

Saturation of crab traps: reduced entry and escapement

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Trap saturation, observed as a reduction in catch rate with increasing catch, has an important limitation on catches of *Cancer productus* and *C. magister*. However, the gap between potential and realized catch/trap-day could be reduced by modifying trap design and fishing strategy. The size of this gap was estimated in fishing experiments on natural crab populations by comparing catches in traps of the same design and fished in the same way except that in *fished* treatments crabs were removed from traps every 2 h for 12 h, and in *not-fished* treatments crabs were merely counted every 2 h for 12 h, but not removed. The cumulative catch from the *fished* treatment provided a minimum estimate of the crabs available to be caught without the catch limitation of saturation. Regardless of trap type, by 8 h elapsed time cumulative catches in *fished* traps were always significantly higher than observed catches in traps *not-fished*. By 12 h elapsed time the former was at least 1.7 times the latter in all experiments.

While saturation could not be eliminated, the catch level at saturation was increased. After 12 h the catch ratios in three trap sizes were 1.0:4.6:9.4 while the ratio of trap sizes was only 1.0:2.0:2.7. Thus, the packing density was higher in larger traps. This was partly explained by different rates of escape from traps. Preventing escapement increased catches by 1.6 times over 12 h. Catches in traps with bait exposed was 2.2 times higher after 12 h than in traps with bait enclosed in perforated containers.

Saturation was shown to have components of escapement and reduced entry since the saturation level increased when escape was prevented, yet the cumulative catch in *fished* traps of the same type was still higher. Reduced entry was assumed to be due to crabs inside traps intimidating those outside which otherwise would have entered.

Introduction

Gear saturation is observed as reduced catch rate with increasing catch, or, as defined by Beverton and Holt (1957, p. 94), "... the tendency for the fishing power of a unit of gear to be reduced as the catch in it increases". Although gear saturation is an old concept (Van Oosten, 1935), its importance and causes have not been well documented.

The purpose of this study was to demonstrate the importance of saturation on the crab catch in baited traps and to identify some of the factors influencing saturation. The study consisted principally of controlled fishing experiments with variations in soak time, trap design, and bait placement.

Cancer productus, the red crab, was the main subject although observations on *Cancer magister*, Dungeness crab, confirmed some of the results obtained with *C. productus*. *C. productus* was chosen because of its abundance in the study area in Departure Bay, British Columbia, and its ready response to baited traps. *C. magister* was included because it was also available in inshore waters and it supports a commercial fishery from Alaska to California.

Materials and methods

Study area

Trapping experiments with *C. productus* were conducted in 1976 in Departure Bay from either the boat dock of the Pacific Biological Station or from a small boat within 100 m of the dock. The bottom was mud with sparse eel grass cover or with no vegetation. Fishing depths followed an apparent seasonal change in crab distribution from about 3 m at low tide in June down to about 9 m in July–August and back to 3 m in October–November. Temperature ranged from 10°C to 15°C and salinity from 26 to 32‰ throughout the study. Trapping of *C. magister* was conducted in September 1976 in Knight Inlet, British Columbia, at depths of 1 to 3 m at low tide on sand bottom. Temperature was 14°C but salinity was not measured.

Traps

Two basic trap designs, top entrance for *C. productus* experiments and side entrance for *C. magister* experiments, are illustrated in Figure 1.

