HAUNTED WATERS: AN ESTIMATE OF GHOST FISHING OF CRABS AND LOBSTERS BY TRAPS

by

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Abstract:

Ghost fishing is the mortality caused by lost fishing gear and as such, its effect on target populations is difficult to quantify. This study seeks to rectify that by developing a methodology to estimate the effect of ghost fishing by lost pots and traps on large crustaceans (crabs and lobsters). Forty-four case studies, consolidated from published literature on the amount of lost traps and their mortality rates, are used as the basis of the calculations. Missing parameters are inferred from existing values in similar case studies. A Monte Carlo simulation is used to analyze the sensitivity of the results to uncertainties in the input data. The mean estimate of ghost fishing as a percentage of reported landings, over the forty-four case studies, is 3.8%. Ghost fishing is a management issue to contend with, especially in areas where fishing effort is high. Improved legislation on using biodegradable twine and/or Galvanic Time Release mechanisms has and will ameliorate the destructive impact of lost traps on vulnerable ecosystems.

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Chapter I Introduction

While the ocean's resources were once thought to be inexhaustible, reports that bottom fisheries were declining and catches were diminishing were beginning to be published in the early 1900s (Garstang cited in Chopin *et al.* 1997). The fishing industry moved into the 20th century with the realisation that the abundance of fish was limited and that fishing practises must be moderated for the industry to continue. Yet, most fish stocks today are still fully exploited or severely depleted. Millions of dollars are poured into the science that manages these stocks, but until recently, only a piece of the puzzle has been studied in detail. Fisheries scientists tend to focus on fishing mortality from commercial landings and, to a lesser degree, artisinal and recreational landings. As a result, many techniques employed by fisheries scientists to prevent overfishing, such as Individual Transferable Quotas or limited fishing access time, focus on limiting the landings; that is, the known mortality from fishing gear. However, landings comprise only one portion of overall fishing mortality.

Chopin *et al.* (1997) list the other causes of mortality due to fishing as: illegal and misreported landings; mortality associated with discards; mortality associated with fish after escape from fishing gear; mortality associated with ghost fishing; mortality associated with fish passively dropping off or out of fishing gears; mortality associated with fish avoiding the fishing gear; mortality associated with predation after escape; and mortality due to changes in habitat associated with fishing. Because many of these fishing-induced mortalities are indirect, it is difficult to assess their impact on fish populations. However, as studies have shown, they are significant enough to warrant some examination. For example, Alverson *et al.* (1997) estimated that the average amount of bycatch is 30% of total reported landings, although an update by Kelleher (in press) lowers it to 8%. When most fish resources are fished at or over maximum capacity (Chopin *et al.* 1997), this is still a significant amount. This paper focuses on the impacts of mortality associated with ghost fishing, specifically that of crabs and lobsters.

While the phrase 'ghost fishing' might bring to mind the haunting vision of drowned fishers guiding incorporeal nets in the depths of the ocean, the reality is not so poetic; it is, however, just as chilling. Storms, accidents, or littering at sea cause lost gear that may continue to capture fish for some time. For example, 42,000 to 63,000 lobster pots are lost every year in New England, corresponding to 20-30% of the gear that is used (Smolowitz 1978b). When lobsters are caught in these traps, they die from starvation or predation if they cannot escape. Their decomposing bodies act as bait for other lobsters, which are drawn to the trap and are captured as well. This vicious cycle continues for the effective life of the trap, which can last up to 15 years (High and Worlund in Stevens 1996).

For the purposes of this paper, I will be using the following terms and definitions:

- **Lost gear** refers to fishing gear that is lost by fishers, either through theft or at sea.
- **Ghost gear** refers to fishing gear that "continue fishing after all control of that gear is lost by the fisherman" - (Smolowitz 1978b)
- **Derelict gear** is gear that can no longer fish due to damage. (after Breen 1990)

Ghost fishing, then, is the removal of fish from a population by lost fishing gear, but the definition of ghost gear appears to be flexible in literature. Some authors use the terms 'lost gear' and 'ghost gear' interchangeably, and others use one to mean the other. However, not all lost gear is capable of ghost fishing; for instance, gear can be lost due to thefts or degradation.

Though concern has been raised over the impacts of lost gear, few studies have been done to quantify them. Certainly, there have been few attempts to consolidate the individual studies to see the overall picture, and no attempts to examine ghost fishing on a global scale. However, ghost fishing is an issue that is present in any fishery that uses passive gears - especially when the species most likely to be affected are those originally targeted by the ghost gear (Brown 1998).

Fishing gear can be lost in a variety of ways. Buoy lines that mark the locations of traps can be cut by vessel traffic, frayed through negligence or age, tangled in storms, towed away by gillnetters or trawlers, cut deliberately in disputes among fishers, lost if their locations are not properly recorded, or simply misplaced. In Norway (Godøy 2003) and New Brunswick, Canada (Mallet *et al.* 1988), drifting ice causes considerable loss of traps. Additionally, traps may be abandoned, especially by fishers who are only in the fishery for the short-term. In a survey of blue crab fishers in the Gulf of Mexico, 25% of the individuals interviewed fished six months or less (Guillory *et al.* 2001). Uplines may break during hauling. Lobster fishers who do not actively fish during the winter sometimes 'wet store' coated-wire traps at sea, resulting in greater losses from winter storms and boat traffic (Carr and Harris 1987). All these lost traps may ghost fish for the rest of their effective lives, and fishers are charged nothing for this damage, nor does the loss form part of their quota.

The period in which ghost gear remain active is affected by the material from which the trap is made, its location, and the season in which it is lost. In North America, legislation requires many crab fisheries to use Galvanic Timed Releases (GTRs) or biodegradable plastic on traps to render them inoperable after a set time, shortening their ghost fishing period if lost. Traps that do not use GTRs continue to fish for up to 15 years

(High and Worlund 1979), until destroyed by storm damage, burial in sand, corrosion, woodborers, or other vagaries.

If traps are dragged by boat traffic, moved by storms off the continental shelf, or moved into areas where they are unlikely to attract prey, their ghost fishing effectiveness would be low. Likewise, traps that are lost off-season would catch little prey -- but if they were still intact by the next season, their ghost fishing potential would be fulfilled.

Once gear is lost, it can interact with prey through a variety of mechanisms. Ghost traps mainly capture the original target species, but may catch others as well. For example, ghost tanner crab traps in Kodiak, Alaska, captured not only tanner crabs, but also red king crabs, pacific octopus, rockfish, arrowtooth flounder, sunflower stars, and sea cucumbers (Stevens *et al.* 2000). Animals that have been trapped in ghost gear usually starve to death, turn to cannibalism of newly molted crustaceans, or make easy prey for outside predators (Breen 1990). Their dead bodies often serve as bait for additional captures, as with lobsters. Even if the animals manage to escape the traps, they may have mortal wounds or weakened defences that lower their chances for survival after their escape. Regardless of the mechanism, ghost fishing mortality reduces available population biomass, and thus impacts on reproduction, and therefore on fishing.

In light of the potential damage caused by ghost gear, various measures have been taken to minimalise its effects. Legislation has been put into place to require the use of properly marked buoys, escape gaps, and degradable plastics or galvanic timed releases. In Alaska, all traps used at sea are required to have a panel that will open after the destruction of degradable fibre (Breen 1985); as are traps in Puerto Rico and the Virgin Islands (Paul 1984). Federal law in the United States mandates escape vents and a degradable panel that would allow legal sized lobsters and most other prey to escape ghost pots (Carr and Harris 1987). Some fisheries use 'habipots' that lobsters can use as shelter and enter and leave unhindered (Smolowitz 1978b).

Pre-emptive prevention of ghost fishing by decreasing the number of traps lost is another method for reducing the damage caused by lost gear. Assigning trap-free lanes in areas of heavy boat traffic prevents buoy lines from being tangled or cut. The most effective way of reducing trap loss would be to reduce fishing effort.

Even given the myriad methods used to decrease the impact of ghost fishing, it remains an issue in the fishing industry. Reducing fishing effort is difficult and expensive to enforce (Breen 1990), and escape ports ameliorate but do not eliminate the problem of ghost fishing (Stevens *et al.* 1993). While some fisheries in North America are legally mandated to fit escape gaps or biodegradable panels on traps, this is not necessarily true for the rest of the world. For example, there is no such legislation in the

United Kingdom other than bylaws in two areas: the Cumbria Sea Fisheries and States of Jersey (Bullimore 2001). Furthermore, even fisheries that do use biodegradable panels and galvanic timed releases cannot be sure of the precision of the devices (Kimker 1994) and the traps are capable of actively ghost fishing for the period before they are made ineffective. Certain moulded plastic escape panels in lobster traps may be large enough to release lobsters, but not larger fish that enter the trap (Carr and Harris 1987). Meanwhile, gear manufacturers are developing more durable traps that would last longer for fishers, but also have longer ghost fishing lives if lost. A recent advertisement boasts of a maintenance-free trap that "does not rust, won't rot, is impervious to marine borers, and is capable of withstanding the rigours of many highly productive seasons." (INFOFISH 1995)

Given that ghost fishing does have an impact on fisheries resources despite the preventive actions taken to reduce their damage, it behooves us to determine just how much damage is done. By consolidating and standardising information from published studies on ghost fishing and proposing a methodology to estimate the amount of ghost fishing in an area, this thesis strives to quantify ghost fishing activity relative to reported landings. Missing values were inferred from similar, established values to complete the data set. Monte Carlo simulations were then run to provide confidence limits for the results. Forty-four case studies were examined in total and presented with a parameter list, a narrative to explain the source of the values used, and a summary of variances used in the Monte Carlo simulations. The thesis concludes with a discussion of uncertainties in the methodology and possible ways to alleviate the impact of ghost fishing.

