Abstract—Over 230 metric tons of octopus is harvested as bycatch annually in Alaskan trawl, long-line, and pot fisheries. An expanding market has fostered interest in the development of a directed fishery for North Pacific giant octopus (*Enteroctopus dofleini*). To investigate the potential for fishery development we examined the efficacy of four different pot types for capture of this species. During two surveys in Kachemak Bay, Alaska, strings of 16–20 sablefish, Korean hair crab, shrimp, and Kodiak wooden lair pots were set at depths ranging between 62 and 390 meters. Catch-per-unit-of-effort estimates were highest for sablefish and lair pots. Sablefish pots caught significantly heavier North Pacific giant octopuses but also produced the highest bycatch of commercially important species, such as halibut (*Hippoglossus stenolepis*), Pacific cod (*Gadus macrocephalus*), and Tanner crab (*Chionoecetes bairdi*).

Evaluation of the capture efficiency and size selectivity of four pot types in the prospective fishery for North Pacific giant octopus (*Enteroctopus dofleini*)

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The North Pacific giant octopus (*Enteroctopus dofleini*) is a benthic cephalopod fished throughout its range from Baja California to the Aleutian Islands in Alaska and westward in the Pacific Ocean to Japan. Many artisanal fisheries use trailing hooks, longlines, handlines, and spears as means of harvest. Since the 1970s, increasing overseas food markets and local bait industries have triggered several attempts to develop a commercial fishery for the North Pacific giant octopus (hereafter referred to as "giant octopus" in this article) in Alaska (Paust, 1997), but little is known about the efficacy of different gear types for the capture of this species in Alaska.

Currently, the Alaska Department of Fish and Game allows commercial harvest of octopus within state waters only as incidental catch managed under state permits. Retention levels as bycatch vary from about 5% in the pot gear fishery for shrimp in southeast Alaska to about 20% in the state groundfish fisheries. Paust (1997) compared four lair pot designs and found that because of low construction costs, reduced space needed for storage, relative ease of handling, and a superior fishing performance over other lair pot designs, the wooden Kodiak pot would be the best choice for fishery development in Alaska. No baited pots were included in Paust's study design. Paust (1997) assumed new entrants into a directed fishery for giant octopus will most likely integrate directed fishing for the giant octopus as an off-season or secondary fishery. Such a developing fishery would have high start-up costs and no proven returns, limiting its participants to using fishing gear from other fisheries. Given the value of data on the effectiveness at capturing giant octopus with equipment already used in Alaska fisheries, we examined the efficiency and size selectivity of four pot types for their use in a directed fishery for this species.

Materials and methods

Two surveys were completed (2–13 October 2006, and 25 November to 6 December 2006) in Kachemak Bay, Alaska (Fig. 1). Four types of pots were used during the course of the study: lair, Korean hair crab, sablefish, and shrimp pots (Fig. 2). Lair pots were constructed of wood, measured 60.96 cm × 30.48 cm × 30.48 cm with a 15.42 cm × 30.48 cm opening, and were left unbaited. Korean hair crab pots consisted of PVC piping and were 45 cm tall and had a 100-cm base diameter and a 26-cm plastic

