Abstract.–Sidescan sonar was used to locate 189 putative lost crab pots in a 4.5 km^2 area of Chiniak Bay, near Kodiak, Alaska. Subsequent observations of 15 such objects by submersible and ROV verified that they were indeed crab pots. In 1995 and 1996, 147 pots were recovered from the surveyed and adjacent nonsurveyed areas by grappling, and their condition and contents were examined. Tanner crabs, *Chionoecetes bairdi*, were the most abundant organism, with 227 found in 24 pots (16% frequency of occurrence); sunflower sea stars (*Pycnopodia helianthoides*) were the most frequent (42%) occupant and second most abundant (189 in 62 pots). Octopuses (*Octopus dofleini*) were significantly associated with pots containing Tanner crabs. Occurrence of crabs in pots was primarily a function of background crab density and differed between the surveyed and nonsurveyed areas. Recently lost pots (< 1yr old) had significantly more male crabs, significantly larger male crabs, and contained seven times more total crabs than older pots (those lost two or more years prior to recovery). The proportion of pots with damaged webbing increased with pot age, but holes in pot webbing did not significantly affect catch per pot.

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Ghost fishing by Tanner crab (*Chionoecetes bairdi*) pots off Kodiak, Alaska: pot density and catch per trap as determined from sidescan sonar and pot recovery data

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Lost and derelict fishing gear is a problem because of concerns about aesthetics at sea, entanglement of marine fauna, and ghost fishing by the gear (Sheldon and Dow, 1975; Smolowitz, 1978a; Breen, 1990). Marine mammals, birds and reptiles (Laist, 1996), nontargeted fish and shellfish (Carr et. al., 1990), and even boats (Kirkley and McConnell, 1997) have become entangled in fishing gear. In this paper ghost fishing is "the ability of fishing gear to continue fishing after all control of that gear is lost by the fisherman," as defined by Smolowitz (1978a).

Attempts to quantify the extent and impacts of ghost fishing have met with variable success (Sheldon and Dow, 1975; Smolowitz, 1978b; High and Worlund, 1979; Muir et al., 1984; Breen, 1987; Parish and Kazama, 1992; Guillory, 1993). Parish and Kazama (1992) concluded that ghost fishing of Hawaiian spiny lobsters (*Panulirus marginatus)* was unimportant because the lobsters could escape from pots easily. Conversely, Sheldon and Dow (1975) estimated that approximately one third of all American lobsters (*Homarus americanus*) entering lost pots would perish. Other studies have identified ghost fishing as a concern or possible problem and have identified potential solutions to reduce resource loss (High, 1976; Pecci et al., 1978; Smolowitz, 1978b; High and Worlund, 1979; Carr and Harris, 1997). The impact of ghost fishing by lost crab pots in Alaska waters has been studied by High and Worlund (1979), Kimker (1994), Stevens (1996), Kruse and Kimker,[1] and Ste-

[1] Kruse, G. H. and A. Kimker. 1993. Degradable escape mechanisms for pot gear: a summary report to the Alaska Board of Fisheries. Regional information report 5J93-01. Alaska Department of Fish and Game (ADFG), 211 Mission Rd., Kodiak, AK 99615, 23 p.

vens et al.[2] High and Worlund (1979) placed red king crab in unbaited square pots; after 16 days, 20% of legal-size crabs remained in the pots. Those crabs that escaped after prolonged enclosure were recaptured at lower rates than those that escaped quickly. Crabs that were placed in closed unbaited square pots exhibited mortalities from 4% to 12% after 16 days.

In our report we examined ghost fishing by lost crab pots in specific areas off the northeast shore of Kodiak Island, Alaska. In Chiniak Bay, the locations of 189 putative lost pots were discovered in April 1994 with sidescan sonar. With this sonar survey as a guide, we estimated the extent of ghost fishing by recovering lost pots and examining their contents. Three studies were conducted: 1) a pilot study within Chiniak Bay in 1995 to develop methods for pot recovery; 2) a targeted study in 1996 to recover specifically identified pots from known locations within Chiniak Bay; and 3) a nontargeted study in 1996 within Chiniak, Kalsin, Womans, and Ugak Bays, to recover pots from areas known to have been heavily fished during past crab fisheries, without attempting to target specific pots. These efforts were carried out jointly by the Alaska Department of Fish and Game (ADF&G) and the National Marine Fisheries Service (NMFS), with assistance from the U.S. Army Corps of Engineers (USACE) and the Kodiak Island Borough (KIB).

Materials and methods

Sidescan sonar survey and *in-situ* observations

The sonar survey was conducted by scientists at SAIC, Inc., using a dual frequency (100/500 KHz) sidescan sonar system (Klein model 595), with both a paper chart and digital data signal processor. Positions were recorded with a differential GPS receiver. The sonar was operated from the Alaska Department of Fish and Game (ADF&G) RV *Resolution* during 6–8 April 1994, in a portion of Chiniak Bay at depths of 100–150 m. Transects 3 km in length were run at a spacing of 75 m, such that the scanning of each line overlapped those on each side by 50%, providing a total coverage of 150%. A total area of approximately 4.5 km^2 was surveyed. From 22 April to 2 May 1995, the two-person submersible *Delta* was used to survey the area for a study of crab behavior (Stevens et al., in press); pots that were encountered accidentally during that study were examined. On 27 April 1995, a remotely operated vehicle (model S2 ROV Phantom, Deep Ocean Engineering, Inc.) equipped with a sector-scanning sonar was also used to locate and examine crab pots.

