified categorical analysis to be applied (Fienberg 1987). Using chi-square tests, comparisons were made between replicates, habitat types, and species in a systematic order. Categories were collapsed or pooled when justified by the lack of significant differences (Siegel and Castellan 1988).

## Results

### Trap stability and faunal interactions

Estimated seas of 4–6 ft and currents of 1–2 knots were common at the study site. They produced no observable effect on the physical integrity of the plastic traps. Movement of traps across the substrate was not detected, despite frequent observations of the interconnecting groundline actively moving in the bottom surge. The two halves of the trap without hinge pins shifted 2 cm apart. Over the 6-month period, the traps became encrusted with sessile organisms, including bryozoans, corals, and fish eggs. Occasionally adult fish larger than the opening of the escape vent were found in the traps; however, most of these departed through the trap entrance as a diver approached.

Adults of both spiny and slipper lobsters local to the surrounding study site entered the traps. Of the 12 such occurrences of lobsters recorded during the 6-month survey, 7 lobsters left before the last inspection of the monthly observation period, indicating that they did not occupy the traps for more than 30 consecutive days. Three lobsters were observed entering and exiting within the same 48-hour observation period. Nine of the 12 lobsters were found in traps on even bottom.

One dead spiny lobster comprised the only mortality observed within the 6-month field evaluation. Postmortem examination and the presence of lobster debris in the area around the trap suggested death by predation. Sightings of known predators such as octopus, eels, jacks, and sharks were routine. Large eels often occupied the traps, occasionally with lobsters.

### Trap stocking experiment

Molt-stage evaluation indicated that 27% of the spiny lobsters and 1% of the slipper lobsters were in the premolt stage at deployment. Mortality was limited to seven spiny lobsters, five in the laboratory and two in the field. All of these lobsters were in premolt stage at deployment and died during or shortly after molting. Despite the limited mortality, the number of deaths in the laboratory trials differed significantly from zero

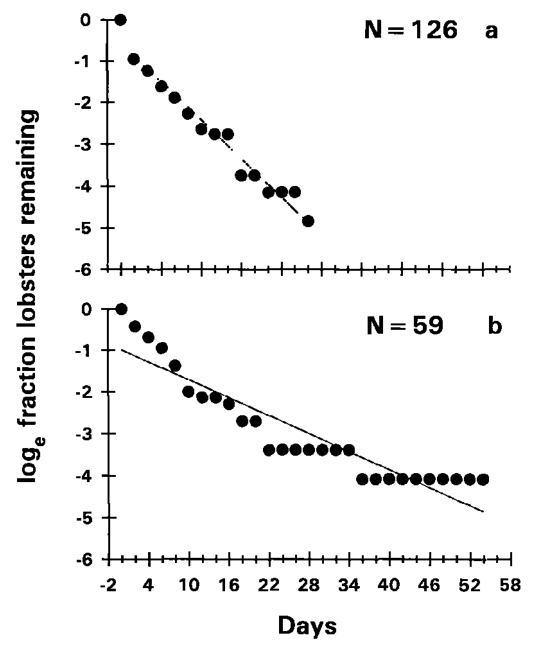


**Figure 2**
Persistence of occupancy of plastic traps stocked with spiny *Panulirus marginatus*, and slipper *Syllarides squamosus*, lobsters (combined) in the (a) field and (b) laboratory.

($\chi^2$ 5.42, $P$ 0.02). This was not true for the field trials ($\chi^2$ 2.06, $P$ 0.15), and mortalities in the laboratory and field were significantly different ($\chi^2$ 4.74, $P$ 0.03). Consequently, the two test situations were evaluated separately, with all animals that died excluded from the trap-occupation analysis.

Contingency tables were used to test for differences in the exit distributions for various groups of the data (Fienberg 1987). Within each species, the distributions of exits were first compared between replicate trap strings within the same habitat type and were found not to be significantly different (spiny lobster—high relief, $\chi^2$ 3.22, $P$ 0.50; even substrate, $\chi^2$ 10.00, $P$ 0.19; slipper lobster—high relief, $\chi^2$ 3.33, $P$ 0.50; even substrate $\chi^2$ 9.52, $P$ 0.22). Therefore, the distributions of exits for the two replicates were pooled within each habitat type. Within each species, exits were then compared for the effect of the two habitat types and were found not significantly different (spiny lobster—$\chi^2$ 10.81, $P$ 0.21; slipper lobster—$\chi^2$ 4.53, $P$ 0.72). The distributions of two habitat types were then pooled within each species, and exits of the two species were not significantly different ($\chi^2$ 16.93, $P$ 0.08). Consequently, the distributions of the two species in all field trials were combined ($N$ 126 lobsters after 2 early mortalities) for further comparisons.

Within each species, exits observed in the tank were compared with the field data pooled by replicate and habitat type and were not significantly different (spiny lobster—$\chi^2$ 14.42, $P$ 0.21; slipper lobster—$\chi^2$ 13.63, $P$ 0.09). Exits of spiny and slipper lobsters in the tank were not significantly different ($\chi^2$ 11.55, $P$ 0.32), and the data were subsequently pooled ($N$ 59 lobsters after 5 early mortalities). A comparison of exits of all lobsters in the tank (pooled) and all lobsters in the field (pooled) showed a significant difference ($\chi^2$ 23.889, $P$ 0.03).