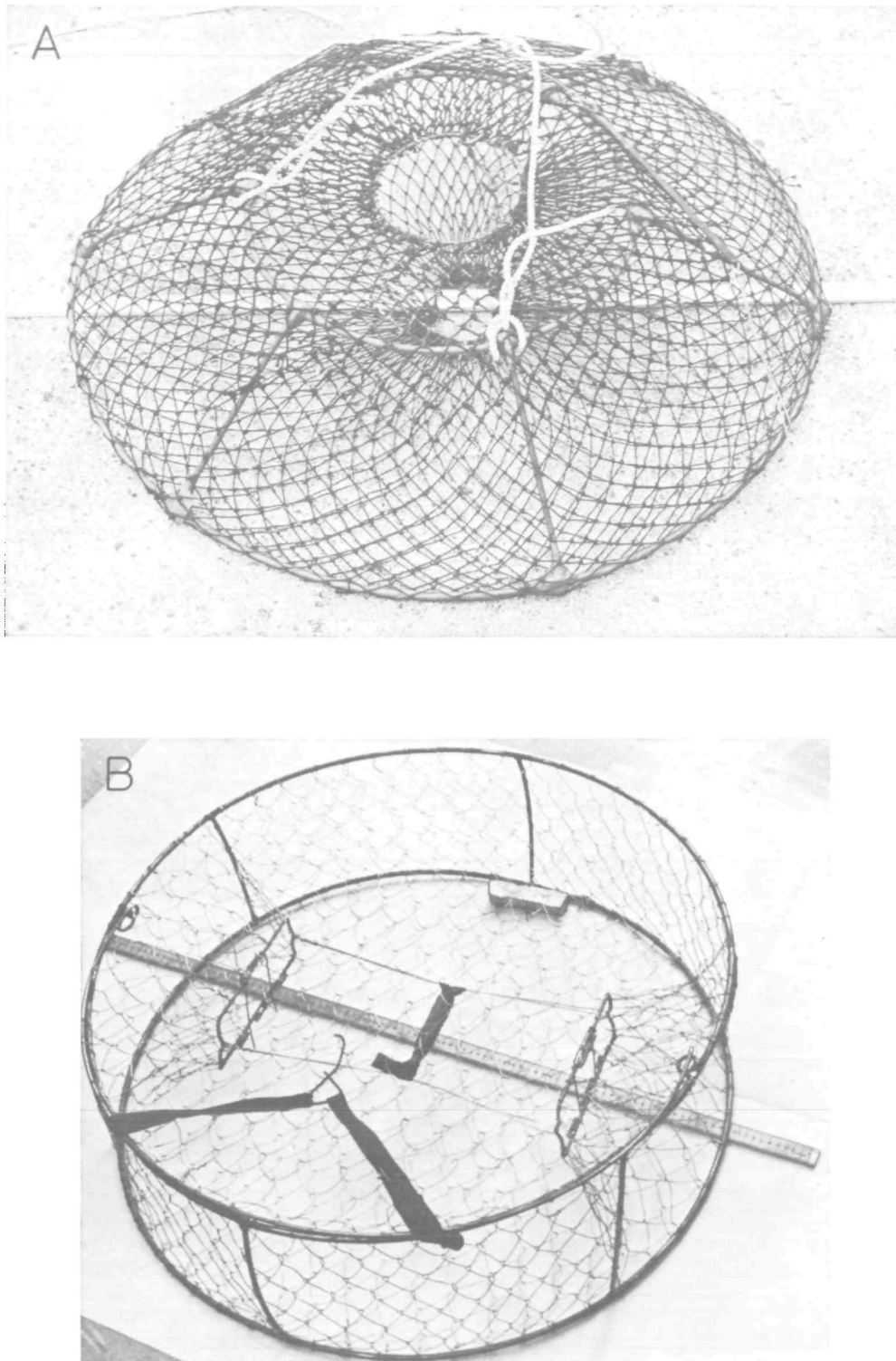


Figure 1. A) Top entrance trap; B) side entrance trap.

The top entrance trap was cone shaped and constructed of steel rods covered with heavy synthetic mesh. Dimensions of the most commonly used traps were 15 cm high, 78 cm bottom diameter, and 40 cm top diameter with a 15 cm diameter opening in the centre of the top. For an experiment on trap size two additional traps of similar shape and construction were included but with top and bottom diameters of 15 and 55 cm, and 50 and 90 cm respectively. Traps were baited with frozen herring either impaled on a wire or placed in a 500 ml plastic bottle containing many 1 cm diameter holes. In each case the bait was wired to the inside bottom of the trap in the centre.