Chapter II Methodology

The problem with assessing the impact of indirect fishing mortality such as ghost fishing is that it is, by nature, difficult to directly observe. How does one locate 5,000 lost cod pots in Newfoundland and record all the organisms they kill on an annual basis? Mortality caused by ghost fishing is too expensive to assess on a large scale, so they are studied in experiments, with the assumption that the results obtained from controlled experimentation are representative of what occurs in the ocean.

To examine the extent of damage caused by lost gear, scientists need to know how much gear is lost and how much mortality each gear causes. Surveys from fishers can be used to get an idea of the number of gear that is lost in a trip and the estimate can be used as a factor for the results from the experiments. Counting the number of lost pots observed in a fixed area using underwater vehicles is an alternate method (Chopin *et al.* 1997). Capture rates and species mortality are studied by simulating lost gear in a controlled area, where they are regularly checked for victims. Crab pots in Alaska have been studied most extensively, where researchers check catches by bringing the pots up onto boats and setting them again or by sending scuba divers to determine mortality *in situ*.

Studies on ghost fishing have been done in various parts of the world, specifically in North America, but there have been few reviews of those studies. Breen (1990) and Chopin *et al.* (1997) summarised a number of studies that estimated the numbers of lost gear. This thesis consolidates and standardises information found in various studies of ghost fishing in regional waters in order to make estimates of ghost fishing mortality and compare different fisheries in quantitative terms. Ghost fishing mortality in various case studies is presented as a percentage of the reported catch, and the methodology is outlined below.

2.1 Case studies chosen

Fisheries used in the case studies were chosen on the basis of available information. A literature search was done to look for studies on recovering lost gear or field experiments on the mortality of animals in ghost traps, as these two parameters are specific to ghost fishing. The information from the studies was then consolidated to form case studies of 44 fisheries, 36 of which were in 13 US states (including one in Hawaii), 6 in Canada, and 2 in Ireland. Case studies that were missing parameters crucial to identifying them as unique fisheries, such as total gear or total reported landings, or specific to the target species, such as species weight, were not used.

2.2 Flow chart of calculations

In order to obtain an estimate of ghost fishing in a fishery relative to its reported landings, the following parameters were extracted from published articles:

- Number of gear active in a fishery (by number of fishers, boats, or gear)
- Rate of loss per fishery or per boat (as a percentage of total number of gear)
- Amount of gear lost per year (either pulled from the literature or calculated from the above two parameters)
- Percentage of lost gear assumed to be ghost fishing (as a percentage of lost gear)
- Time during which a pot is actively ghost fishing (number of years)
- Mortality rate of animals in lost pots (average number of animals per pot)
- Average weight of species caught in the pots (kilograms)
- Reported landings of the species in question in the particular fishery in that year (tonnes); if no year was specified, then the year of the publication was used.

The numbers were used to compute annual amounts and rates, without accounting for seasonal variability, owing to paucity of studies considering this factor. The number of traps in an area and the animals caught are assumed to be at equilibrium. Recreational fisheries were not included, due to paucity of data and difficulty in determining how often recreational fishers worked, although the fishing effort can be considerable in some cases.

Figure 2.1 demonstrates how the parameters are used to determine the amount of ghost fishing. Parameters correspond to the numbering system used in Visual Basic code for the uncertainty analysis, which is explained in Section 2.3. 'Number of fishers' and 'Number of traps per fisher' are labelled differently because they are not used in the code: their product ('Total gear') is used rather than the individual parameters. This allows the code to begin in a standard position whether total gear is given in a reference or it has to be calculated from number of fishers and number of traps per fisher.

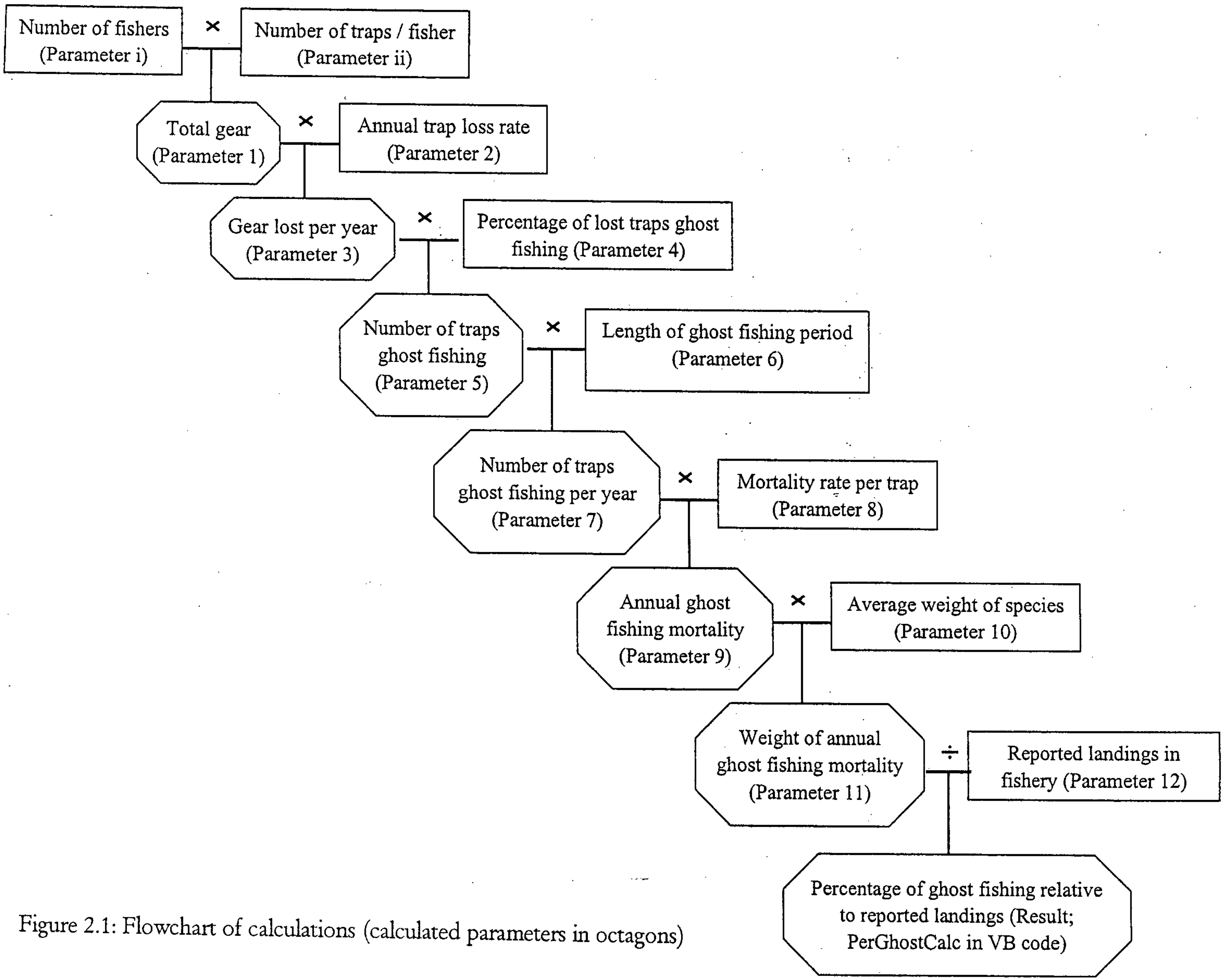

Figure 2.1: Flowchart of calculations (calculated parameters in octagons)

2.3 Inferences on missing parameters

Some published articles provided one or more parameters estimated; others concentrated on a specific parameter. If all the required parameters were not available in a given case study, the missing parameter was obtained from an average of similar fisheries for which estimates were available. If no similar fishery existed, the grand mean of all case studies with a value for that parameter was taken.

Each case study was then ranked in order of reliability of its data, its rank depending on how many parameters it supplied. Of the 44 case studies, 1 study provided all eight key parameters (see above); 5 were missing 1; 17 were missing 2; 16 were missing 3, and 5 were missing 4 (Table 1). Note that although some case studies were missing the same number of parameters, it was not necessarily the same parameters that were missing for all of them.

Table 1: Number of case studies with missing parameters

Number of missing parameters (out of 8)	Number of case studies applicable
0	1
1	5
2	17
3	16
4	5

Several assumptions had to be made when implementing this approach, notably that if certain parameters may vary in different studies, all other factors are the same. Also, field experiments done over a short period at a specific location were assumed to be representative of annual conditions in a larger region, and the number of animals in a ghost trap is assumed to be at equilibrium when counted. Since not all studies specified whether all of the lost gear ended up ghost fishing, I took the average of the values in the case studies where the percentage of lost gear actually ghost fishing was given, unless specified otherwise.

2.4 Monte Carlo Simulations

Due to uncertainties in the parameters, a Monte Carlo analysis was done on each case study to obtain confidence limits for the ghost fishing estimates. Missing parameters inferred from values in other case studies (in section 2.3) were given distributions based on those from the other studies using the formula:

$$Sd((X+Y)/n) = (sqrt(Var(X) + Var(Y)))/n$$

where *n* is the number of values used to infer the missing parameter.

In the Monte Carlo analyses, values were given as confidence intervals, which were expressed as percentages of their absolute values. When uncertainty was expressed in the form of standard errors, these were doubled to generate approximate confidence intervals. When a range is presented rather than a mid-point estimate, the mid-range was used, with the upper and lower limits of the range expressed as a percentage of the median. Where no measure of variability was available in a given study, the mean uncertainty for the parameter in question in similar fisheries was applied, or the grand mean was used if estimates were unavailable for similar fisheries.

With upper limits, midranges, and lower limits available to describe the confidence interval of each parameter, a symmetrical triangular distributions was assumed. This distribution gives equal significance to the three values used in the distributions and eliminates the problem posed by the asymptotic tail in a normal distribution. Monte Carlo simulations were run for each of the case studies to get a distribution of possible ghost fishing estimates. A Visual Basic program was written for this process using data from a Microsoft Excel spreadsheet (Appendix 1). Monte Carlo simulations were sampled 10,000 times each.