Half of the 126 spiny and slipper lobsters stocked in the field and 33% of the lobsters stocked in the laboratory exited within 48 hours after being placed in the traps. Ninety percent or more of the exits in both tank and field trials occurred within the first 16 days. All field animals had left by day 30, and all laboratory animals by day 56. The overall exit pattern of the lobsters suggested an exponential model. The data were fitted to the log-transformed exponential function

$$\ln_e (N_t/N_0) = bt,$$

where $N_t$ is the number of lobsters remaining after time t from $N_0$ lobsters initially stocked. The parameter b was estimated with a log-linear regression procedure for the field traps (b = −0.16/day; $r^2$ 0.992, SE 0.284, $P$<0.001) and for the laboratory traps (b = −0.094/day, $r^2$ 0.961, SE 0.632, $P$<0.001; Fig. 2).

Stocked spiny and slipper lobsters exited and reentered field traps in at least 13 instances; 6 lobsters returned to the same trap. One spiny lobster was observed exiting three traps within 6 days.

## Discussion

### Trap stability

The lack of structural damage and appreciable movement of the plastic traps in the field contrasts with the popular opinion of experienced fishermen that lost traps break up and roll off the banks into waters beyond the depth range of lobsters. Fishermen routinely report movement of trap strings as a result of powerful swells moving across the commercial banks. Despite the frequently observed movement of the groundline by swells at the Oahu study site, it is likely that the study site does not fully duplicate the power of the long-term swells common in the NWHI. Lost traps may not shift on the bottom as much as actively fished traps. Buoys and interconnecting polypropylene line provide additional lift and resistance to water motion; therefore, fully rigged strings of traps are more likely to move than isolated traps severed from the groundline. A 1990 systematic diving survey of 33 sites around 2 of the prominent NWHI commercial lobster fishing banks revealed only 2 mangled derelict traps (F. Parrish, unpubl. data). The failure to locate large amounts of lost gear may be partly explained by this survey being incidental to other work. Total gear losses in 1989 averaged about 1 trap/nm$^2$ over the total estimated area of the lobster fishing grounds (Landgraf et al. 1989). Lost gear could be heavily concentrated in a few of the more intensively fished areas that the survey may have missed.

A trap manufacturer (Fathoms Plus Marine Implementation) has made available a corrodible pin which is intended to allow the halves of plastic traps to eventually fall apart once the pin deteriorates. The fact that our pinless trap remained relatively intact for 6 months in the field suggests that the synthetic plastic clips on the trap roof will continue to hold the trap together, especially for fisheries conducted in calmer seas.

### Mortality and movement of lobsters

Seven deaths among the 192 spiny and slipper lobsters within the 56-day study represent low mortality when compared with the natural mortality estimates from the fishery population modeling by Haight and Polovina (1992). Extrapolation of the experiment's percentage of mortality from 2 months to 1 year (22%) is close to half the fishery's annual estimated natural mortality (40%). The fact that only animals that began the trials in premolt condition died suggests that lobsters at this stage are less fit. The probability that this mortality would occur only with premolt individuals by chance alone is $<0.001$ (Agresti 1990). Increased vulnerability to a poor physical environment, conspecific aggression, or predation have been associated with molting (Conan 1985). It seems likely that the higher percentage of spiny lobster in premolt stage accounts for some of the difference in mortality between spiny and slipper lobsters.

The significantly higher mortality observed in the laboratory compared with the field does not support the idea that undetected predation substantially affected the field results. The relatively low absolute level of total mortality suggests that such predation is probably minimal at the field site. However, with mortality being higher in the laboratory than in the field, no estimate of predation is possible.

More than twice as many deaths were observed in the laboratory as in the field, even though the field trials involved twice as many lobsters and three times as many were in the premolt stage. This suggests a less healthy or fit laboratory population, which is consistent with the significantly slower exit of pooled species from traps in the laboratory versus in the field. Aspects of the laboratory environment (e.g., water quality, lighting, diet) may have degraded the physical condition of the lobsters or affected their behavior, inhibiting their exit, or providing less inducement to leave the traps than that encountered in the field. It seems likely that our field assessment provides a better estimate of natural exit patterns.

With a study design similar to ours, Munro (1974) examined the rate of fish exiting unbaited traps. His theoretical model suggests that the number exiting per day may be a fixed fraction of the current trap occupancy, and that catch eventually reaches an asymptote when trap entrances are balanced by exits. Our number of stocked lobsters declined approximately exponentially, approaching zero asymptotically. However, the total occupancy of traps declined daily until it reached a low and varying level at which exits were roughly matched by entrances of lobsters. This final, low level of trap occupancy at the end of the stocking experiment seems consistent with native occupancy observed during the monthly field monitoring.

In our stocking tests, some individuals likely left a trap and reentered it undetected between censuses, particularly in the field test where the observation interval was 48 hours. Based on independent probabilities of exit and entry estimated from our field data, the theoretical joint probability of such reentry was as high as 0.06, and probably about 12 individuals left and reentered the same trap undetected during the full 26-day field stocking experiment.

## Conclusion

Our results indicate that spiny and slipper lobsters are not restrained by lost molded-plastic traps for periods long enough to cause serious harm. There is no evidence that such lost traps result in increased mortality. The absence of any apparent trap-induced mortality and the low incidence of identifiable in-trap mortality due to predation suggest that ghost fishing by these traps contributes little to the total mortality of the population. Such traps, when unbaited and intact, may best be considered short-term artificial shelters that lobsters enter and exit occasionally, more or less at will.

## Acknowledgments

Thanks are due to Steve Kaiser for advice on selection of study sites and to Bill and Joanne Goebert for providing ready access to those sites. Ray Boland, Karl Bromwell, Theresa Martinelli, and Leslie Timme assisted in the rigorous program of field monitoring. Greatly appreciated are the statistical and substantive comments of Deborah Goebert, Robert Moffitt, James Parrish, and Jeffrey Polovina.

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