1995 pilot study

Pots identified from the sidescan sonar survey were plotted on a map (Fig. 1), then numbered. A random sample of 23 single pots was chosen for trial recovery in April 1995. A short (7.6-m) grappling chain, designed to hook the pot or its floating line, or both, was towed from the main boom of the RV *Resolution*. The grappling chain was lowered into the water when the ship was approximately 250 m from the estimated position of the targeted pot, then towed past the position at less than 5.6 km/h (3 kn). If the recovery operation was not successful, the vessel would continue to tow the grappling chain in a circle around the same position until the pot was hooked or until we gave up. When a pot was hooked, it was brought onboard with the ship's crane. Information about the pot and its contents was recorded, including pot type, condition, damage to the frame or webbing, and presence of bait jars and biodegradable mesh. In most cases the grapple snagged the steel frame of the pot and it was not possible to determine if snagging action caused additional damage to the webbing.

In our paper, we use the terms "trap" and "pot" interchangeably. The three types of crab traps most commonly used in the Gulf of Alaska are square, pyramidal, and conical (see High and Worlund, 1979, for detailed descriptions). Square pots are the most commonly used type in the Bering Sea and are made with steel frames, usually >2 × 2 m, with two funnel-shaped entrance tunnels on opposite sides. Pyramidal and conical pots are slightly smaller and have a single square or round entrance at the top, which is usually fitted with a plastic collar. All three of these types of pots are covered with nylon twine webbing. Cod pots are square pots that have been modified for cod fishing by the addition of restriction devices to prevent entry of crabs and escapement of cod. Subsistence pots, used to capture crabs for personal consumption, may be any of the above styles of pots or variations thereof. Pot conditions were rated on a subjective five-point scale from "very poor" to "excellent." Criteria used to evaluate condition included the condition of webbing (presence of holes or major gaps), numbers of broken frames and corner joints, and estimated age of the pot. Pots coded as "good" or "excellent" were assumed to have been lost less than one year and were probably placed for subsis-

[2] Stevens, B. G., J. A. Haaga, and W. E. Donaldson. 1993. Underwater observations on behavior of king crabs escaping from crab pots. Alaska Fisheries Science Center processed report 93-06. Alaska Fisheries Science Center, NMFS, 7600 Sand Point Way NE, Seattle, WA 98115, 14 p.

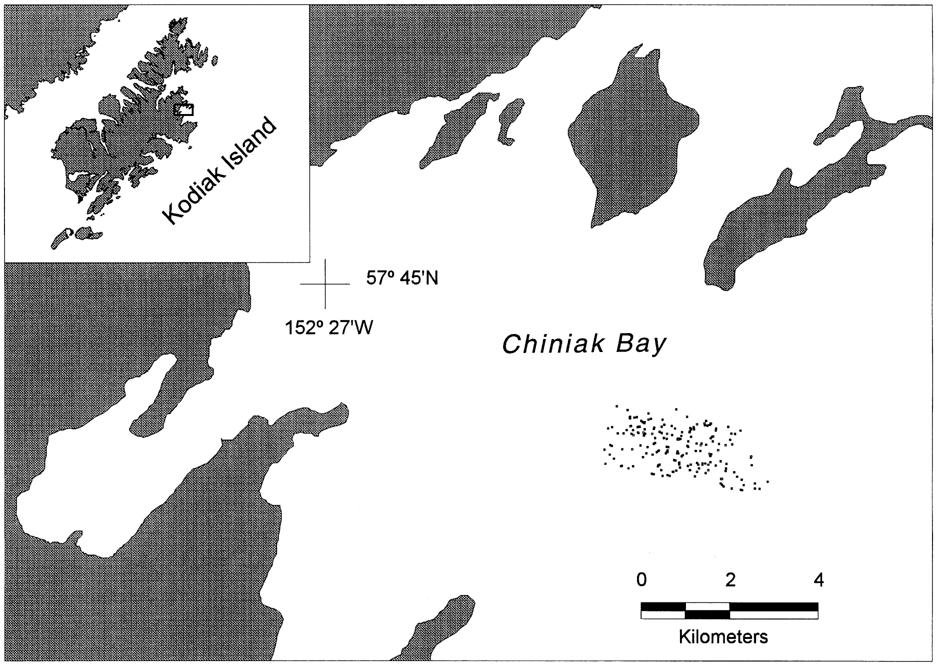

Figure 1

Chart of Chiniak Bay, Kodiak Island, Alaska, showing position of pots discovered by sidescan sonar survey. Inset shows location of Chiniak Bay on Kodiak Island.