In order to determine how many samples were required for the Monte Carlo simulations, a two-sample F-test on varying number of runs was conducted on Monte Carlo results from the South Carolina blue crab fishery which was among the five case studies with four missing parameters and therefore, presumably, the most uncertainty. The trials were run twice and their variances compared. The probability of F being smaller than the critical value for various numbers of runs is as follows:

Table 2: Comparison of F-test results

Number of runs	**Probability of F < = critical value**
10	0.051
100	0.456
1000	0.339
10000	0.390

The null hypothesis assumes that the variances of the two populations (or trial runs, in this case) are equal; only when F is less than or equal to the F-test statistic's cumulative distribution function (CDF) is the null hypothesis rejected. Only the trials in which the Monte Carlo simulations were sampled 10 times had a 95% probability of rejecting the null hypothesis. Even sampling 100 times is sufficient in that the probability that the two trial runs did not differ significantly enough in their results to reject the null hypothesis.

Additionally, Efron and Tibshirani (1986) state that 1,000 samples is an approximate minimum to compute reasonably accurate confidence intervals. Sampling 10,000 times allows the graphing of a smoother frequency distribution.

CHAPTER III Case Study Results

Results from the methodology applied to the case studies are presented below. Note the repetition of procedure in the case studies; this allows each case study to stand individually without the need to allude to others for references. Case studies are ordered by taxonomic group and then by number of missing parameters. Species groupings were chosen following the assumption that different species act differently in their capture behaviour, which would impact their mortality rate in lost traps. Figure 3.1 shows the phylogenetic relationships between the species studied in this thesis (based on information from Rawlings *et al.* 2004).

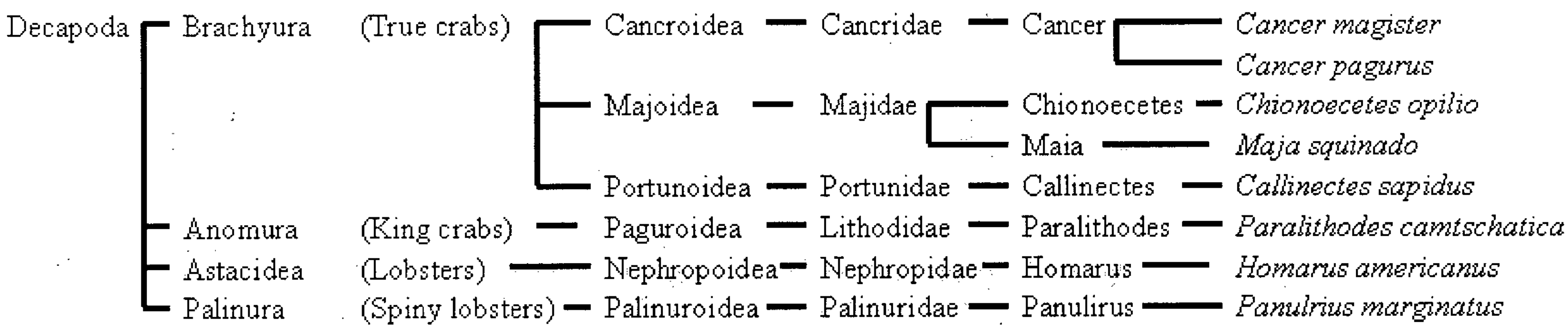

Figure 3.1: Phylogenetic tree of species studied

3.1 True crabs

Case studies with 0 missing parameters:

British Columbia Dungeness crab fishery 1984

Parameter list

The following parameters were used in the calculations demonstrated in the flow chart in Figure 2.1. Italics denote that the value was calculated from previous parameters.

	Parameter i:	104 vessels
×	Parameter ii:	252.4 ± 26% traps per vessel
=	Parameter 1:	*26,250 traps*
×	Parameter 2:	10.9%
=	Parameter 3:	*2,861 traps*
×	Parameter 4:	53.5%
=	Parameter 5:	*1,531 traps*
×	Parameter 6:	2.2 years
=	Parameter 7:	*3,338 traps*
×	Parameter 8:	9.3 +7%/-15% crabs· $trap^{-1}year^{-1}$
=	Parameter 9:	*31,319 crabs*
×	Parameter 10:	0.68 kg
=	Parameter 11:	*21,297 kg*
÷	Parameter 12:	292 t
=	Result:	*7.3%*

Narrative

All data for the Dungeness crab (*Cancer magister*) fishery in the Fraser River Estuary, British Columbia, were obtained from Breen (1987). In 1983, 104 vessels in the fishery used an average of 252 traps per vessel, so the total number of traps in use was estimated to be 26,250. The trap loss rate was estimated to be 10.9%, resulting in 2,861 traps lost annually. 53.5% of those traps were actually ghost fishing, and their lifespan was estimated at 2.2 years, so the number of traps ghost fishing, assuming that the system was at equilibrium, would be 3,338. Each trap caused a mortality of 9.3 crabs per year; the total annual mortality is thus 31,319 crabs. With a mean weight per crab of 0.68 kg, the ghost fishing catch becomes 21,297 kg, 7.3% of the 292 t of the reported landed in 1984.

Monte Carlo simulation

Breen (1987) estimated that each vessel used an average of 252.4 traps where the 95% confidence limit is 186-319, or 252.4 ± 26%. The mortality rate was 9.3 crabs· $trap^{-1}year^{-1}$ where the 95% confidence limit is 7.88 -9.95 crabs· $trap^{-1}year^{-1}$, or 9.3 +7%/-15% crabs· $trap^{-1}year^{-1}$.

The distribution of ghost fishing mortality as a percentage of the reported landed catch is shown in Figure 3.1.1.

Case studies with 1 missing parameter:

California Dungeness crab fishery 1986

Parameter list

The following parameters were used in the calculations demonstrated in the flow chart in Figure 2.1. Italics denote that the value was calculated from previous parameters.

	Parameter i:	Not provided
	Parameter ii:	Not provided
	Parameter 1:	Not provided
	Parameter 2:	Not provided
	Parameter 3:	100,000 traps lost
×	Parameter 4:	96.9% + 3.1%/- 51.3%
=	Parameter 5:	*96,853 traps*
×	Parameter 6:	0.375 ± 11% years
=	Parameter 7:	*36,320 traps*
×	Parameter 8:	12.9 crabs· $trap^{-1}year^{-1}$
=	Parameter 9:	*466,970 crabs*
×	Parameter 10:	0.68 kg
=	Parameter 11:	*317,539 kg*
÷	Parameter 12:	3,520,873 kg
=	Result:	*9.0%*

Narrative

The Californian Department of Fish and Game estimates a loss of 100,000 Dungeness crab (*Cancer magister*) traps per year (Kennedy 1986). There was no indication of whether all the traps were ghost fishing. To achieve a conservative estimate, it was assumed that not all the lost traps would ghost fish, and a modifier of 96.9% was applied. This modifer was the mean calculated from other case studies where this parameter was specified: 46.5% in the 1987 BC Dungeness crab fishery (Breen 1987); 100% in the 1990 Chiniak Bay red king crab fishery (assumed from R. Meyer, pers comm to Smolowitz 1978a); 100% in the 1976 Atlantic offshore lobster fishery (assumed from Smolowitz 1978b); 100% in the 1969-1989 Gulf of St. Lawrence snow crab fishery (assumed from Vienneau and Moriyasu 1994); 100% in the 1987 Gulf of St. Lawrence snow crab fishery (Mallet *et al.* 1998); 100% in the 1987 New Brunswick snow crab fishery (Mallet *et al.* 1998); 100% in the Louisiana blue crab fishery c. 1993 (Guillory 1999); 100% in the 1988 Louisiana blue crab fishery (Guillory 1999); 100% in the 1993 Louisiana blue crab fishery (Guillory 1999); and 100% in the 1974 Newfoundland snow crab fishery (Miller 1977). The result was 96,853 ghost fish traps.

To ameliorate potential losses of crab populations from ghost fishing, the California Dungeness crab fishers are using cotton webbing that renders lost traps inoperable after approximately 4-5 months. Taking the midrange from this estimate and assuming that the rate of entry of lost traps was equal to the rate of degradation, 36,320 traps are estimated to be ghost fishing inshore in the area annually. In 1970, Dahlstrom (1975 cited in Pacific Marine Fisheries Commission 1978) retrieved 90 crabs in 7 crab traps in California; the average is 12.9 crabs per trap. The length of time in which these traps had been ghost fishing is unknown; for the purposes of this case study, it is assumed that they had been fishing for one year and that the number of caught crabs was in equilibrium - that is, the number of crabs taken from the available population at any given time. When the mortality rate is applied to the number of ghost fishing traps, the annual mortality is 466,970 crabs. To express this mortality as a percentage of the reported landings, the average weight for Dungeness crab (0.68 kg;(Breen 1987) was applied. The weight of Dungeness crab mortality from ghost traps was therefore estimated to be 317,539 kg, or 9.0% of the reported landings in California in 1986 (3,520,873 kg; National Marine Fisheries Service 2004).

Monte Carlo Simulation

The percentage of traps lost to ghost fishing is the grand mean calculated from case studies where the parameters were given, which results in 96.9% + 3.1%/- 51.3% of lost traps (96.9% ± 51.3%, with the upper limit truncated at 100%).

Kennedy (1986) estimated the lifespan of a ghost fishing trap at 4-5 months, which translates to 0.375 years ± 11%.

The distribution of ghost fishing mortality as a percentage of the reported landed catch is shown in Figure 3.1.2.