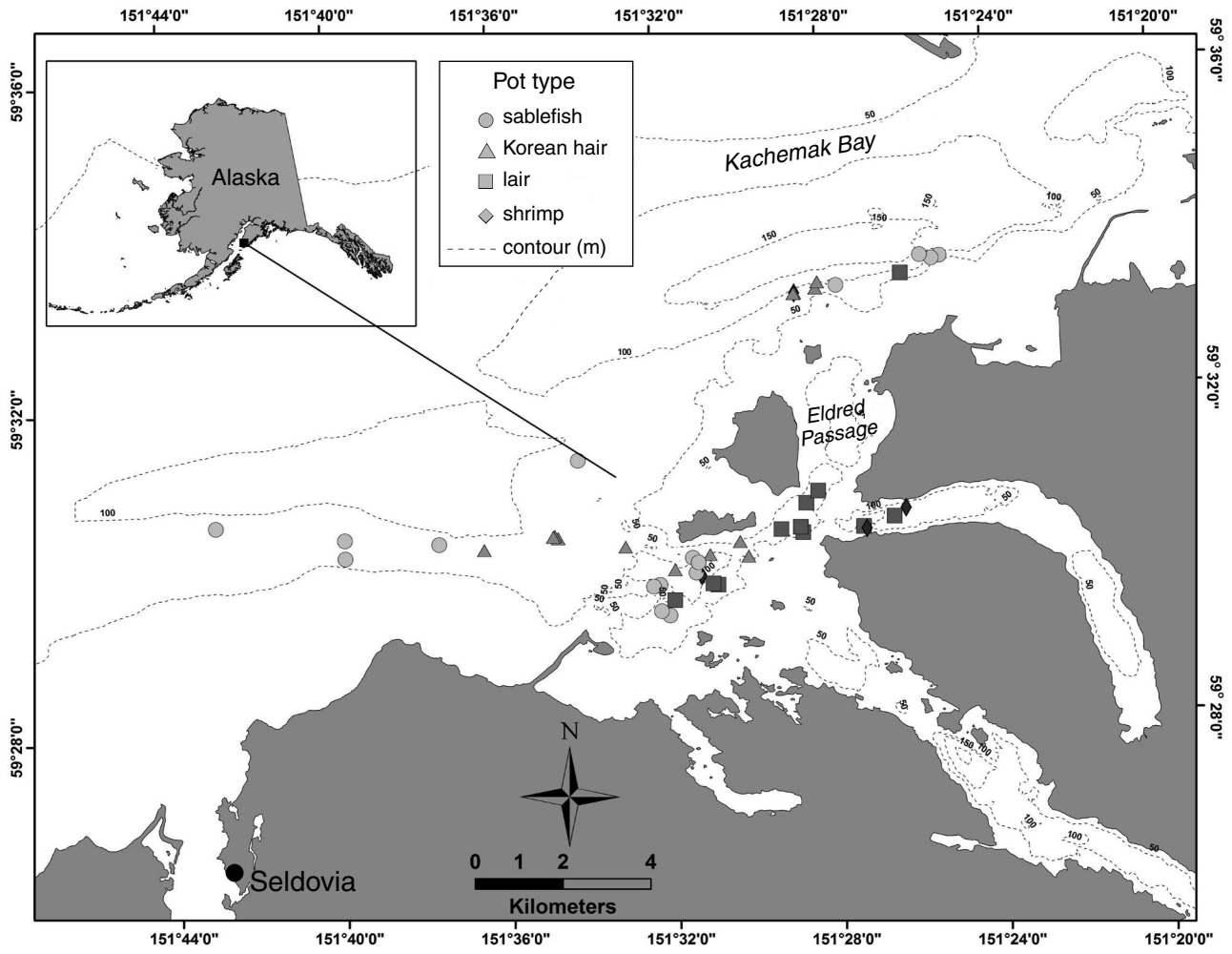

Figure 1

Map of Kachemak Bay, Alaska, and location of pots set to catch North Pacific giant octopus (*Enteroctopus dofleini*) to evaluate the efficiency of the pots for use in a directed North Pacific giant octopus fishery. Each marker represents the first marker buoy in a string of 16–20 pots, set during two surveys in 2006.

tunnel. Sablefish pots were made of 1.3-cm rebar and measured 147 cm tall and had a 122-cm bottom ring and a 71-cm top ring. The sock tunnel opening was 25 cm wide and located 76 cm from the bottom. The net used was 7-cm mesh black seine net. Korean hair crab and sablefish pots were baited with chopped herring. Both commercial and personal-use Ladner shrimp pots had three 7.62-cm tunnel openings and were baited with either herring or prawn pellets.

Each string of pots consisted of a single pot type to best replicate fishing practices and to make the process of setting and retrieving pots as safe as possible. Each string of pots consisted of 20 pots spaced nine meters apart and two marker buoys were attached to each end. Lair pot strings had only 16 pots. We removed the shrimp pots from the sampling design for the second survey because of their low catch per unit of effort (CPUE).