Crabs could escape the top entrance trap by crawling across the mesh suspended upside down until they found the opening. To prevent escape some traps were fitted with a 6 cm deep plastic collar recessed in the opening. A crab approaching the opening from the inside would be prevented access by the recessed collar which was too slippery to crawl around. To test the effectiveness of the collar, 8 middle-sized traps, 4 with collars and 4 without, were each stocked with 10 crabs. After 24 h set in the sea, 1 of 40 crabs had escaped from traps with collars and 29 of 40 had escaped from traps without collars.

Side entrance traps were cylindrical and constructed entirely of stainless steel, including the mesh. Dimensions were 75 cm diameter by 25 cm high. The two opposite side entrances sloped up from the bottom edge of the trap and were each fitted with two trigger wires that only opened inward. These were effective in preventing escapement of large *C. magister* (High, 1976), but some crabs less than 13 cm carapace width probably escaped since *C. productus* of this size were able to escape (Miller, 1978).

Experimental design

Fished and *not-fished* treatments were employed for *C. productus*, providing data for potential and realized catch per trap over 12-h periods. *Fished* traps were hauled and emptied every 2 h for 12 h and the trapped crabs removed from the area. Catch data were presented as the accumulated catch over the six observation times of an experiment. Traps *not-fished* were also hauled every 2 h for 12 h, but crabs were counted and returned to the water still in the traps. Here catch data were the observed number of crabs in a trap at each observation. *Not-fished* traps were often watched carefully while they were being lowered to the bottom. Never did a crab escape or even appear to attempt escape during this procedure. Traps for each treatment were set a few metres apart in random order. Both members of a pair were assumed to be exposed to the same density of crabs and in the same physical environment. Although catches in *fished* traps were sometimes considerably higher at night, suggesting a diurnal cycle of activity, this did not affect the comparison of treatments since they were always run simultaneously. All experiments began between 1000 h and 1200 h. Baiting procedure was identical for all treatments in an experiment (with one exception for each of *C. productus* and *C. magister* noted in results) and the bait was changed once or twice during an experiment so it was fresh and in excess.

In some experiments traps were *not-fished* in either treatment but trap design or bait placement was the experimental variable. Here, all traps were again hauled and the crabs counted every 2 h but the crabs were left in the traps. The procedure was otherwise the same as above.

Table 1. Sample data set for crab catch per trap with treatments of bait exposed (I) and bait enclosed (II). The top row gives the times of hauling after the trap was first set. The data are plotted in Figure 2.

| Time (h) Treatment Replication | 2 | | 4 | | 6 | | 8 | | 10 | | 12 | |
|--------------------------------------|--------|----|-------|----|--------|----|--------|----|-------|----|--------|----|
| | I | II | I | II | I | II | I | II | I | II | I | II |
| 1 | 7 | 3 | 8 | 3 | 12 | 6 | 17 | 6 | 21 | 5 | 21 | 4 |
| 2 | 5 | 2 | 11 | 3 | 12 | 3 | 12 | 6 | 12 | 6 | 20 | 6 |
| 3 | 5 | 2 | 4 | 4 | 18 | 9 | 18 | 9 | 17 | 12 | 16 | 10 |
| 4 | 15 | 5 | 15 | 8 | 17 | 12 | 25 | 14 | 23 | 18 | 23 | 15 |
| 5 | 12 | 6 | 10 | 7 | 12 | 6 | 15 | 6 | 15 | 11 | 16 | 9 |
| Total | 44 | 18 | 48 | 25 | 71 | 36 | 87 | 41 | 88 | 52 | 96 | 44 |
| ¹ Homogeneity χ^2 | 0.3 | | 2.5 | | 2.1 | | 0.8 | | 5.1 | | 5.8 | |
| ² Totals χ^2 | 10.9** | | 7.2** | | 11.8** | | 16.6** | | 9.2** | | 19.3** | |

¹ 4 degrees of freedom; ² 1 degree of freedom. ***P* < 0.01.