tence use, whereas pots coded as "fair," "poor," or "very poor" were assumed to have been lost more than one year. Commercial fishing for Tanner crabs around the northeast quadrant of Kodiak Island has been closed since January 1994, and for king crab since 1983[3]; therefore no commercial crab pots have been used in the region since that time, although subsistence pots are still allowed. Therefore, recovered pots would have to have been lost at least 2 years previously (prior to April 1993), unless used for subsistence purposes. Since 1977, the state of Alaska has required that all crab pots contain an 18-inch (45.7-cm) segment of biodegradable twine that degrades within 90 days (Alaska Statutes, 1996). For this reason, all pots were examined for the presence and condition of degradable twine. However, it was not our goal to study the effectiveness of biodegradable twine because suitable control pots were not available. Furthermore, absence of biodegradable twine was inconclusive when holes were present in the webbing, because it could have indicated either that the twine had already degraded or that no twine had been present and holes resulted from some other cause.

[3] ADF&G (Alaska Dept. Fish and Game). 1996. Annual management report for the shellfish fisheries of the Westward Region, 1996. Regional information report 4K97-41. ADF&G, 211 Mission Rd. Kodiak, AK 99615.

For all crabs found in pots, carapace width (CW) was measured to the nearest mm with vernier calipers across the widest part of the carapace, excluding spines. Abundance of all other species inside the pot and size of commercially important species was also recorded. These procedures were repeated for each pot. All retrieved pots had their webbing cut and were disposed of at a location designated by the USACE and the KIB.

Targeted study

From 17 June to 18 July 1996, the procedures developed during 1995 were again used, with some modifications. The study was conducted by biologists aboard the contracted fishing vessel *Big Valley*. Pots were randomly selected for retrieval from the list of putative pot positions. Gear used for this study was a grappling beam made of 6.4 m long, 5.1 cm diameter steel pipe, and was pulled by a braided steel wire cable with a synthetic bridle. A 183-m tag line and buoy were attached to the beam to retrieve the device if the tow line was broken. Attached to the beam were six grapples, each consisting of a 1.2-m long "V" bar with two 30-cm arms welded so as to project forward and down. After the first week, a second set of arms was welded to the grapples facing upward, and on 8 July 1996, 7.6-cm barbs were welded to the ends of each arm to prevent snagged lines or pot frames from slipping off during recovery. The grapple beam was lowered into the water with enough cable to maintain a 2:1 scope (ratio of wire out to depth), and towed through the suspected pot position. If no pot was hooked, additional transects were run parallel to the first, or the vessel was set into a sharp turn and the beam was towed in a circle. Hooked pots were retrieved with the ship's crane, while the vessel ran at a slow speed. Recovered pots were designated by the number of the most likely sonar position where they were found, and information was recorded as during the pilot study. The southeast section of the sonar-surveyed area could not be sampled owing to underwater cables and rocks.

Nontargeted study

The nontargeted study was conducted by the skipper and crew of the FV *Big Valley* without biologists aboard during 19–31 August 1996 and 5–21 October 1996. Previous attempts to snag randomly selected (i.e. targeted) pots were not particularly efficient because only 43 pots were recovered during 32 days of fishing. Therefore, instead of targeting specific pots for recovery, the skipper was instructed to fish haphazardly at his own discretion in areas where commercial crab fishing had previously been conducted, but without knowing specific pot locations. This method was more efficient and productive. The grapple beam was damaged, however; therefore it was replaced with a 30-m long weighted chain, to which were attached six short grapples, each with four barbed tines. The long grapple chain was towed at 2.8 km/h in a constant 10 turn until a pot was hooked. Recovered pots were given sequential numbers, and data were recorded as before.

Data analysis

Because Tanner crabs were the target species for most pots, associations between the presence of Tanner crabs and other species were tested by contingency table (chi-square) analysis. To reduce empty cells, Tanner crabs were combined into logarithmic categories (0, 1–9, 10–99, >99) before analysis. Association between pot condition and sex of the crabs was also tested by means of chi-square. For this purpose, pots were regrouped into two categories designated "best" (including pots coded as "excellent" or "good") and "worst" (including "fair," "poor," or "very poor" pots). Mean sizes of crabs in various condition categories are given as mean ±SE and were compared by means of the Mann-Whitney *U*-test (MWU) because variances were typically unequal (Zar, 1984). Catch of crabs or other organisms is expressed as catch per pot (CPP, i.e. crab per pot). CPP was not standardized by time because we could not adequately determine how long each pot had been in the water. The effect of holes in pot webbing on crab CPP was tested with the MWU-test; additionally, binomial confidence intervals were calculated for the proportion of pots with crabs and compared for overlap between pots with holes and those without. The null hypothesis was that torn pot webbing had no effect on CPP.