New Brunswick snow crab fishery 1987

Parameter list

	Parameter i:	81 vessels (not used in calculation)
	Parameter ii:	Not provided
	Parameter 1:	Not provided
	Parameter 2:	Not provided
	Parameter 3:	2,466 traps
×	Parameter 4:	100%
=	Parameter 5:	*2,466 traps*
×	Parameter 6:	0.417 + 141%/-100% years
=	Parameter 7:	*1,029 traps*
×	Parameter 8:	44.3 crabs· $trap^{-1}year^{-1}$
=	Parameter 9:	*45,581 crabs*
×	Parameter 10:	0.576 kg
=	Parameter 11:	*26,238 kg*
÷	Parameter 12:	7,341,092 kg
=	Result:	*0.36%*

Narrative

In 1987, 81 vessels in the New Brunswick snow crab (*Chionoecetes opilio*) fishery held licenses and lost between them a total of 2,466 traps during the season (Mallet *et al.* 1998). In their own calculations, Mallet *et al.* (1998) assumed that all traps would be capable of ghost fishing; because this case study is derived from that publication, the same assumption was made here. However, no estimate for the functional lifespan of the traps was available, so an average length of time, 0.417 years, was taken from all case studies in which ghost fishing period was specified. The values from those case studies were: 2.2 years in the 1984 BC Dungeness crab fishery (Breen 1987); 0.418 years in the 1969-70 Alaska red king crab fishery (Kimker 1990); 0.375 years ± 11% in the 1986 California Dungeness crab fishery (Kennedy 1986); 0.245 +44%/-19% years in the 1992 Cook Inlet red king crab fishery (Kimker 1990); and 0.243 ± 33% years. The last value is a composite in itself, obtained from 0.241 +20.8%/-27.1% years (Kimker 1990) and 0.245 +44%/-19% years (Kimker 1990), and used in 9 case studies: 1993 Bering Sea crab fishery; 1993 Bering Sea red king crab fishery; 1990 Bristol Bay red king crab fishery; 1991 Bristol Bay red king crab fishery; 1994 Bristol Bay red king crab fishery; 1996 Bristol Bay red king crab fishery; Chiniak Bay red king crab fishery in the 1990s; and 2 1991 eastern Bering Sea snow crab fisheries.

Assuming that the rate of entry of lost traps was equal to the rate of degradation, 1,029 traps are estimated to be ghost fishing in New Brunswick annually. In a trawl survey of the Gulf of St. Lawrence, Mallet *et al.* (1998) found a mean of 44.3 crabs per lost trap, which takes the annual ghost fishing mortality to 45,581 individuals. Mallet *et al.* (1998) equate 44.3 individuals per trap with 25.5 kg per trap, which suggests that the average weight of snow crabs in that system is 0.576 kg. Therefore, the mortality from ghost traps is 26,238 kg. Snow crab landings in the southwestern Gulf of St. Lawrence amounted to 11,782,000 kg in 1987 (Mallet *et al.* 1998) and the New Brunswick fleet had 81 of the 130 licensed fishers in the southwestern Gulf of St. Lawrence. Assuming the landings are proportionate throughout the fishery, New Brunswick's catch is 7,341,092 kg. The proportion of ghost fishing catch with relation to reported landings is thus 0.36 %. Mallet *et al.* (1998), without taking into account the functional life of a lost trap, estimated the catch lost to ghost fishing to be 62,900,000 kg, or 0.36% of New Brunswick's reported catch.

Monte Carlo Simulation

The values for the lifespan of ghost fishing traps in this case study was an average of thirteen other case studies, some of which had asymmetrical variances. In the cases where variances were asymmetrical, the average of the variances in each case study was taken and used towards the following formula:

$$Sd((X+Y)/13) = (sqrt(Var(X) + Var(Y)))/13$$

resulting in a mean of 0.417 + 141%/-100% years (0.417 ± 141%, with the lower limit truncated at 0).

The distribution of ghost fishing mortality as a percentage of the reported landed catch is shown in Figure 3.1.3.

Gulf of St. Lawrence snow crab fishery 1966-1989

Parameter list

	Parameter i:	Not provided
	Parameter ii:	Not provided
	Parameter 1:	Not provided
	Parameter 2:	Not provided
	Parameter 3:	831 traps
×	Parameter 4:	100%
=	Parameter 5:	*831 traps*
×	Parameter 6:	0.417 + 141%/-100% years

=	Parameter 7:	*347 traps*
×	Parameter 8:	41 crabs· $trap^{-1}year^{-1}$
=	Parameter 9:	*14,216 crabs*
×	Parameter 10:	0.572 kg
=	Parameter 11:	*8,132 kg*
÷	Parameter 12:	11,782,000
=	Result:	*0.069%*

Narrative

Between 1966 and 1989, 19,110 traps were lost in the Gulf of St. Lawrence snow crab (*Chionoecetes opilio*) fishery (Vienneau and Moriyasu 1994). Assuming that the rate of loss was uniform throughout the 23 years, 831 traps would have been lost annually. The estimate of trap loss involved only traps lost at sea, so it is assumed that they were all capable of ghost fishing. No estimate for the functional lifespan of the traps was available, so an average length of time, 0.417 years, was taken from all case studies in which ghost fishing period was specified. The values from those case studies were: 2.2 years in the 1984 BC Dungeness crab fishery (Breen 1987); 0.418 years in the 1969-70 Alaska red king crab fishery (Kimker 1990); 0.375 years ± 11% in the 1986 California Dungeness crab fishery (Kennedy 1986); 0.245 +44%/-19% years in the 1992 Cook Inlet red king crab fishery (Kimker 1990); and 0.243 ± 33% years. The last value is a composite in itself, obtained from 0.241 +20.8%/-27.1% years (Kimker 1990) and 0.245 +44%/-19% years (Kimker 1990), and used in 9 case studies: 1993 Bering Sea crab fishery; 1993 Bering Sea red king crab fishery; 1990 Bristol Bay red king crab fishery; 1991 Bristol Bay red king crab fishery; 1994 Bristol Bay red king crab fishery; 1996 Bristol Bay red king crab fishery; Chiniak Bay red king crab fishery in the 1990s; and 2 1991 eastern Bering Sea snow crab fisheries.

Assuming that the rate of entry of lost traps was equal to the rate of degradation, 347 traps are estimated to be ghost fishing in the Gulf of St. Lawrence annually. Vienneau and Moriyasu (1994) determined that the mortality rate of crab caught by a lost trap is 50% that of regularly functioning traps; applied to the observed CPUE in the Spring 1993 fishery of 82 individuals per trap, the 347 lost traps would kill an average of 14,216 snow crabs each year. Vienneau and Moriyasu (1994), based on unpublished data from Y. Chiasson, DFO Gulf Region, state that the average individual weight is 0.572 kg. The weight of ghost fishing catch is thus 8,132 kg, 0.069% of the reported 11,782,000 kg landed in 1987 (Mallet *et al.* 1998).

Monte Carlo Simulation

The values for the lifespan of ghost fishing traps in this case study was an average of thirteen other case studies, some of which had asymmetrical variances. In the cases where variances were asymmetrical, the average of the variances in each case study was taken and used towards the following formula:

$$Sd((X+Y)/13) = (sqrt(Var(X) + Var(Y)))/13$$

resulting in a mean of 0.417 + 141%/-100% years (0.417 ± 141%, with the lower limit truncated at 0).

The distribution of ghost fishing mortality as a percentage of the reported landed catch is shown in Figure 3.1.4.

Gulf of St. Lawrence snow crab fishery 1987

Parameter list

	Parameter i:	130 vessels (not used in calculation)
	Parameter ii:	Not provided
	Parameter 1:	Not provided
	Parameter 2:	Not provided
	Parameter 3:	3,958 traps
×	Parameter 4:	100%
=	Parameter 5:	*3,958 traps*
×	Parameter 6:	0.417 +141%/-100% years
=	Parameter 7:	*1,651 traps*
×	Parameter 8:	44.3 crabs· $trap^{-1} year^{-1}$
=	Parameter 9:	*45,581 crabs*
×	Parameter 10:	0.576 kg
=	Parameter 11:	*42,110 kg*
÷	Parameter 12:	11,782,000 kg
=	Result:	*0.36 %*

Narrative

The New Brunswick snow crab (*Chionoecetes opilio*) fishery, which involves eighty-one of the 130 licensed fishers in the southwestern Gulf of St. Lawrence (including New Brunswick, Quebec, and Cape Breton Island), lost 2,466 traps in 1987 (Mallet *et al.* 1998). Assuming a proportional rate of loss in the southwestern Gulf of St. Lawrence fishery, 3,958 traps would have been lost in that area. In their own calculations for the amount of ghost fishing in the New Brunswick snow crab fishery, Mallet *et al.* (1998) assumed that all traps would be capable of ghost fishing; because this case study is derived from that publication, the same assumption was made here. However, no estimate for the functional lifespan of the traps was available, so an average length of time, 0.417 years, was taken from all case studies in which ghost fishing period was specified. The values from those case studies were: 2.2 years in the 1984 BC Dungeness crab fishery (Breen 1987); 0.418 years in the 1969-70 Alaska red king crab fishery (Kimker 1990); 0.375 years ± 11% in the 1986 California Dungeness crab fishery (Kennedy 1986); 0.245 +44%/-19% years in the 1992 Cook Inlet red king crab fishery (Kimker 1990); and 0.243 ± 33% years. The last value is a composite in itself, obtained from 0.241 +20.8%/-27.1% years (Kimker 1990) and 0.245 +44%/-19% years (Kimker 1990), and used in 9 case studies: 1993 Bering Sea crab fishery; 1993 Bering Sea red king crab fishery; 1990 Bristol Bay red king crab fishery; 1991 Bristol Bay red king crab fishery; 1994 Bristol Bay red king crab fishery; 1996 Bristol Bay red king crab fishery; Chiniak Bay red king crab fishery in the 1990s; and 2 1991 eastern Bering Sea snow crab fisheries.