To facilitate handling, captured giant octopuses were placed in mesh bags and kept in individual (53 liters/ 60.7×40.4×31cm) Rubbermaid® containers. Containers were filled with seawater and the water was exchanged every five minutes by using a pump placed approximately one meter below the surface of the water. The sex of each animal was determined by the presence (male) or absence (female) of the hectocotylized right third arm. If the animal had lost the tip of its right third arm we could not determine sex. We recorded morphometric measurements including the interocular distance (IOD), mantle length (ML), and wet weight, as well as any identifying marks for each individual. Muscle tissue from the tip of the left third arm was clipped and preserved in 95% ethanol for future genetic analysis.

Descriptive summary statistics of individuals captured, capture rates of each pot type, and capture rates by survey were tabulated. A paired t-test was used to compare the weights of males (n=114) and females (n=128) captured. We could not determine sex for 8 individuals. They were omitted from all analyses of differences between the sexes. Size selectivity was as-

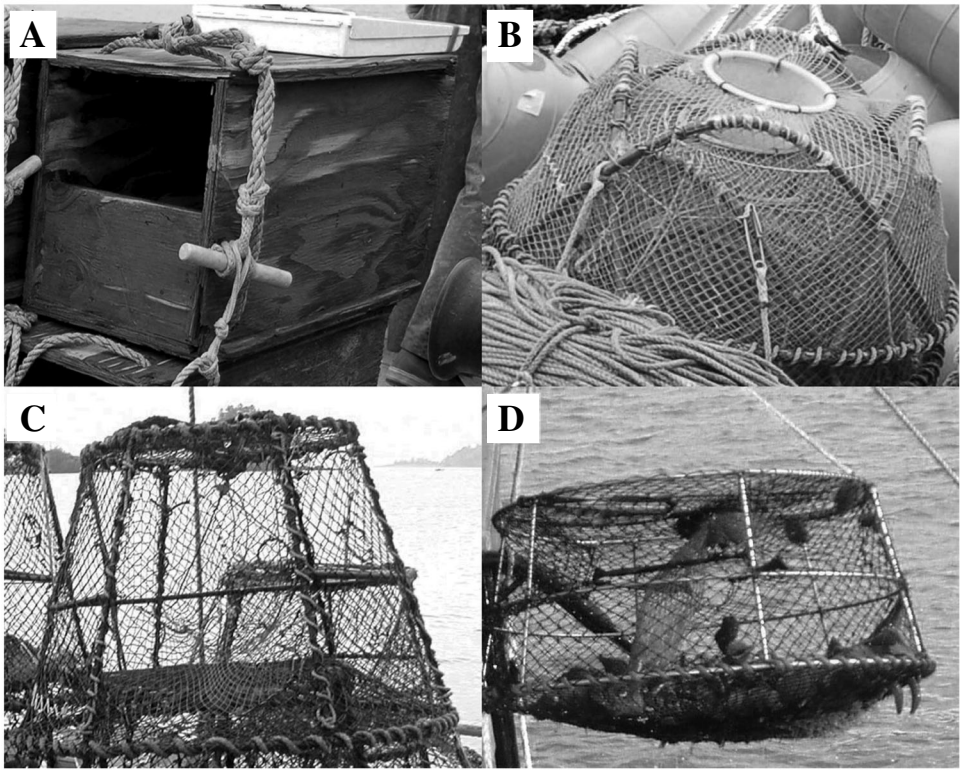

Figure 2

The four pot types we evaluated in Kachemak Bay, Alaska, in 2006 to determine their efficiency in capturing North Pacific giant octopus (*Enteroctopus dofleini*) for use in a directed fishery: (**A**) Lair pots; (**B**) Korean hair crab pots; (**C**) sablefish pots; and (**D**) shrimp pots.

sessed by comparing mean weight of octopuses caught in each pot type. Because of heteroscedasticity in the data we used a nonparametric Welch analysis of variance (ANOVA) to test for variation in the weight of octopuses by pot type, followed by Tukey's *post hoc* tests. In order to diminish the potential confounding effects of differences in depths at which pots were set, we reanalyzed weight by pot-type data using only giant octopuses caught within Eldred Passage where depth did not differ significantly by pot type, using an ANOVA and Fisher's least significant difference (LSD) test. Individual chi-square tests were used to determine whether there was a disproportionate number of males or females caught in any one trap type.