Results

Sonar survey and *in-situ* observations

Submersible observations in 1995 and previous years showed that seafloor substrates in the surveyed area were primarily sandy silt with occasional areas of compacted mud, and bottom contour was relatively flat below 100 m depth (senior author, personal obs.). The soft mud bottom absorbed most of the transmitted sonar energy and reflected very little. As a result, crab pots and other anthropogenic objects were easily distinguishable with the sidescan sonar. At least 189 objects were believed to be crab pots; 177 were single and 12 were connected together in groups of 2 to 5. In some cases attached lines could also be distinguished by sonar. Density of crab pots in the 4.5-km^2 area examined was 42 pots/km^2. At least 15 of these objects were later observed with the submersible *Delta* and the ROV, and all were verified to be crab pots, including a group of five pots connected together by tangled lines. Also noticeable were several large linear features up to 2 km long; one was later observed from the *Delta* to be a drag scar or ditch, approximately 0.5 m deep and 3–5 m wide.

Condition of pots recovered

A total of 147 pots of varying age, size, and type were retrieved during the three studies (Table 1; Fig. 2). Detailed information on location, condition, and contents of each pot is contained in a separate data report.[4] Seventy-two pots were recovered from inside the sonar-surveyed portion of Chiniak Bay (these are subsequently referred to as "inside" pots), including

[4] Vining, I., S. Byersdorfer, W. E. Donaldson, B. G. Stevens, and G. Edwards. 1997. Lost crab and cod pot recovery and ghost fishing in Chiniak Bay and other areas in the waters around Kodiak Island, Alaska. Regional information report 4K97-42. Alaska Dept. of Fish and Game, 211 Mission Rd., Kodiak, Alaska 99615, 93 p.

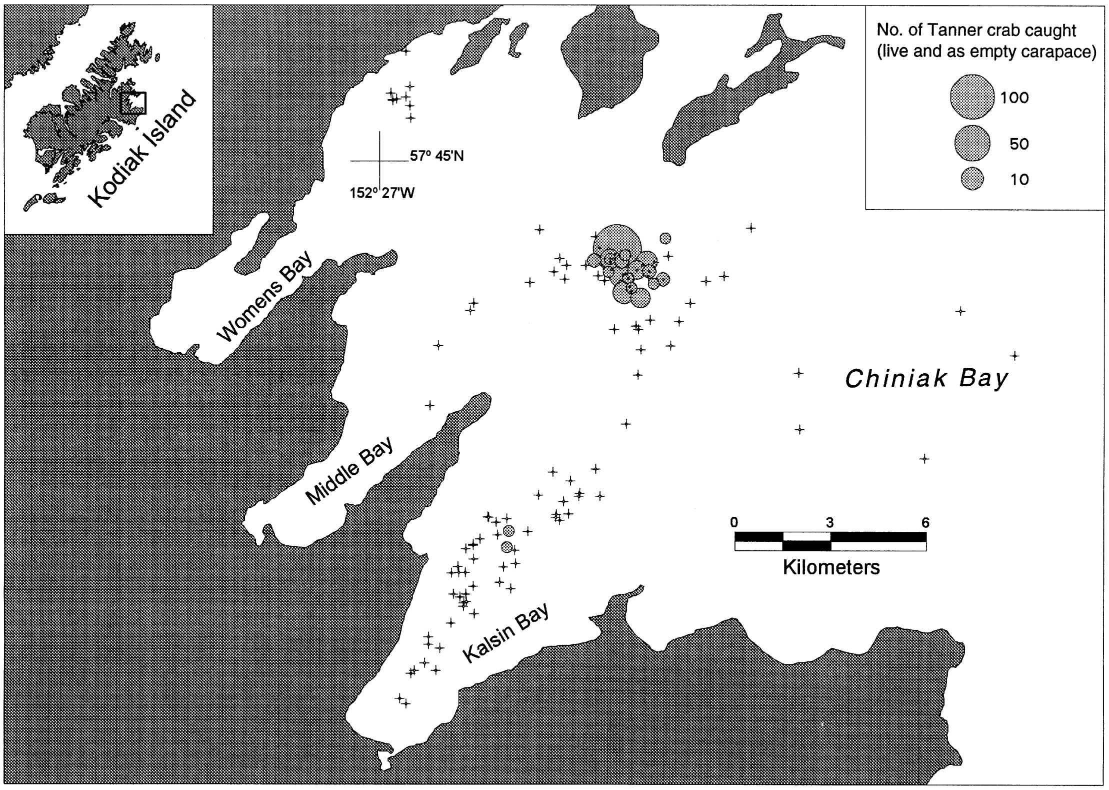

Figure 2

Location of pots retrieved from Chiniak Bay and adjacent areas during all studies, and index of Tanner crab catch per pot (crab per pot). Smallest circles represent one crab, and crosses represent pots with no crabs. Location of the three pots retrieved from Ugak Bay is not shown.