For each experiment consistency – or homogeneity – among replications was tested by a chi-square (χ^2) contingency test and treatment differences were tested by a one degree of freedom χ^2 on the treatment totals. Working in the field with an endemic crab population I could not assume that all replications, including different times and locations, were sampling the same crab density, but I hoped that the experimental treatments produced the same relative catches among replications. In the example given in Table 1 the non-significant homogeneity χ^2 s for all six hauling times supported this assumption. In fact, among all experiments only 4 of 42 of these tests were significant. Referring again to Table 1, significant χ^2 tests on treatment totals show that more crabs were caught by traps with bait exposed than by traps with bait enclosed at all six hauling times.

Crab size was not treated as a variable in any of the experiments with *C. productus*. The range included was 7 to 14 cm carapace width with a mode of 10 cm. Crabs smaller than 7 cm were excluded in counts because they were rare (less than 15% of the total) and probably made a small contribution to saturation relative to larger crabs.

Results

Cancer productus

The first two experiments tested the hypotheses that exposing the bait would increase catches and eliminate the trap saturation effect. Exposed bait did indeed increase the catch, and the difference was significant at the first observation, (that is after 2 h) (Fig. 2, Table 1). Consequently, exposed bait was

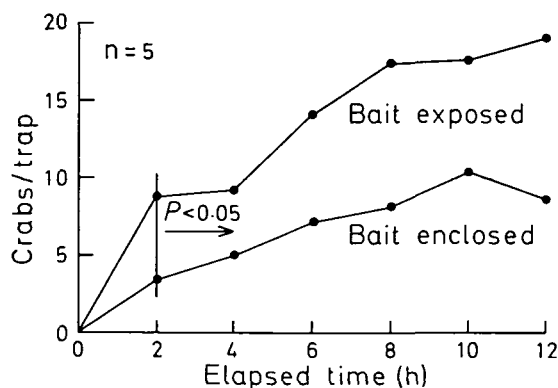


Figure 2. Test of the hypothesis that catch is greater when bait is exposed than when bait is enclosed in perforated containers. Both treatments *not-fished*. Vertical line and horizontal arrow indicate that treatments are significantly different from 2 h onward.

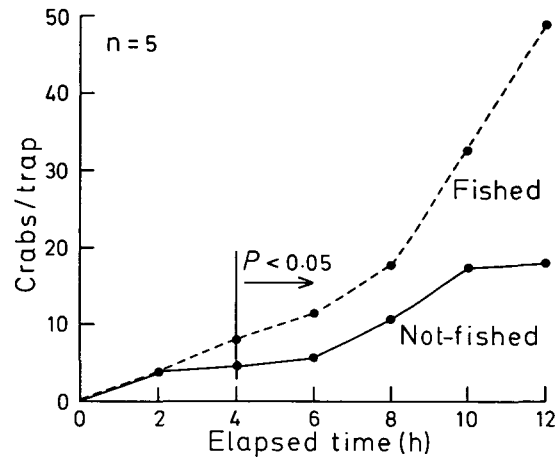


Figure 3. Test of the hypothesis that catch is not limited by trap saturation when bait is exposed.

used in all subsequent experiments. Exposing the bait did not eliminate the saturation effects, however, as catch differences in *fished* and *not-fished* traps were significant by 4 h and increased to a ratio of 2.7:1 by 12 h (Fig. 3).

The next experiment showed that catch was a function of trap size and that saturation limited catches in all three trap sizes tested (Fig. 4). Bait attraction was assumed to be identical in all three trap sizes and ease of gaining entry to traps was also assumed to be similar (if not identical) because traps had similar shapes and entrances. Thus, catch differences were attributed to saturation. For traps *not-fished*, the catch in medium traps exceeded the catch in small ones at 2 h and the catch in large traps exceeded the catch in medium ones at 4 h. Surprisingly, these catches were not a linear function of trap size. As shown in Table 2 the ratios of catches were much greater than the ratios of trap bottom area; consequently, crab packing density increased with trap size. Packing densities for the total inside surface areas are also given since crabs sometimes crawled on the sides and tops of traps. The ratios of trap bottom areas are nearly identical to the ratios