No standardized method exists to measure octopus CPUE. In octopus fisheries around the world CPUE is tailored to the type of fishery (Defeo and Castilla, 1998; Hernandez-Garcia et al., 1998; Sanchez et al., 2004). There are markets for both food and bait giant octopuses and in Alaska the fishery would not be size selective. In a full-time directed fishery where the ability to turn over gear is important, "the total catch in kilograms (kg) per days soaked" may be a most useful expression of effort. In contrast, kilograms per pot may be a more useful indicator of effort in a part-time fishery. The number of pots soaking may be more important if a vessel is employed to simultaneously take part in another fishery while its pots for giant octopus are soaking. Irrespective of the fishery structure, whether full-time or concurrent, both CPUE estimates provide valuable information for resource management. Both CPUE estimates were calculated for each individual survey and then averaged over surveys. No statistical tests were performed on CPUE data because the averages calculated over the two surveys are based on two estimates. Catch-per-unit-of-effort values for shrimp pots represent point estimates because shrimp pots were fished only in the first survey. We compared the average soak time of lair pots that caught giant octopuses to those that did not by using a *post hoc* *t*-test to investigate anecdotal evidence that would indicate that longer soak times increase the likelihood of capture.

Results

We captured a combined total of 254 giant octopuses, four of which were dead and omitted from further analysis. The number of individuals captured was consistent

between surveys; 122 and 128 individuals captured in the first and second surveys, respectively. Of the total 250 individuals captured, the numbers caught among the pot types was as follows: 107 in lair pots, 35 in Korean hair pots, 102 in sablefish pots, and 6 in shrimp pots.

Sablefish pots captured significantly heavier individuals than all other pot types (Fig. 3), but the weight of these giant octopuses captured in the other three pot types did not differ significantly from one another (Welch ANOVA, df=3,32.241, F=28.115, P<0.001 Tukey HSD). The depth at which pots were set, however, was not determined at random. Larger giant octopuses may be found in deeper water resulting in biased estimates. Although a regression of weight by depth showed a very weak correlation (coefficient of correlation (r^2)=0.0019, P=0.49), in order to mitigate the potential confounding effects of depth, we re-analyzed weight by pot type using only giant octopuses caught within Eldred Passage where depth did not differ significantly by pot type. Giant octopuses caught in sablefish pots remained significantly heavier than those caught in both lair and shrimp pots, but there was not a significant difference in mean weight between sablefish and Korean hair crab pots (ANOVA, df=3, F=10.599, P<0.001 Fisher's LSD). Among the 112 males and 126 females captured, males were heavier than females (t-test, df=1, F=7.166, P=0.008). However, this finding did not seem to be driving the observed difference in weight by pot type because for each pot type both sexes were equally likely to be captured (lair: χ^2=0.154, P=0.695, Korean hair crab: χ^2=0.030, P=0.862, sablefish: χ^2=0.853, P=0.356, and shrimp: χ^2=0, P=1).

Capture efficiency varied both temporally and with the CPUE index (kg/days soaked vs. kg/pot set). Between the two surveys the efficiency of both lair and Korean hair crab pots increased and the efficiency of sablefish pots decreased. The average CPUE for all pot types between surveys ranged from 5.5 kg/pot (±1.7 SD [standard deviation]) for the lair pots to 0.4 kg/pot for shrimp pots, and 17.6 kg/days soaked (±2.7 SD) for the sablefish pots to 2.1 kg/days soaked for shrimp pots (Fig. 4). Lair pots that caught giant octopuses were not soaked longer than pots that did not capture octopuses (t-test df=1, F=0.214, P=0.644).

Both sablefish and Korean hair crab pots caught large numbers of commercially important crab and fish species as bycatch. Korean hair crab pots caught Tanner crabs (*Chionoecetes bairdi*) and Pacific cod (*Gadus macrocephalus*; sizes ranging from 26 to 100 cm total length). Sablefish pots caught *C. bairdi*, *G. macrocephalus,* and halibut (*Hippoglossus stenolepis*; sizes ranging from 29 to 112 cm total length). Lair and shrimp pots did not contain bycatch of commercially important species. Other bycatch species, caught in all four pot types were lyre crabs (*Hyas lyratus*), decorator crabs (*Oregonia gracilis*), sunflower sea stars (*Pycnopodia helianthoides*), and Oregon hairy tritons (*Fusitriton oregonensis*).