7 pots recovered during the pilot study and 43 pots recovered during the targeted study. Three of these were not previously detected by sonar and were presumed to be subsistence pots less than a year old, lost after the sonar survey was conducted, because commercial fishing had been closed in this area for over two years. An additional 22 inside pots were recovered during the nontargeted study. The remaining 75 pots were recovered from outside the surveyed area ("outside" pots) during the nontargeted study. Square pots were the most common (50%, including two cod pots), followed by pyramidal (24%) and conical (16%). Nine round pots (6%) were recovered, all of which were less than 1.07 m in diameter and were covered with a wire mesh that does not degrade easily; these were probably intended to catch Dungeness crabs (*Cancer magister*). Additional pots included two small subsistence type pots, one rectangular shrimp pot, and one made from a 55-gal oil drum.

Intact biodegradable twine was found in only eight commercial pots (3 square, 2 pyramid, 3 conical). Of those eight, four were classified as being in good condition, two as fair, one as poor, and for one pot, data on its condition were not available (Table 2). Three of these had other holes in the webbing. Eighty-eight pots had holes in the webbing; for 85 of these pots, the holes might have been the result of the degradation of biodegradable twine (excluding the three mentioned above with intact twine). However, as stated previously, without evidence of biodegrad-

Table 1

Types of pots recovered from Chiniak Bay and other bays during pilot, targeted, and nontargeted studies.

Pot type	Number of pots	% of total pots
Square	73	50
Pyramid	35	24
Conical	24	16
Cod	2	1
Round	9	6
Subsistence	2	1
Shrimp	1	1
55-gal. drum	1	1
Total	147	

Table 2

Presence of biodegradable twine and damaged pot webbing, by condition of pot. Only 133 commercial style pots were included.

Condition	Intact bio-twine	Damaged webbing	Total	% damaged
Excellent	0	0	2	0
Good	4	16	33	48
Fair	2	33	49	67
Poor	1	20	29	69
Very poor	0	15	16	94
Unknown	1	4	4	100
Total	8	88	133	

able twine, we were not able to determine if gaps in the webbing resulted from short-term degradation of biodegradable twine, longer-term degradation of nylon webbing, encounters with other fishing gear, damage during grappling and recovery, or from some other process. Generally, the proportion of pots with damaged webbing increased as the condition of the pot degraded (Table 2). Forty-five (34%) of the commercial pots had no biodegradable twine or gaps in the webbing that would have allowed crabs to escape and therefore were probably illegally set; 19 of these were rated as good or excellent, and 26 as fair to very poor.

Organisms

Organisms were found within 97 pots, including 40 (56%) of the inside pots and 57 (76%) of the outside pots. Tanner crab was the most abundant species (227 caught, mean 1.54 CPP), and second most frequent occurring in 24 pots (16%) (Table 3). The majority of Tanner crabs occurred in just two inside pots that contained 125 and 22 crabs, respectively; both pots were in good condition and were presumed to have been lost less than a year, so they were probably set for subsistence purposes. Excluding these two pots, Tanner crab CPP was only 0.55. Sunflower stars (*Pycnopodia helianthoides*) occurred most frequently (42%) and were the second most abundant species (189 caught, mean 1.29 CPP). The next most abundant species were hairy tritons (*Fusitriton oregonensis*), 174 were caught (15% occurrence), and white anemones (*Metridium senile*), 64 were caught (3% occurrence), although some of the latter may have been epibionts that were detached from the webbing during pot retrieval. In addition, we found, but did not count, many more individuals and species attached to the exterior of the pot and attached lines, including barnacles, tubiculous polychaetes, anemones, bryozoans, brachiopods, mussels, clams, snails, seastars, and basket stars (*Gorgonocephalus* sp.)

During the pilot study, 3 octopuses (*Octopus dofleini*) were found in 4 pots with Tanner crabs, suggesting that octopuses, which are known predators of Tanner crabs (senior author, personal obs.), entered the pot to prey on the crabs. Of 16 octopuses recovered during the entire study, 6 occurred in pots with Tanner crabs, and all 4 pots with 10 or more Tanner crabs (accounting for 181 of 227 crabs) contained at least one octopus, including the pot with 125 Tanner crabs. Presence and absence of octopuses was significantly associated with Tanner crabs (in logarithmic categories; χ^2=26.3). This association may have been underestimated because octopuses were not always located inside the pot. Using the ROV, we observed one octopus sitting on top of a pyramidal pot; in such a position, it probably would have been lost during grappling and recovery.

Crabs

The recovered pots contained a total of 195 live Tanner crabs, 2 dead crabs, and 30 empty carapaces. From their size and condition, these empty carapaces were considered to be the result of death or predation, rather than molting, and were not measured. Twenty-three of 32 empty carapaces or dead crabs (72%) were found in pots with octopuses. Of the live crabs, 191 were found in inside pots, and 4 in outside pots. Mean CW of all Tanner crabs was 129.8 ±1.8 mm for males (n=160), and 85.1 ±3.0 mm for females (n=35).