Table 2. Comparison of catches in three trap sizes after 12 h soak time

| Trap size | Ratios of trap bottom area | Catch ratio | Trap area (cm ² /crab) bottom | inside surface |
|-----------|----------------------------|-------------|--|----------------|
| Small | 1.0 | 1.0 | 792 | 1709 |
| Medium | 2.0 | 4.6 | 346 | 752 |
| Large | 2.7 | 9.4 | 225 | 483 |

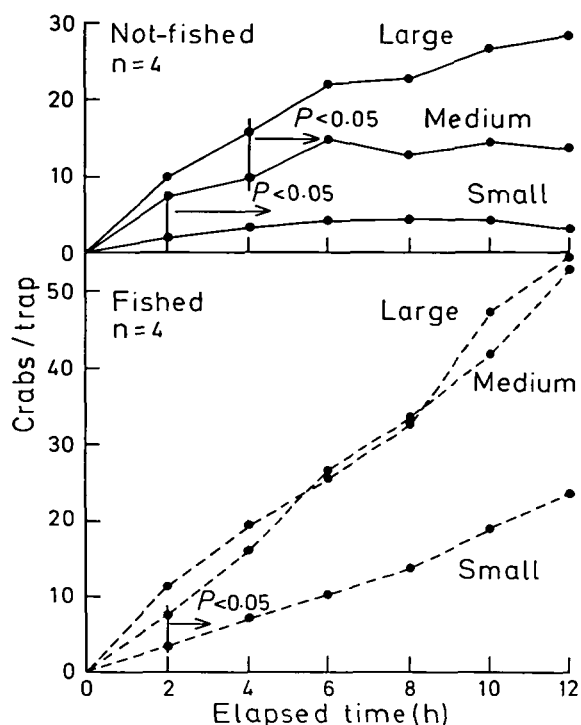


Figure 4. Tests of the hypotheses that catch increases with trap size and that saturation restricts catch in all trap sizes.

of total inside surface areas. Saturation was also demonstrated by comparing *fished* and *not-fished* traps of the same size. Here, differences were significant by 4 h in small and medium traps and by 6 h in large traps. The fact that catches in small *fished* traps were lower than in medium and large *fished* traps indicates that catches in small traps were limited by saturation in even less than 2 h, the interval between emptying.

Rates of escape from the three trap sizes were observed in an attempt to explain the higher crab density in larger traps. Ten crabs were stocked in each trap, the traps set in the field and then lifted after 1, 2, 4, 8, and 12 h to count the crabs remaining. Five crabs were also placed in a trap fitted with a collar that prevented escape as a control for crabs entering. Only one crab entered these control traps in five replications. All stocked crabs were taken from the laboratory where they had been held for a few days to a few weeks. Chi-square tests were again used to investigate homogeneity among replications (none were significant) and to compare treatment totals at each observation time.

The ease of escapement from the small trap (Fig. 5) suggests this is an important contributor to the low

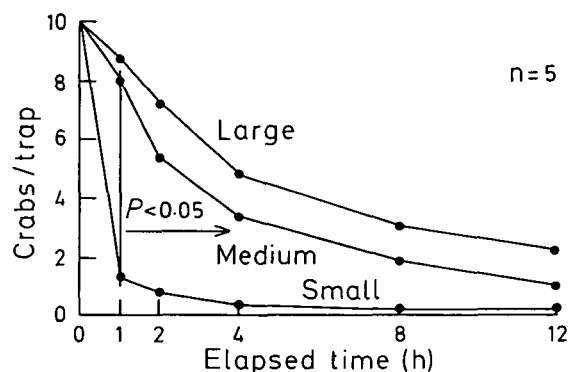


Figure 5. Test of the hypothesis that catch differences in three trap sizes can be explained by differences in the rates of escape.

packing density relative to larger traps; however, the data are inconclusive regarding the relative crab densities in medium and large traps. The number of crabs remaining in the small trap was significantly less than in the two larger traps at every observation. Whereas slightly more crabs escaped from the medium than from the large trap, the difference was not statistically significant. This experiment failed to mimic trapping experiments in ways that complicate interpretation of results: traps had no bait, all traps began with the same number of crabs, crabs were introduced to traps by hand, and there were no entrants to traps during the experiment.