Assuming that the rate of entry of lost traps was equal to the rate of degradation, 1,651 traps are estimated to be ghost fishing in the Gulf of St. Lawrence annually. In a trawl survey of the Gulf of St. Lawrence, (Mallet *et al.* 1998) found a mean of 44.3 crabs per lost trap, which takes the annual ghost fishing mortality to 73,155 individuals. Mallet *et al.* (1998) equate 44.3 individuals per trap with 25.5 kg per trap, which suggests that the average weight of snow crabs in that system is 0.576 kg. Therefore, the mortality from ghost traps is 42,110 kg, or 0.36% of the reported 11,782,000 kg landed in 1987 (Mallet *et al.* 1998). Mallet *et al.* (1998) estimate the mortality from ghost traps at 125,800 kg, which would make it 1.7% of the reported catch.

Monte Carlo Simulation

The values for the lifespan of ghost fishing traps in this case study was an average of thirteen other case studies, some of which had asymmetrical variances. In the cases where variances were asymmetrical, the average of the variances in each case study was taken and used towards the following formula:

$$Sd((X+Y)/13) = (sqrt(Var(X) + Var(Y)))/13$$

resulting in a mean of 0.417 + 141%/-100% years (0.417 ± 141%, with the lower limit truncated at 0).

The distribution of ghost fishing mortality as a percentage of the reported landed catch is shown in Figure 3.1.5.

Case studies with 2 missing parameters:

Washington State Dungeness crab fishery 1975-1976

Parameter list

	Parameter i:	Not provided
	Parameter ii:	Not provided
	Parameter 1:	Not provided
	Parameter 2:	Not provided
	Parameter 3:	6,577 traps
×	Parameter 4:	96.9% + 3.1%/- 51.3% of lost traps ghost fishing
=	Parameter 5:	*6,370 traps ghost fishing*
×	Parameter 6:	0.417 + 141%/-100% years
=	Parameter 7:	*2,658 traps*
×	Parameter 8:	114 crabs· $trap^{-1}year^{-1}$
=	Parameter 9:	*303,162 crabs*
×	Parameter 10:	0.68 kg
=	Parameter 11:	*206,150 kg*
÷	Parameter 12:	3,716,753 kg
=	Result:	*5.6%*

Narrative

In the 1975/1976 season, Dungeness crab (*Cancer magister*) fishers in Washington lost an estimated 6,577 traps (Northup 1978 cited in Muir *et al.* 1984). There was no indication of whether all the traps were ghost fishing. To achieve a conservative estimate, it was assumed that not all the lost traps would ghost fish, and a modifier of 96.9% was applied. This modifer was the mean calculated from other case studies where this parameter was specified: 46.5% in the 1987 BC Dungeness crab fishery (Breen 1987); 100% in the 1990 Chiniak Bay red king crab fishery (assumed from R. Meyer, pers comm to Smolowitz 1978a); 100% in the 1976 Atlantic offshore lobster fishery (assumed from Smolowitz 1978b); 100% in the 1969-1989 Gulf of St. Lawrence snow crab fishery (assumed from Vienneau and Moriyasu 1994); 100% in the 1987 Gulf of St. Lawrence snow crab fishery (Mallet *et al.* 1998); 100% in the 1987 New Brunswick snow crab fishery (Mallet *et al.* 1998); 100% in the Louisiana blue crab fishery c. 1993 (Guillory 1999); 100% in the 1988 Louisiana blue crab fishery (Guillory 1999); 100% in the 1993 Louisiana blue crab fishery (Guillory 1999); and 100% in the 1974 Newfoundland snow crab fishery (Miller 1977). The result was 6,370 ghost fish traps.

No estimate for the functional lifespan of the traps was available, so an average length of time, 0.417 years, was taken from all case studies in which ghost fishing period was specified. The values from those case studies were: 2.2 years in the 1984 BC Dungeness crab fishery (Breen 1987); 0.418 years in the 1969-70 Alaska red king crab fishery (Kimker 1990); 0.375 years ± 11% in the 1986 California Dungeness crab fishery (Kennedy 1986); 0.245 +44%/-19% years in the 1992 Cook Inlet red king crab fishery (Kimker 1990); and 0.243 ± 33% years. The last value is a composite in itself, obtained from 0.241 +20.8%/-27.1% years (Kimker 1990) and 0.245 +44%/-19% years (Kimker 1990), and used in 9 case studies: 1993 Bering Sea crab fishery; 1993 Bering Sea red king crab fishery; 1990 Bristol Bay red king crab fishery; 1991 Bristol Bay red king crab fishery; 1994 Bristol Bay red king crab fishery; 1996 Bristol Bay red king crab fishery; Chiniak Bay red king crab fishery in the 1990s; and 2 1991 eastern Bering Sea snow crab fisheries.

Assuming that the rate of entry of lost traps was equal to the rate of degradation, 2,658 traps are estimated to be ghost fishing inshore in the area annually. In a 1982 study in the Columbia River estuary, Muir *et al.* (1984) used four standard commercial crab traps to examine the escape of Dungeness crabs in simulated lost traps. Over a 28-day period, 35 crabs died in the four traps (an average of 8.75 crabs per trap). Assuming the same mortality rate throughout the year, the yearly mortality can be extrapolated to 114 individuals per trap, resulting in 303,162 individuals caught in all lost traps annually. To express this mortality as a percentage of the reported landings, the average weight for Dungeness crab (0.68 kg; Breen 1987) was applied. The weight of Dungeness crab mortality from ghost traps was therefore estimated to be 206,150 kg, or 5.6% of the averaged landings for Washington State averaged between 1975 and 1976 (3,716,753 kg; National Marine Fisheries Service 2004).

Monte Carlo Simulation

The percentage of traps lost to ghost fishing is the grand mean calculated from case studies where the parameters were given, which results in 96.9% + 3.1%/- 51.3% of lost traps (96.9% ± 51.3%, with the upper limit truncated at 100%).

The values for the lifespan of ghost fishing traps in this case study was an average of thirteen other case studies, some of which had asymmetrical variances. In the cases where variances were asymmetrical, the average of the variances in each case study was taken and used towards the following formula:

$$Sd((X+Y)/13) = (sqrt(Var(X) + Var(Y)))/13$$

resulting in a mean of 0.417 + 141%/-100% years (0.417 ± 141%, with the lower limit truncated at 0).

The distribution of ghost fishing mortality as a percentage of the reported landed catch is shown in Figure 3.1.6.

Louisiana blue crab fishery c. 1999

Parameter list

	Parameter i:	Not provided
	Parameter ii:	Not provided
	Parameter 1:	500,000 traps
×	Parameter 2:	10%
=	Parameter 3:	*50,000 traps*
×	Parameter 4:	100%
=	Parameter 5:	*50,000 traps*
×	Parameter 6:	0.417 + 141%/-100% years
=	Parameter 7:	*20,862 traps ghost fishing annually*
×	Parameter 8:	53.8 ± 34.1% crabs· $trap^{-1}year^{-1}$
=	Parameter 9:	*1,122,388 crabs*
×	Parameter 10:	0.16 kg
=	Parameter 11:	*178,190 kg*
÷	Parameter 12:	18,897,136 kg
=	Result:	*0.94%*

Narrative

In Louisiana, approximately 500,000 commercial blue crab (*Callinectes sapidus*) traps are in use annually (Guillory 1999). If 10% of those traps are lost, approximately 50,000 traps are added in Louisiana each year (Guillory 1999). Guillory (1999) assumes that all these lost traps are ghost fishing, but gives no estimate for the duration of their functional lives, so the average (0.417 years) was taken from other case studies where this parameter was specified and applied. The values from those case studies were: 2.2 years in the 1984 BC Dungeness crab fishery (Breen 1987); 0.418 years in the 1969-70 Alaska red king crab fishery (Kimker 1990); 0.375 years ± 11% in the 1986 California Dungeness crab fishery (Kennedy 1986); 0.245 +44%/-19% years in the 1992 Cook Inlet red king crab fishery (Kimker 1990); and 0.243 ± 33% years. The last value is a composite in itself, obtained from 0.241 +20.8%/-27.1% years (Kimker 1990) and 0.245 +44%/-19% years (Kimker 1990), and used in 9 case studies: 1993 Bering Sea crab fishery; 1993 Bering Sea red king crab fishery; 1990 Bristol Bay red king crab fishery; 1991 Bristol Bay red king crab fishery; 1994 Bristol Bay red king crab fishery; 1996 Bristol Bay red king crab fishery; Chiniak Bay red king crab fishery in the 1990s; and 2 1991 eastern Bering Sea snow crab fisheries. Assuming that the rate of entry of lost traps was equal to the rate of degradation, 20,862 traps are estimated to be ghost fishing in the area annually.

In Guillory's (1993) study of ghost fishing by blue crab traps in Louisiana, an average of 25.8 individuals died per trap. Arcement and Guillory (1993) performed a comparison of mortality of crabs in traps that had escape rings and those that had no escape rings. In the former, an average of 5.3 individuals were killed per trap in a 2-month period. In the latter, an average of 17.3 individuals were killed per trap in a 2-month period. Assuming that mortality rate is uniform throughout the study period and throughout the year, annual mortality is and 31.8 and 103.8 crabs per trap respectively. The average of these three values is 53.8 crabs$\cdot$ trap^{-1}year^{-1}.

Applied to the previous parameter, the annual mortality from ghost traps is 1,122,388 crabs. The average weight of blue crabs in October 1999 to November 2000 landings was 0.35 lbs, or 0.16 kg (Murphy *et al.* 2001). The weight of ghost fishing catch is thus 178,190 kg, or 0.94% of the reported 18,897,136 kg landed in 2001 (National Marine Fisheries Service 2004).

Monte Carlo Simulation

The values for the lifespan of ghost fishing traps in this case study was an average of thirteen other case studies, some of which had asymmetrical variances. In the cases where variances were asymmetrical, the average of the variances in each case study was taken and used towards the following formula:

Sd((X+Y)/13) = (sqrt(Var(X) + Var(Y)))/13

resulting in a mean of 0.417 + 141%/-100% years (0.417 ± 141%, with the lower limit truncated at 0).

The mortality rate is taken as the mean from three values, 53.8 crabs$\cdot$trap^{-1}year^{-1} ± 34.1%, as explained in the narrative above.