Pot condition, an indicator of time elapsed since it was lost, was examined for its effect on the size of crabs caught. No excellent pots contained crabs, but 152 crabs were recovered from 4 good pots. A total of 166 Tanner crabs were found in 7 out of 42 best pots (17% frequency of occurrence), whereas 61 Tanner crabs were found in 17 of 105 worst pots (16%) (Table 4); mean CPP was 6.8 times greater in best pots (3.95) than in worst pots (0.58), but this difference was not significant (MWU, Z=0.152, P>0.5). Mean CW of 141 male Tanner crabs from best pots (135.6 ±1.3 mm) was significantly larger than for 19 males from worst pots (87.1 ±6.0 mm: MWU, Z=6.29, P<0.001; Table 4). This difference was significant even after excluding pot no. 301, which contained 125 crabs; in this case, mean CW of 26 male crabs in best pots was 130.6 ±5.7 mm (MWU, Z=4.194, P<0.001). Seventy males larger than legal size (138 mm CW), with a mean CW of 144.9 mm were found in best pots; no legal males were found in worst pots. There was no significant difference in mean CW of

Table 3

Abundance of organisms found inside recovered pots. Mean values for all pots, with and without the pot containing the highest number of individuals.

Common name	Species name	Total	Maximum no. per pot	Average no. per pot	Average without max	Total no. pots with species	% of pots with species
Tanner crab	*Chionoecetes bairdi*	227	125	1.54	0.69	24	16
sunflower sea star	*Pycnopodia helianthoides*	189	13	1.29	1.2	62	42
hairy triton	*Fusitriton oregonensis*	174	50	1.18	0.84	22	15
anemone (white)	*Metridium senile*	64	50	0.44	0.1	5	3
tube worms	*Crucigera* spp.	50	50	0.34	0	1	1
green sea urchin	*Strongylocentrotus droebachiensis*	38	17	0.26	0.14	11	7
decorator crab	*Oregonia gracilis*	17	3	0.12	0.1	10	7
sun star	*Solaster* spp.	16	12	0.11	0.03	4	3
giant Pacific octopus	*Octopus dofleini*	16	3	0.11	0.09	14	10
sea cucumber	Holothuroidea	12	3	0.08	0.06	8	5
Neptune snail	*Neptunea* spp.	9	3	0.06	0.04	5	3
lyre crab	*Hyas lyratus*	9	5	0.06	0.03	4	3
kelp crab	*Pugettia gracilis*	7	3	0.05	0.03	4	3
candlefish	*Mallosus villosus*	6	6	0.04	0	1	1
rough-eye rockfish	*Sebastes aleutianus*	5	2	0.03	0.02	4	3
hermit crab	*Pagurus* sp.	5	2	0.03	0.02	4	3
sculpin	Cottidae	5	1	0.03	0.03	5	3
Hind's scallop	*Chlamys rubida*	4	2	0.03	0.01	3	2
yellow Irish lord	*Hemilepidotus jordani*	4	2	0.03	0.01	2	1
red king crab	*Paralithodes camtschaticus*	4	3	0.03	0.01	2	1
rockfish	*Sebastes* spp.	3	1	0.02	0.01	3	2
Pacific cod	*Gadus macrocephalus*	3	1	0.02	0.01	3	2
arrowtooth flounder	*Atheresthes stomias*	1	1	0.01	0	1	1
basket star	*Gorgonocephalus caryi*	1	1	0.01	0	1	1
Beringius snail	*Beringius* sp.	1	1	0.01	0	1	1
blue mussel	*Mytilus trossulus*	1	1	0.01	0	1	1
dogwinkle	*Nucella lamellosa*	1	1	0.01	0	1	1
flathead sole	*Hippoglossoides elassodon*	1	1	0.01	0	1	1
red urchin	*Strongylocentrotus franciscanus*	1	1	0.01	0	1	1
ribbed Neptune	*Neptunea lyrata*	1	1	0.01	0	1	1
mottled sea star	*Evasterias troschelii*	1	1	0.01	0	1	1

Table 4

Comparison of Tanner crab catch, sex, and size, by pot condition. ("Best" pots include those coded as good or excellent; "worst" pots include those coded as fair, poor, very poor, or in unknown condition.)

Parameter	Best pots	Worst pots	Mann Whitney *U*-test
Number of pots	42	105	
Number with Tanner crabs	7 (17%)	17 (16%)	
Number of Tanner crabs	166	61	
Crabs per pot	3.95	0.58	Z= 0.152, P>0.5
Number of legal males	70	0	
Total males	141	19	
Mean CW (SE), males	135.6 (1.3)	87.1 (6.0)	Z=6.29, P<0.001
Total females	11	24	
Mean CW (SE), females	81.3 (7.5)	86.9 (2.7)	Z=1.48, P>0.1

females from best pots (81.3 ±7.5 mm, n=11) or worst pots (86.9 ±2.7 mm, n=24) (MWU, Z=1.48, P>0.1). Numbers of male crabs were significantly associated with best pots, whereas female crabs were associated with worst pots χ^2=53.7, P<0.001); however, this result was highly dependent on two pots with the highest number of males (117) and females (8) respectively. Exclusion of those two pots reduced the χ^2 value to insignificance (3.4, P>0.05). Males composed 93% of crabs in best pots and 44% in worst pots. This result may be due primarily to the fact that pots in good condition retained large males that could have escaped more easily from damaged pots.