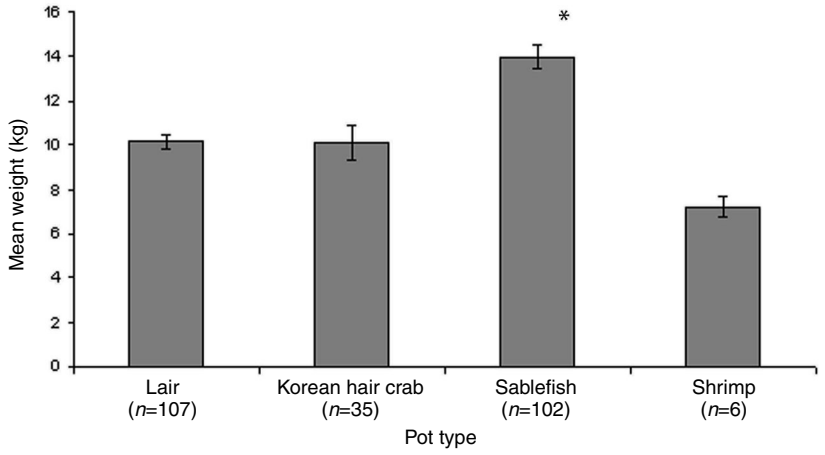

Figure 3

Mean weight (±standard error [SE]) in kilograms and numbers (in parentheses) of North Pacific giant octopus (*Enteroctopus dofleini*) caught in each of the four pot types, during two surveys in Kachemak Bay, Alaska, in 2006, evaluated for size selectivity for use in a directed North Pacific giant octopus fishery. The asterisk indicates a significant difference at P<0.001.

Discussion

The internal volume of each pot may be a better indicator than the size of the pot entrance for the potential size of giant octopuses that will be caught. Although lair, Korean hair crab, and sablefish pots had similar size openings, the success of the sablefish pots may have been due to their volume being three times greater than that of the Korean hair crab pots and nearly twenty times that of the lair pots. The ability of giant octopuses to enter a trap is most likely determined by the size of its beak, the only hard part of its body.

Variation in the size of North Pacific giant octopuses caught by the different pot types may be influenced by differences in depth or substrate rather than by pot type alone. However, when pots laid at similar depths in Eldred Passage were analyzed, we observed similar trends in the data, indicating that sablefish pots have the potential to capture larger giant octopuses than the other pots.

Pot efficiency changed with different measurements of effort. Lair pots, because of their long soak times, may be more useful in a fishery where operators are fishing for giant octopus and another species concurrently. Anecdotal evidence from the use of lair pots indicates