The distribution of ghost fishing mortality as a percentage of the reported landed catch is shown in Figure 3.1.7.

Louisiana blue crab fishery c. 1993

Parameter list

	Parameter i:	Not provided
	Parameter ii:	Not provided
	Parameter 1:	650,000 traps
×	Parameter 2:	10%
=	Parameter 3:	*65,000 traps*
×	Parameter 4:	100%
=	Parameter 5:	*65,000 traps*
×	Parameter 6:	0.417 + 141%/-100% years:
=	Parameter 7:	*27,121 traps ghost fishing annually*
×	Parameter 8:	53.8 ± 34.1% crabs· $trap^{-1}year^{-1}$
=	Parameter 9:	*1,459,104 crabs*
×	Parameter 10:	0.16 kg
=	Parameter 11:	*231,647 kg*
÷	Parameter 12:	18,897,136 kg
=	Result:	*1.2 %*

Narrative

In the Louisiana blue crab (*Callinectes sapidus*) fishery, over 650,000 traps are used (Guillory *et al.* 1994 cited in Arcement and Guillory 1994). Guillory (1999) estimates an annual trap loss rate of 10% in the fishery; 65,000 traps would be added to the ghost fishing fleet each year. Guillory (1999) assumes that all these lost traps are ghost fishing, but gives no estimate for the duration of their functional lives, so the average (0.417 years) was taken from other case studies where this parameter was specified. The values from those case studies were: 2.2 years in the 1984 BC Dungeness crab fishery (Breen 1987); 0.418 years in the 1969-70 Alaska red king crab fishery (Kimker 1990); 0.375 years ± 11% in the 1986 California Dungeness crab fishery (Kennedy 1986); 0.245 +44%/-19% years in the 1992 Cook Inlet red king crab fishery (Kimker 1990); and 0.243 ± 33% years. The last value is a composite in itself, obtained from 0.241 +20.8%/-27.1% years (Kimker 1990) and 0.245 +44%/-19% years (Kimker 1990), and used in 9 case studies: 1993 Bering Sea crab fishery; 1993 Bering Sea red king crab fishery; 1990 Bristol Bay red king crab fishery; 1991 Bristol Bay red king crab fishery; 1994 Bristol Bay red king crab fishery; 1996 Bristol Bay red king crab fishery; Chiniak Bay red king crab fishery in the 1990s; and 2 1991 eastern Bering Sea snow crab fisheries. Assuming that the rate of entry of lost traps was equal to the rate of degradation, 27,121 traps are estimated to be ghost fishing in the area annually.

In Guillory's (1993) study of ghost fishing by blue crab traps in Louisiana, an average of 25.8 individuals died per trap. Arcement and Guillory (1993) performed a comparison of mortality of crabs in traps that had escape rings and those that had no escape rings. In the former, an average of 5.3 individuals were killed per trap in a 2-month period. In the latter, an average of 17.3 individuals were killed per trap in a 2-month period. Assuming that mortality rate is uniform throughout the study period and throughout the year, annual mortality is and 31.8 and 103.8 crabs per trap respectively. The average of these three values is 53.8 crabs· $trap^{-1}year^{-1}$.

Applied to the previous parameter, the annual mortality from ghost traps is 1,459,104 crabs. The average weight of blue crabs in October 1999 to November 2000 landings was 0.35 lbs, or 0.16 kg (Murphy *et al.* 2001). The weight of ghost fishing catch is thus 231,647 kg, or 1.2% of the reported 18,897,136 kg landed in 2001 (National Marine Fisheries Service 2004).

Monte Carlo Simulation

The values for the lifespan of ghost fishing traps in this case study was an average of thirteen other case studies, some of which had asymmetrical variances. In the cases where variances were asymmetrical, the average of the variances in each case study was taken and used towards the following formula:

$$Sd((X+Y)/13) = (sqrt(Var(X) + Var(Y)))/13$$

resulting in a mean of 0.417 + 141%/-100% years (0.417 ± 141%, with the lower limit truncated at 0).

The mortality rate is taken as the mean from three values, 53.8 crabs· $trap^{-1}year^{-1}$ ± 34.1%, as explained in the narrative above.

The distribution of ghost fishing mortality as a percentage of the reported landed catch is shown in Figure 3.1.8.

Louisiana blue crab fishery 1988

Parameter list

Parameter i: 2,800 fishers
Parameter ii: 200 traps
Parameter 1: *560,000 traps*

×	Parameter 2:	10%
=	Parameter 3:	*56,000 traps*
×	Parameter 4:	100%
=	Parameter 5:	*65,000 traps*
×	Parameter 6:	0.417 + 141%/-100% years
=	Parameter 7:	*23,366 traps*
×	Parameter 8:	25.8 crabs· $trap^{-1}year^{-1}$
=	Parameter 9:	*502,835 crabs*
×	Parameter 10:	0.16 kg
=	Parameter 11:	*95,706 kg*
÷	Parameter 12:	24,366,026 kg
=	Result:	*0.36%*

Narrative

Approximately 2,800 licensed commercial blue crab (*Callinectes sapidus*) fishers used an average of 200 traps each in Louisiana in 1988 (Roberts and Thompson 1982 cited in Guillory 1993). Guillory (1999) estimates an annual trap loss rate of 10% in the fishery; 56,000 traps would be added to the ghost fishing fleet each year. In the same paper, he assumes that all these lost traps are ghost fishing, but gives no estimate for the duration of their functional lives, so the average (0.417 years) was taken from other case studies where this parameter was specified. The values from those case studies were: 2.2 years in the 1984 BC Dungeness crab fishery (Breen 1987); 0.418 years in the 1969-70 Alaska red king crab fishery (Kimker 1990); 0.375 years ± 11% in the 1986 California Dungeness crab fishery (Kennedy 1986); 0.245 +44%/-19% years in the 1992 Cook Inlet red king crab fishery (Kimker 1990); and 0.243 ± 33% years. The last value is a composite in itself, obtained from 0.241 +20.8%/-27.1% years (Kimker 1990) and 0.245 +44%/-19% years (Kimker 1990), and used in 9 case studies: 1993 Bering Sea crab fishery; 1993 Bering Sea red king crab fishery; 1990 Bristol Bay red king crab fishery; 1991 Bristol Bay red king crab fishery; 1994 Bristol Bay red king crab fishery; 1996 Bristol Bay red king crab fishery; Chiniak Bay red king crab fishery in the 1990s; and 2 1991 eastern Bering Sea snow crab fisheries.

Assuming that the rate of entry of lost traps was equal to the rate of degradation, 23,366 traps are estimated to be ghost fishing in the area. The study of ghost fishing by blue crab traps that corresponds to the fishing effort used above estimates an average of 25.8 individuals killed per trap. Applied to the previous parameter, the annual mortality from ghost traps is 602,835 crabs. The average weight of blue crabs in October 1999 to November 2000 landings was 0.35 lbs, or 0.16 kg (Murphy *et al.* 2001). The weight of ghost fishing catch is thus 95,706 kg, or 0.36% of the reported 24,366,026 kg landed in 1988 (National Marine Fisheries Service 2004).

Monte Carlo Simulation

The values for the lifespan of ghost fishing traps in this case study was an average of thirteen other case studies, some of which had asymmetrical variances. In the cases where variances were asymmetrical, the average of the variances in each case study was taken and used towards the following formula:

$$Sd((X+Y)/13) = (sqrt(Var(X) + Var(Y)))/13$$

resulting in a mean of 0.417 + 141%/-100% years (0.417 ± 141%, with the lower limit truncated at 0).

The distribution of ghost fishing mortality as a percentage of the reported landed catch is shown in Figure 3.1.9.

Newfoundland snow crab fishery 1974

Parameter list

	Parameter i:	Not provided
	Parameter ii:	Not provided
	Parameter 1:	12,000 traps
	Parameter 2:	Not provided
	Parameter 3:	1,000 traps lost per year
×	Parameter 4:	100%
=	Parameter 5:	*1,000 traps*
×	Parameter 6:	0.417 + 141%/-100% years
=	Parameter 7:	*417 traps*
×	Parameter 8:	10.4 ± 50% crabs· $trap^{-1}year^{-1}$
=	Parameter 9:	*4,339 crabs*
×	Parameter 10:	0.57 kg
=	Parameter 11:	*2,490 kg*
÷	Parameter 12:	33,000,000 kg
=	Result:	*0.08%*

Narrative

An estimated 12,000 traps were fished in 1974 in the Newfoundland snow crab (*Chionoecetes opilio*) fishery, 1,000 of which were lost and assumed to be capable of ghost fishing (Miller 1977). In the absence of an estimate for the functional life of the ghost traps, an average of ghost fishing period (0.417 years) was taken from all other case studies that had a value for this parameter was used. The values from those case studies were: 2.2 years in the 1984 BC Dungeness crab fishery (Breen 1987); 0.418 years in the 1969-70 Alaska red king crab fishery (Kimker 1990); 0.375 years ± 11% in the 1986 California Dungeness crab fishery (Kennedy 1986); 0.245 +44%/-19% years in the 1992 Cook Inlet red king crab fishery (Kimker 1990); and 0.243 ± 33% years. The last value is a composite in itself, obtained from 0.241 +20.8%/-27.1% years (Kimker 1990) and 0.245 +44%/-19% years (Kimker 1990), and used in 9 case studies: 1993 Bering Sea crab fishery; 1993 Bering Sea red king crab fishery; 1990 Bristol Bay red king crab fishery; 1991 Bristol Bay red king crab fishery; 1994 Bristol Bay red king crab fishery; 1996 Bristol Bay red king crab fishery; Chiniak Bay red king crab fishery in the 1990s; and 2 1991 eastern Bering Sea snow crab fisheries.