Even though we could not determine whether holes in webbing were caused by the degradation of biodegradable twine, recovery, or some other process, we examined their influence on crab CPP. The four highest CPPs for Tanner crabs (10, 17, 22, and 125) occurred in pots without holes, but there was no significant difference in CPP between pots with intact or torn webbing (MWU=1.17, P>0.26). Therefore, we could not reject the hypothesis that pot holes have no effect on CPP. The 95% confidence intervals around the proportion of intact pots containing crabs (10 of 41; P=0.244, 95% CI range: 0.124–0.403) overlapped those for holed pots with crabs (14 of 106; P=0.132, 95% CI range: 0.074–0.211) and included the mean of the latter. Thus the binomial test also failed to reject the null hypothesis. Lack of significance in these tests may be partly due to the high number of pots without crabs in both groups.

In addition to Tanner crabs, four male red king crabs (*Paralithodes camtschaticus*) were found in two outside pots. One pot contained 3 legal-size red king crabs with a mean CW of 161 mm and a recently dead Pacific cod which probably acted as bait; the other pot contained a single red king crab of 54 mm CW.

Discussion

Sidescan sonar has been used to assess the coverage of fishing grounds by bottom trawlers (Krost et al., 1989) but, to our knowledge, has not previously been used to determine the prevalence of ghost fishing by pots or other lost gear. Sonar is a very effective tool in this regard; lost crab pots could easily be identified by their shape and attached lines were often visible on the sonar plots. Occasionally other unidentified objects were observed; some of these could have been extremely degraded pots and one looked like the chassis of a truck or shipping van. Since this study was conducted, we have also tested a laser line-scanning system; its resolution (±1 cm) is much better than that afforded by sonar and allowed us to identify crabs and other organisms on the bottom as well as inside crab traps (Tracey et al., 1998).

The mean CPP (1.54 crab/pot) for all Tanner crabs does not seem particularly excessive. However, much of these data were obtained from an area where heavy fishing pressure had not occurred for 2.5 years. CPP in the best (i.e. most recently lost) pots was almost seven times that in the worst (i.e. oldest) pots; even though this difference was not statistically significant, it represents an important trend. Thus, examining lost pots soon after an active fishery has closed would probably yield high estimates of trapped crabs, and more males of larger sizes.

In addition to catch rates, it is necessary to know the number of actively fishing ghost pots. One "ballpark" estimate of pot loss rates in the eastern Bering Sea is 20,000 pots per year (Alaska Board of Fisheries, cited in Paul et al., 1994), but this estimate was made at a time when up to 100,000 pots were being used in Bering Sea crab fisheries annually. In 1997, the Alaska Board of Fisheries imposed pot limits in the Bering Sea and required all pots to be registered for each crab fishery, partly to reduce loss of pots when weather or ice prevented their recovery. Since then, fewer pots have been used in the Bering Sea, and pot loss rates are presumably lower. In 1999, 50,720 pots were registered for the Bering Sea snow crab (*C. opilio*) fishery; preliminary information indicates that about 1% of these may be lost and replaced during the fishery, as boats return to port for unloading.[5] However, not all lost pots are replaced during intensive fisheries, and during short (<1 week) king or Tanner crab fishery openings, boats do not return to port (a 2-d round trip) or replace pots until after the fishery closes; such losses are not reported. Pot losses as low as 10% per year would contribute 5000 lost pots each year. Subsistence pots, on the other hand, are not accounted for, are not required to be registered, and have practically no restricted locations.

Stevens (1996) concluded that the number of active ghost pots would reach a maximum over time, due to the arithmetic increase in lost pots and exponential decay processes. If 7000 pots with a half-life of 4 years were lost annually, the number of active ghost pots would stabilize at 44,000 after 40 yr, although most would begin to accumulate by year 25 (Stevens, 1996). This is a reasonable time frame for accumulation, because pot fishing for crabs in the Bering Sea has been conducted since at least 1966. However,

[5] Morrison, R. 1999. ADF&G, P.O. Box 308, Dutch Harbor, AK 99692. Personal commun.

extrapolation of ghost pot densities in Chiniak Bay to a 40,000 km^2 area of the Bering Sea (where fishing for king, Tanner, and snow crab is particularly intensive) would yield 1.68 million pots in various stages of degradation. The actual number is probably somewhere between these extremes.