The next two experiments tested the hypotheses that catch would be increased by preventing escape and that saturation was due entirely to escape. Traps fitted with collars caught more than traps without collars, and the difference was significant by 8 h (Fig. 6). Preventing escape did not eliminate saturation, however, as catch differences in *fished* and *not-fished* traps (both with collars) were also significant by 8 h (Fig. 7). By 12 h, the cumulative catch in *fished* traps was 1.7 times greater than the

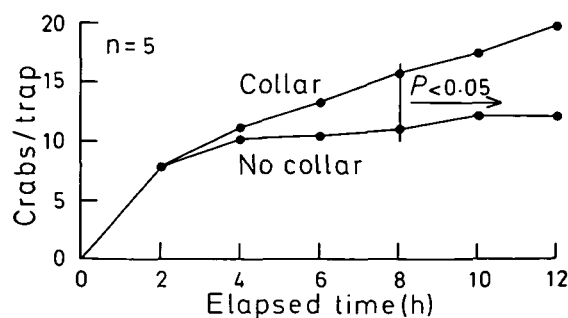


Figure 6. Test of the hypothesis that catch increases if escape is prevented.

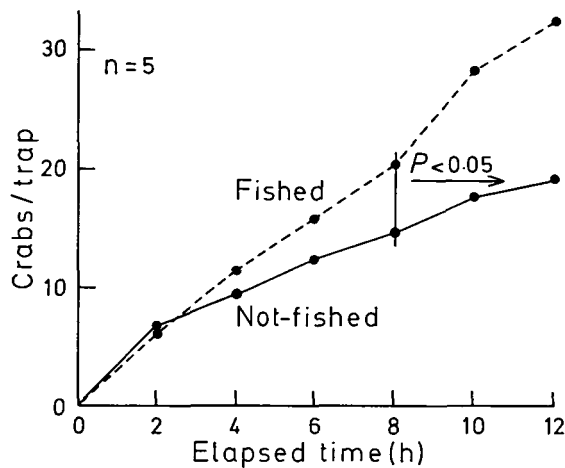


Figure 7. Test of the hypothesis that saturation does not limit catch if escape is prevented.

catch in traps *not-fished*. Thus, both escapement and reduced entry were factors in saturation.

The last experiment with *C. productus* demonstrated the synergistic effects of exposed bait, collar to prevent escape, and *fished* strategy compared with enclosed bait, no collar, and *not-fished* strategy (Fig. 8). At the time of this experiment in early November, catches were very low during daylight so saturation was evident only during the last 6 h of observation. In spite of this, by 12 h the ratio of catches in the two treatments was 4.9:1.

The variables discussed above produced increases in catches ranging from 1.6 to 4.9 times after 12 h fishing (Table 3). If the *fished: not-fished* comparisons had been continued for more than 12 h, the catch differences would certainly have been greater since these differences were increasing at the end of every experiment.

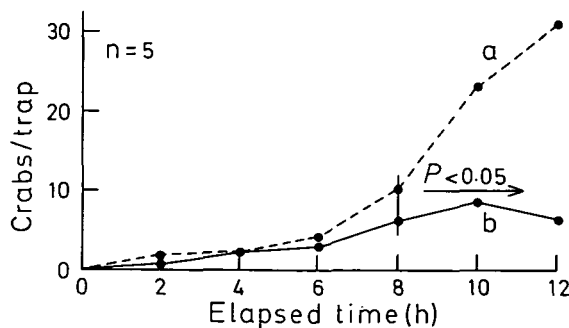


Figure 8. A comparison between the combined effect on catch of the *fished* strategy, escape-proof collars, and exposed bait (a) and the *not-fished* strategy, no collars, and enclosed bait (b).