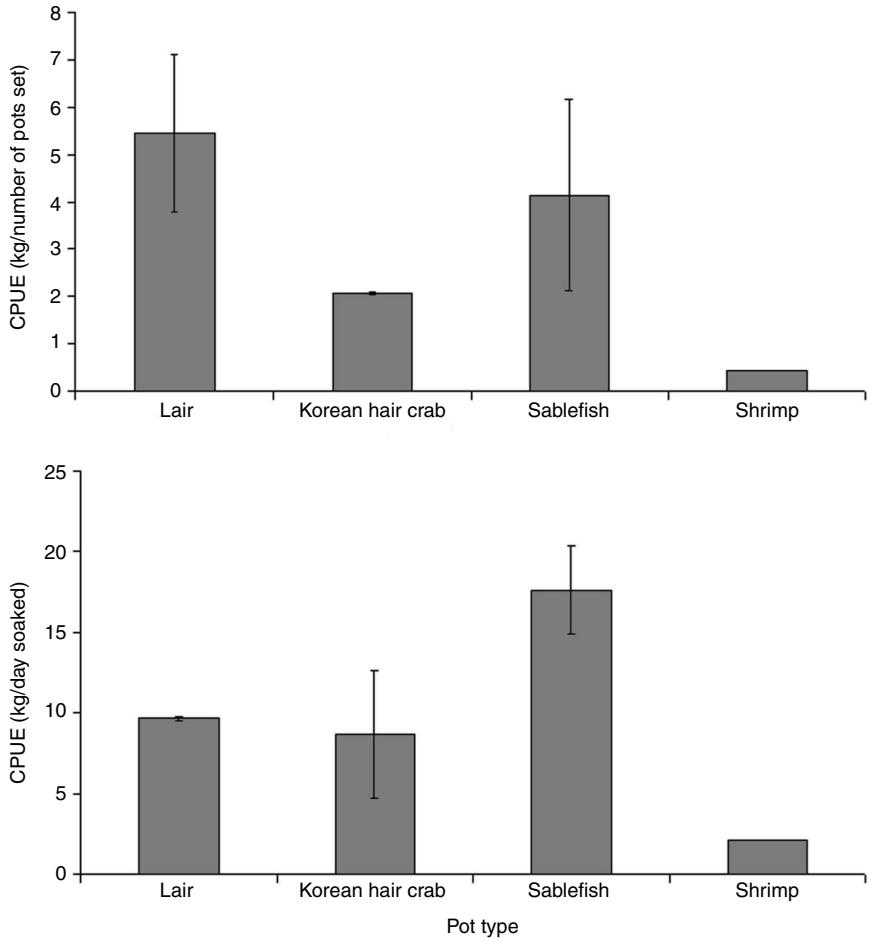

Figure 4

Mean catch per unit of effort (CPUE; ±standard deviation [SD]), measured as both kilograms per hours soaked and kilograms per number of pots set, for each of the four pot types evaluated for capture efficiency of North Pacific giant octopus (*Enteroctopus dofleini*) during two surveys in Kachemak Bay, Alaska, in 2006. Estimates of CPUE are based on a mean of two estimates; therefore no statistical tests were performed.

an optimal soak time of approximately seven days. These pots do not require baiting to be effective and therefore it is unlikely that prolonged soak times (longer than seven days) will decrease their effectiveness. We suspect that increasing the total volume of the pot and decreasing the size of the opening of lair pots may increase catch rates.

Sablefish pots proved to be the most efficient gear type tested in terms of kilograms per hours soaked, indicating that fewer pots could be fished with short soak times. Although their efficiency in terms of kg/pot may be lower than that of lair pots, shorter soak times allow for increased pot turnover. The capital investment for fishermen already using pots in the sablefish fishery would be minimal and the season could begin after the sablefish season closes in November. Shrimp pots captured relatively few octopuses and those caught generally were smaller in size, possibly because of the small diameter of the pot entrance. Korean hair crab pots caught only slightly larger individuals and had a similarly low CPUE, despite having a much larger entrance.

The high incidence of bycatch of commercially important species by the sablefish pots may limit their usefulness in a directed fishery for North Pacific giant octopus. Vessels targeting the giant octopus would not be allowed to target any other species and all bycatch would be limited to a small percentage of the total weight of the giant octopus onboard. Bycatch reducing devices have been successful in reducing the bycatch of sea turtles (Fratto et al., 2008), crabs (Furevik et al., 2008), and birds (Butler and Heinrich, 2007) in multiple pot fisheries while maintaining high catch rates of their target species. Depending on our ability

to minimize bycatch by sablefish pots, it may be a better strategy to use a pot type that is less efficient in terms of kilograms per hours soaked, but that has a lower bycatch rate.

Additional considerations to the season and type of pot used in a directed North Pacific giant octopus fishery must be made to ensure that fishermen are not disproportionately harvesting spawning giant octopuses. During two captures in which we manipulated females, they extruded spermatophores. Although females after spawning survive to care for eggs, males die within a month of copulation (Hartwick, 1983; Arnold et al., 1987) leading us to assume that the four octopuses captured dead were recently spawned males. Due to decomposition of the bodies we could not confirm sex; however, other observations of deteriorating body conditions of males during the second survey support this conclusion. Lair pots, to be efficient, rely on the giant octopuses using them as a den for short periods of time. During the breeding season, females may use these pots to lay and brood their eggs. If females do use lair pots for denning and giant octopuses exhibit a migration to inshore waters to reproduce (Hartwick, 1983), care must be taken to ensure a large enough escapement to prevent localized depletions and ensure sustainable harvest.

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