If a reliable estimate of pot loss existed, it would be tempting to speculate on the numbers of crabs killed owing to ghost fishing. However, our estimate of 3.95 Tanner crabs per "best" pot represents only a "snapshot" of the ghost fishing process and does not account for cumulative mortality over time. The difference in CPP between best (3.95) and worst pots (0.58) illustrates that numbers of trapped crabs decline over time, due to escapement, predation, mortality, and reduced capture or retention rates. Starvation may account for a large part of the mortality. Kimker (1994) found 39% mortality among legal-size (>139 mm CW) male Tanner crabs that were kept in closed crab pots for 119 days; some of this mortality was undoubtedly due to cannibalism of weaker crabs (Kimker, 1994). Mortality was low for the first 30 days, then increased linearly through the remainder of the experiment. Starvation may be delayed even longer; Paul et al. (1994) held Tanner crabs in laboratory tanks for fixed periods without food, then gave them unlimited access to food. Only 10% mortality occurred among crabs during 90 d while they were held without food, but 100% mortality occurred during the following 140 days during which time they had access to food. Overall mortality ranged from 40% for those starved 60 days to 100% for those starved 90 days (Paul et al., 1994), which is consistent with the findings of Kimker (1994). Predation by octopus (High, 1976) and sunflower seastars (Breen, 1987) has also been implicated as a cause of mortality of crabs in pots. Octopus were important predators in our study and may cause a significant portion of initial mortality. In a year-long study of blue crab (*Callinectes sapidus*) ghost fishing, Guillory (1993) concluded that, of crabs that were recruited after loss of bait, 51% escaped and 45% died. Although mean CPP was only 1.0 (similar to our study) during weekly pot retrievals, the average total CPP for the entire year was 48 crabs, of which 26 (55%) died (Guillory, 1993).

Escapement probably accounts generally for the decline in numbers of crabs found in lost pots. Escapement of legal-size (>165 mm CW) king crabs from pots tended toward an asymptotic value of 80%, whereas escapement of smaller crabs was 92% after periods of 14 to 16 d (High and Worlund, 1979). Escapement rate probably depends upon behavioral differences between species. Video observations of crabs in square pots showed that both Tanner and king crabs tended to aggregate in the corners of pots, but during random movements some crabs accidentally found the entrance tunnel and escaped through it.[2] Tanner crabs are too small to reach the tunnel unless there are large numbers in the pot, allowing them to climb on top of one another to reach the tunnel opening. In addition, degradable twine in Tanner crab pots should create gaps in the webbing within weeks or months after loss, although 34% of our pots had intact webbing even after 1–2 years in the water. That such a large proportion contained no degradable twine suggests that, at a minimum, one third of the commercial crab pots used in the Kodiak region prior to 1994 were illegally constructed. Apparently, fishermen were taking advantage of the very sparse law enforcement presence in Alaskan ports.

Crabs continue to enter lost pots, even without bait. High and Worlund (1979) showed that king crabs continue to enter unbaited pots for up to 16 days. Breen (1987) showed that unbaited traps caught Dungeness crab (*Cancer magister*) at the same rate one year after becoming lost as they did when first set. He estimated that lost traps caught 17 Dungeness crabs per year, of which almost half (9.3) died, and the remainder escaped. Tanner and king crab traps are quite different from Dungeness crab pots, which are made with stainless steel webbing that degrades very slowly. Nevertheless, Breen's (1987) study clearly demonstrates that entry, escapement, and mortality rates of crabs in lost pots is a dynamic process.

Seasonality is also an important factor in ghost fishing. Breen (1987) found varying crab numbers in pots at different times of the year and concluded that a study must be conducted all year round to obtain the best estimate of crab ingress rates. Guillory (1993) found that recruitment of blue crabs to ghost pots, mortality, and escapement all varied seasonally. High turnover rates can lead to high capture and mortality rates; 2/3 of blue crabs entering traps died or escaped within 2 weeks (Guillory, 1993). Thus it is not possible to estimate mortality from a single observation of recovered traps because the number of crabs in the trap represents a balance of continuous ingress, egress, and mortality rates.

During the 1996 ADF&G annual Gulf of Alaska crab trawl survey,[6] the density of Tanner crabs was approximately 1685 crab/km^2 in Chiniak Bay, 97 in Kalsin Bay, and 76 in Middle Bay, for an average

[6] Urban, D. 1997. Bottom trawl survey of crab and groundfish: Kodiak Island, Chignik, and South Peninsula areas, 1996. Regional Information Rep. 4K97-58. Alaska Dept. of Fish and Game, 211 Mission Rd. Kodiak, AK 99615.

density of 943 crab/km^2 in the sonar-surveyed and nonsurveyed study areas combined. Relative CPP of pots recovered during our study reflected the trawlable densities in each bay; CPP was 2.70 for pots in Chiniak Bay, 0.04 in Kalsin Bay, and 0 in Middle Bay. For both the 1996 trawl survey and our pot retrieval studies, the Chiniak area had the highest density of Tanner crabs, with Kalsin Bay second, and Middle Bay last. Chiniak Bay is also a site where female Tanner crabs aggregate continuously and form high density spawning aggregations in the spring (Stevens et al., 1994).

Knowledge of the abundance of lost pots and numbers of crabs in these pots is required to estimate the impact of ghost fishing, but are not enough in themselves. A more complete assessment of ghost fishing by crab pots will require estimates for rates of ingress, egress, as well as mortality rates of crabs and studies on the degradation rates of biodegradable twine and other structural components of crab traps. Improved enforcement of existing regulations could help reduce ghost fishing. Current estimates of total pot losses are just guesses but could be substantially improved by surveying fishermen or requiring them to report pot losses.

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