Table 3. Ratios of catches after 12 h in traps of different designs or fished with different strategies.

| Comparison | Catch ratio |
|--|-------------|
| Exposed versus enclosed bait, <i>not-fished</i> , no collar | 2.2:1 |
| <i>Fished</i> versus <i>not-fished</i> , bait exposed, no collar | 2.7:1 |
| Medium versus small trap, <i>not-fished</i> , no collar, bait exposed | 4.7:1 |
| Large versus medium trap, <i>not-fished</i> , no collar, bait exposed | 1.7:1 |
| Collar versus no collar, <i>not-fished</i> , bait exposed | 1.6:1 |
| <i>Fished</i> versus <i>not-fished</i> , collar, bait exposed | 1.7:1 |
| <i>Fished</i> , collar, bait exposed versus <i>not-fished</i> , no collar, bait enclosed | 4.9:1 |

Cancer magister

Commercial traps were fished for this commercial species in a commercial fishing area using two strategies. A common commercial strategy (*not-fished*) was placing herring in a perforated box and leaving the trap for a 48-h soak. My only modification was to lift the traps and count the catch after 5, 10, 24, and 48 h. The second strategy (*fished*) was to expose the herring impaled on a wire, remove the crabs, and rebait the traps after 5, 10, and 24 h. Logistics of the field operation did not permit more frequent observations. Allocation of strategies to trap locations was randomized as with *C. productus*, but an unpaired *t*-test rather than a chi-square test was used to compare strategies because replications were unequal.

The commercial strategy clearly caught only a small fraction of the crabs potentially available to the traps (Fig. 9). After 5 h catches from the two

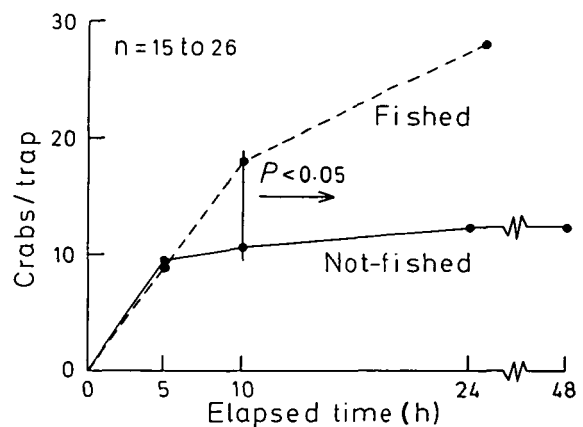


Figure 9. A comparison between catch using a common commercial fishing strategy of 48 h soak time and enclosed bait, and a modified strategy of exposed bait and fishing traps three times per day.

strategies were nearly identical. However, catches in traps that were *not-fished* increased from only 9.5 to 12.4 crabs/trap over 5 to 24 h, and remained unchanged from 24 to 48 h. By contrast, the catches in the traps that were *fished* were nearly identical at each observation: 9.1, 9.0, and 10.0, giving a cumulative catch of 28.1 crabs/trap at 24 h. Extrapolating the *fished* strategy to catches for a second 24-h period would yield a *fished: not-fished* ratio of 4.5:1. Because mean catches for both strategies at all soak times were similar, 9.0 to 12.5 crabs/trap, I assume that catches were limited by saturation in less than 5 h. Thus, more frequent fishing would have produced a larger *fished: not-fished* catch ratio. Exposed bait was probably no asset to the *fished* strategy since 1) after 5 h catches with exposed and enclosed bait were the same and 2) greater than average catches (about 9/trap) of these large crabs consumed all the bait (about 1 kg) within 5 h.