Assuming that the rate of entry of lost traps was equal to the rate of degradation, 417 traps are estimated to be ghost fishing in the area annually. In an experiment to determine whether traps continue to fish after bait is gone, (Miller 1977) discovered that traps with dead crabs as bait attracted 0.6 crabs per trap, none of which escaped. The study took place over 3 weeks, so assuming that the catch rate remained constant throughout the year, the annual ghost fishing mortality from all traps is 4,339 individuals. With the average weight of snow crabs at 0.57 kg (Industry Canada 2004), the weight of ghost catches from traps with dead crabs as bait is 2,490 kg, or 0.75% of the reported 33,000,000 kg landed in Newfoundland in 1987 (Miller 1977). This is higher than the 0.30% that Miller (1977) estimated. Following the same calculations, traps using squid as bait attract 537 individuals per trap per year or 31 individuals per trap in 3 weeks, resulting in a ghost fishing catch of 3.9% of the reported landings. Traps with a combination of squid and dead crab as bait attracted 132 individuals per trap per year or 7.6 individuals per trap in 3 weeks (Miller 1977), resulting in a ghost fishing catch of 0.97% of the reporting landings, and traps with no bait attract 5.2 individuals per trap per year or 0.3 individuals per trap in 3 weeks (Miller 1977), resulting in a ghost fishing catch of 0.08% of the reported landings.

Monte Carlo Simulation

Miller (1977) estimated the mortality rate of snow crab by lost traps in Newfoundland to be 0.6 ± 0. 3 crabs per trap in 3 weeks. Assuming a constant mortality rate, this is 10.4 ± 50% crabs· $trap^{-1}year^{-1}$.

The values for the lifespan of ghost fishing traps in this case study was an average of thirteen other case studies, some of which had asymmetrical variances. In the cases where variances were asymmetrical, the average of the variances in each case study was taken and used towards the following formula:

Sd((X+Y)/13) = (sqrt(Var(X) + Var(Y)))/13

resulting in a mean of 0.417 + 141%/-100% years (0.417 ± 141%, with the lower limit truncated at 0).

The average weight of snow crabs is the mean of two snow crab case studies in the Gulf of St. Lawrence. Vienneau and Moriyasu (1994) estimated 0.572 kg and Mallet *at al.* (1998) estimated 0.574 kg. The mean is therefore 0.574 kg ± 0.35%.

The distribution of ghost fishing mortality as a percentage of the reported landed catch is shown in Figure 3.1.10.

Pacific Coast Dungeness crab fishery 1971-1972

Parameter list

	Parameter i:	Not provided
	Parameter ii:	Not provided
	Parameter 1:	138,000 traps
×	Parameter 2:	10%
=	Parameter 3:	*13,800 traps*
×	Parameter 4:	96.9% + 3.1%/- 51.3%
=	Parameter 5:	*13,366 traps*
×	Parameter 6:	0.417 + 141%/-100% years
=	Parameter 7:	*5,577 traps*
×	Parameter 8:	22.0 ± 42% crabs· $trap^{-1}year^{-1}$
=	Parameter 9:	*122,569 crabs*
×	Parameter 10:	0.68 kg
=	Parameter 11:	*83,347 kg*
÷	Parameter 12:	3,538,080 kg
=	Result:	*2.4%*

Narrative

Approximately 138,000 Dungeness crab (*Cancer magister*) pots were used in Washington, Oregon, and California in the 1971-1972 season, of which 10% was lost (Pacific Marine Fisheries Commission 1978); therefore, 13,800 traps were lost that year. There was no indication of whether all the traps were ghost fishing. To achieve a conservative estimate, it was assumed that not all the lost traps would ghost fish, and a modifier of 96.9% was applied. This modifer was the mean calculated from other case studies where this parameter was specified: 46.5% in the 1987 BC Dungeness crab fishery (Breen 1987); 100% in the 1990 Chiniak Bay red king crab fishery (assumed from R. Meyer, pers comm to Smolowitz 1978a); 100% in the 1976 Atlantic offshore lobster fishery (assumed from Smolowitz 1978b); 100% in the 1969-1989 Gulf of St. Lawrence snow crab fishery (assumed from Vienneau and Moriyasu 1994); 100% in the 1987 Gulf of St. Lawrence snow crab fishery (Mallet *et al.* 1998); 100% in the 1987 New Brunswick snow crab fishery (Mallet *et al.* 1998); 100% in the Louisiana blue crab fishery c. 1993 (Guillory 1999); 100% in the 1988 Louisiana blue crab fishery (Guillory 1999); 100% in the 1993 Louisiana blue crab fishery (Guillory 1999); and 100% in the 1974 Newfoundland snow crab fishery (Miller 1977). The result was13,366 ghost fish traps.

There was no indication of how long the lost traps would remain functional, so an average length of time, 0.417 years, was taken from all case studies in which ghost fishing period was specified. The values from those case studies were: 2.2 years in the 1984 BC Dungeness crab fishery (Breen 1987); 0.418 years in the 1969-70 Alaska red king crab fishery (Kimker 1990); 0.375 years ± 11% in the 1986 California Dungeness crab fishery (Kennedy 1986); 0.245 +44%/-19% years in the 1992 Cook Inlet red king crab fishery (Kimker 1990); and 0.243 ± 33% years. The last value is a composite in itself, obtained from 0.241 +20.8%/-27.1% years (Kimker 1990) and 0.245 +44%/-19% years (Kimker 1990), and used in 9 case studies: 1993 Bering Sea crab fishery; 1993 Bering Sea red king crab fishery; 1990 Bristol Bay red king crab fishery; 1991 Bristol Bay red king crab fishery; 1994 Bristol Bay red king crab fishery; 1996 Bristol Bay red king crab fishery; Chiniak Bay red king crab fishery in the 1990s; and 2 1991 eastern Bering Sea snow crab fisheries.

Assuming that the rate of entry of lost traps was equal to the rate of degradation, and that the numbers remained constant since then, 5,577 traps are estimated to be ghost fishing inshore in the area annually. Demory (1971 cited in Pacific Marine Fisheries Commission 1978) retrieved 117 crab traps in Oregon, where each trap held an average of 31.1 crabs. Dahlstrom (1975 cited in Pacific Marine Fisheries Commission 1978) retrieved 90 crabs in 7 crab traps in California; the average catch rate is 12.8 crabs per trap. The length of time in which these traps had been ghost fishing is unknown; for the purposes of this case study, it is assumed that they had been fishing for one year and that the number of caught crabs was in equilibrium - that is, that is the number of crabs taken from the available population at any given time. The average of these catch rates (22.0 individuals· $trap^{-1}year^{-1}$), applied to all lost traps, results in 122,569 individuals killed by ghost fishing traps per year. With the mean weight per crab at 0.68 kg (Breen 1987), the weight of ghost fishing catch is 83,347 kg, 2.4% of the reported 3,538,080 kg in landings in 1974 (Pacific Marine Fisheries Commission 1978).

Monte Carlo Simulation

The percentage of traps lost to ghost fishing is the grand mean calculated from case studies where the parameters were given, which results in 96.9% + 3.1%/- 51.3% of lost traps (96.9% ± 51.3%, with the upper limit truncated at 100%).

The values for the lifespan of ghost fishing traps in this case study was an average of thirteen other case studies, some of which had asymmetrical variances. In the cases where variances were asymmetrical, the average of the variances in each case study was taken and used towards the following formula:

$$Sd((X+Y)/13) = (sqrt(Var(X) + Var(Y)))/13$$

resulting in a mean of 0.417 + 141%/-100% years (0.417 ± 141%, with the lower limit truncated at 0).

Mortality rate was averaged from other Pacific Coast mortality rates. Demory (1971 cited in Pacific Marine Fisheries Commission 1978) estimated an average of 31.1 crabs killed per trap and Dahlstrom (1975 cited in Pacific Marine Fisheries Commission 1978), estimated an average of 12.8 crabs killed per trap, so the average mortality is 22.0 ± 42%.

The distribution of ghost fishing mortality as a percentage of the reported landed catch is shown in Figure 3.1.11.

Washington State Dungeness crab fishery 1972

Parameter list

	Parameter i:	206 - not used in calculations
	Parameter ii:	Not provided
	Parameter 1:	54,518 traps
×	Parameter 2:	15.7%
=	Parameter 3:	*8,559 traps*
×	Parameter 4:	100%
=	Parameter 5:	*8,559 traps*
×	Parameter 6:	0.417 + 141%/-100% years
=	Parameter 7:	*3,571 traps*
×	Parameter 8:	114 crabs· $trap^{-1}year^{-1}$

=	Parameter 9:	*407,355 crabs*
×	Parameter 10:	0.68 kg
=	Parameter 11:	*277,001 kg*
÷	Parameter 12:	5,616,566
=	Result:	*4.9%*

Narrative

In 1972, 149 boats fished 40,518 traps for Dungeness crabs (*Cancer magister*) in Washington State (Tegelberg 1974). An additional 57 out of state boats fished an additional 14,000 traps, bringing the total number of traps used in the area to 54,518, of which 15.7%, or 8,559 traps, were lost (Tegelberg 1974). An additional 1.5% of the traps were discarded as unusable at the end of the season; since the estimate of trap loss is separate from those that were unusable, it is assumed that all the lost traps were capable of ghost fishing.

No estimate for the functional lifespan of the traps was available, so an average length of time, 0.417 years, was taken from all case studies in which ghost fishing period was specified. The values from those case studies were: 2.2 years in the 1984 BC Dungeness crab fishery (Breen 1987); 0.418 years in the 1969-70 Alaska red king crab fishery (Kimker 1990); 0.375 years ± 11% in the 1986 California Dungeness crab fishery (Kennedy 1986); 0.245 +44%/-19% years in the 1992 Cook Inlet red king crab fishery (Kimker 1990); and 0.243 ± 33% years. The last value is a composite in itself, obtained from 0.241 +20.8%/-27.1% years (Kimker 1990) and 0.245 +44%/-19% years (Kimker 1990), and used in 9 case studies: 1993 Bering Sea crab fishery; 1993 Bering Sea red king crab fishery; 1990 Bristol Bay red king crab fishery; 1991 Bristol Bay red king crab fishery; 1994 Bristol Bay red king crab fishery; 1996 Bristol Bay red king crab fishery; Chiniak Bay red king crab fishery in the 1990s; and 2 1991 eastern Bering Sea snow crab fisheries. Assuming that the rate of entry of lost traps was equal to the rate of degradation and that the values from the previous parameters have remained constant since, 3,571 traps are estimated to be ghost fishing inshore in the area annually.