Discussion

Catch asymptotic with soak time

Results of this study support earlier work that catch per unit of gear is asymptotic with soak time. Catches for all experimental treatments where traps were not emptied could easily be considered asymptotic. In a classic study, Kennedy (1951) demonstrated for gillnet catches an inverse relationship between the size of catch after a one-day soak and increase in catch for a second-day soak. He fitted by hand a family of curves which approached a common asymptote but at different rates. He assumed this rate was a function of fish availability to the gear. Munro (1974) made a prodigious number of observations on catches of a diverse assemblage of tropical reef fishes in large unbaited traps. These were set for 12 to 15 days and minimum estimates for the numbers of fish which escaped or entered were determined from counts made by divers every two to three days. Catches were asymptotic with soak time, including different locations and dates. Catches of shrimp (*Pandalus platyceros*) in baited traps of different design were observed in the laboratory at 0.5, 1, 2, 3, and 4 h soak (Kessler, 1969) and were also asymptotic.

Factors affecting saturation level

It is important to distinguish between average catch per trap and trap saturation level. Most factors known to affect average catch per trap have not been studied for their effect on saturation level. In well-designed studies on the former soak time is held constant,

whereas for the latter soak time is an experimental variable. For example, a trap that was easy to enter might catch more crabs after a short soak than a trap that was difficult to enter, but after a long soak the two traps could saturate at the same level.

Exposing bait increased trap saturation levels for *C. productus*. Handling and eating the bait may have contributed to either olfactory or visual stimulation of crabs outside the trap.

Preventing escapement clearly increased the saturation level for *C. productus*. Munro (1974) argued that the asymptotic relation of catch to soak time in Antillean fish traps resulted from a nearly constant number of fish entering a trap daily and a constant proportion escaping daily. Thus, the saturation level increased with the rate of entry and was reached when the rate of entry equalled the rate of escape.

Contrary to Munro's (1974) hypothesis of a constant rate of entry, reduced entry was shown to contribute to the saturation level for *C. productus* when escape was prevented. Since the only difference in *fished* and *not-fished* treatments was the number of crabs in a trap, I assumed that the lower catches in traps that were *not-fished* were due to crabs inside intimidating crabs outside which would otherwise have entered. This was previously suggested by laboratory observations on trap catches and crab behaviour relative to traps (Miller, 1978).

Trap size was an important variable determining saturation level, but the differences observed were probably due to both escapement and reduced entry. Because of higher packing density of *C. productus* in larger traps, a small increase in trap size gave a large increase in saturation level. Munro (1974) found the increase in catch of tropical fish proportional to the increase in trap size, i.e. the same packing density was maintained. He attributed differences in catches entirely to differences in rates of escapement.

There are no doubt other determinants of saturation level such as crab motivation to enter (e.g., hunger and bait attractiveness) and tolerance of crowding.

Often fishermen claim to have seen traps completely filled with crabs and they reason from this that the saturation level is equal to a trap's physical capacity. There is now ample evidence that a given trap design does not have a constant saturation level. Identical traps fished in the same manner but at different times or places exhibit different saturation levels. For example, comparison of the trap catches with bait exposed in Figure 2 with the medium-sized traps (*not-fished*) in Figure 4, and with traps without collars in Figure 6 shows asymptotic levels of about 18, 14, and 12 crabs/trap. Sinoda and Kobayasi (1969) fished cone shaped traps for the spider crab,

Chionoecetes japonicus, and calculated saturation values of 30 and 43 crabs/trap for two areas. Saturation catch of tropical fish in unbaited traps varied from about 7 to 30 fish/trap in different months but in the same location (Munro, 1974).

Potential for improved catch per trap day

The gap between potential and realized catch/trap day is very large. The higher catch in each experiment with *C. productus* was a minimum estimate of the number of crabs available at the traps to be caught. Catch improvements ranged from 1.6 to 4.9 times over 12 h and, had *fished: not-fished* comparisons run for longer, differences would have been greater. Soak times in baited trap fisheries are rarely less than 24 h and are typically a few days. Using a commercial fishing strategy for *C. magister* (48-h soak) gave less than one-quarter the catch/trap-day of an alternate strategy. Comparing trap catches of sablefish (*Anoplopoma fimbria*) from 12 and 48 h soak times (Hughes, Worlund and Hipkins, 1970), there was potential for tripling catches. Munro (1974) calculated that the total number of reef fish entering unbaited traps over 12 days exceeded the number remaining by at least a factor of 6.

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