In a 1982 study in the Columbia River estuary, Muir *et al.* (1984) used four standard commercial crab traps to examine the escape of Dungeness crabs in simulated lost traps. Over a 28-day period, 35 crabs died in the four traps (an average of 8.75 crabs per trap). Assuming the same mortality rate throughout the year, the yearly mortality can be extrapolated to 114 individuals per trap. The total annual mortality from all lost traps is thus 407,355. To express this mortality as a percentage of the reported landings, the average weight for Dungeness crab (0.68 kg; Breen 1987) was applied. The weight of Dungeness crab mortality from ghost traps was therefore estimated to be 277,001 kg, or

4.9% of the reported 5,616,566 kg landed in Washington State in 1972 (National Marine Fisheries Service 2004).

Monte Carlo Simulation

The values for the lifespan of ghost fishing traps in this case study was an average of thirteen other case studies, some of which had asymmetrical variances. In the cases where variances were asymmetrical, the average of the variances in each case study was taken and used towards the following formula:

$$Sd((X+Y)/13) = (sqrt(Var(X) + Var(Y)))/13$$

resulting in a mean of 0.417 + 141%/-100% years (0.417 ± 141%, with the lower limit truncated at 0).

The distribution of ghost fishing mortality as a percentage of the reported landed catch is shown in Figure 3.1.12.

Washington State Dungeness crab fishery 1973

Parameter list

	Parameter i:	147 vessels not used in calculations
	Parameter ii:	Not provided
	Parameter 1:	37,637 traps
×	Parameter 2:	15.7%
=	Parameter 3:	*5,909 traps*
×	Parameter 4:	100%
=	Parameter 5:	*5,909 traps*
×	Parameter 6:	0.417 + 141%/-100% years
=	Parameter 7:	*2,466 traps*
×	Parameter 8:	114 crabs· $trap^{-1}year^{-1}$
=	Parameter 9:	*281,221 crabs*
×	Parameter 10:	0.68 kg
=	Parameter 11:	*191,230 kg*
÷	Parameter 12:	2,074,041 kg
=	Result:	*9.2%*

Narrative

In 1973, 147 boats fished 37,637 Dungeness crab (*Cancer magister*) traps in Washington State, of which 15.7%, or 5,909 traps, were lost (Tegelberg 1974). An additional 1.5% of the traps were discarded as unusable at the end of the season; since the estimate of trap loss is separate from those that were unusable, it is assumed that all the lost traps were capable of ghost fishing.

No estimate for the functional lifespan of the traps was available, so an average length of time, 0.417 years, was taken from all case studies in which ghost fishing period was specified. The values from those case studies were: 2.2 years in the 1984 BC Dungeness crab fishery (Breen 1987); 0.418 years in the 1969-70 Alaska red king crab fishery (Kimker 1990); 0.375 years ± 11% in the 1986 California Dungeness crab fishery (Kennedy 1986); 0.245 +44%/-19% years in the 1992 Cook Inlet red king crab fishery (Kimker 1990); and 0.243 ± 33% years. The last value is a composite in itself, obtained from 0.241 +20.8%/-27.1% years (Kimker 1990) and 0.245 +44%/-19% years (Kimker 1990), and used in 9 case studies: 1993 Bering Sea crab fishery; 1993 Bering Sea red king crab fishery; 1990 Bristol Bay red king crab fishery; 1991 Bristol Bay red king crab fishery; 1994 Bristol Bay red king crab fishery; 1996 Bristol Bay red king crab fishery; Chiniak Bay red king crab fishery in the 1990s; and 2 1991 eastern Bering Sea snow crab fisheries. Assuming that the rate of entry of lost traps was equal to the rate of degradation and that the values from the previous parameters have remained constant since, 2,466 traps are estimated to be ghost fishing inshore in the area annually.

In a 1982 study in the Columbia River estuary, Muir *et al.* (1984) used four standard commercial crab traps to examine the escape of Dungeness crabs in simulated lost traps. Over a 28-day period, 35 crabs died in the four traps (an average of 8.75 crabs per trap). Assuming the same mortality rate throughout the year, the yearly mortality can be extrapolated to 114 individuals per trap. The total annual mortality from all lost traps is thus 281,221. To express this mortality as a percentage of the reported landings, the average weight for Dungeness crab (0.68 kg; Breen 1987) was applied. The weight of Dungeness crab mortality from ghost traps was therefore estimated to be 191,230 kg, or 9.2% of the reported 2,074,041 kg landed in Washington State in 1973 (National Marine Fisheries Service 2004).

Monte Carlo Simulation

The values for the lifespan of ghost fishing traps in this case study was an average of thirteen other case studies, some of which had asymmetrical variances. In the cases where variances were asymmetrical, the average of the variances in each case study was taken and used towards the following formula:

$$Sd((X+Y)/13) = (sqrt(Var(X) + Var(Y)))/13$$

resulting in a mean of 0.417 + 141%/-100% years (0.417 ± 141%, with the lower limit truncated at 0).

The distribution of ghost fishing mortality as a percentage of the reported landed catch is shown in Figure 3.1.13.

Case studies with 3 missing parameters:

Alabama blue crab fishery 1999-2000

Parameter list

	Parameter i:	174 fishers
×	Parameter ii:	150 traps per fisher
=	Parameter 1:	*26,100 traps*
×	Parameter 2:	35% ± 43%
=	Parameter 3:	*9,135 traps*
×	Parameter 4:	96.9% + 3.1%/- 51.3%
=	Parameter 5:	*8,848 traps*
×	Parameter 6:	0.417 + 141%/-100% years
=	Parameter 7:	*3,692 traps*
×	Parameter 8:	53.8 ± 34.1% crabs· $trap^{-1}year^{-1}$
=	Parameter 9:	*198,607 crabs*
×	Parameter 10:	0.16 kg
=	Parameter 11:	*31,531 kg*
÷	Parameter 12:	1,100,558 kg
=	Result:	*2.9%*

Narrative

In the 1999-2000 season, there were 174 licensed fishers (Guillory *et al.* 2001) with 150 traps each (Heath 1998 cited in Guillory *et al.* 2001) in the Alabama blue crab (*Callinectes sapidus*) fishery, so there were 26,100 traps in use that season in total. L. Hartman (pers. comm. to Guillory *et al.* 2001) estimates the annual rate of trap loss, including theft, in the fishery to be between 20 and 50%. If the midrange is used as the annual rate of trap loss, the calculated number of traps lost that year is 9,135.

Because there is no estimation of what proportion of these traps was stolen and therefore not ghost fishing, an average (96.9%) is taken of the values from other case studies where such a number is given: 46.5% in the 1987 BC Dungeness crab fishery (Breen 1987); 100% in the 1990 Chiniak Bay red king crab fishery (assumed from R.

Meyer, pers comm to Smolowitz 1978a); 100% in the 1976 Atlantic offshore lobster fishery (assumed from Smolowitz 1978b); 100% in the 1969-1989 Gulf of St. Lawrence snow crab fishery (assumed from Vienneau and Moriyasu 1994); 100% in the 1987 Gulf of St. Lawrence snow crab fishery (Mallet *et al.* 1998); 100% in the 1987 New Brunswick snow crab fishery (Mallet *et al.* 1998); 100% in the Louisiana blue crab fishery c. 1993 (Guillory 1999); 100% in the 1988 Louisiana blue crab fishery (Guillory 1999); 100% in the 1993 Louisiana blue crab fishery (Guillory 1999); and 100% in the 1974 Newfoundland snow crab fishery (Miller 1977). The result was96,853 ghost fish traps. When that is applied, the number of traps lost to ghost fishing is calculated to be 8,848.

The same method is used for length of time a lost trap would be actively ghost fishing (0.417 years). The values from those case studies were: 2.2 years in the 1984 BC Dungeness crab fishery (Breen 1987); 0.418 years in the 1969-70 Alaska red king crab fishery (Kimker 1990); 0.375 years ± 11% in the 1986 California Dungeness crab fishery (Kennedy 1986); 0.245 +44%/-19% years in the 1992 Cook Inlet red king crab fishery (Kimker 1990); and 0.243 ± 33% years. The last value is a composite in itself, obtained from 0.241 +20.8%/-27.1% years (Kimker 1990) and 0.245 +44%/-19% years (Kimker 1990), and used in 9 case studies: 1993 Bering Sea crab fishery; 1993 Bering Sea red king crab fishery; 1990 Bristol Bay red king crab fishery; 1991 Bristol Bay red king crab fishery; 1994 Bristol Bay red king crab fishery; 1996 Bristol Bay red king crab fishery; Chiniak Bay red king crab fishery in the 1990s; and 2 1991 eastern Bering Sea snow crab fisheries. The number of traps ghost fishing is calculated to be 3,692, assuming the system is at equilibrium. There is no estimate of mortality per trap in that fishery, so the average of mortalities (53.8 crabs per pot per year) in other blue crab fisheries is applied. The number of crabs killed by ghost traps is therefore 198,607. A generic estimate of the average weight of blue crabs (0.16 kg) was obtained (Murphy *et al.* 2001); the weight of blue crab mortality from ghost traps is therefore estimated to be 31,531 kg, which is 2.9% of the 1,100,558 kg landed in Alabama in 2001 (National Marine Fisheries Service 2004).

Monte Carlo simulation

Gear loss in this fishery was estimated to be between 20% and 50% (L. Hartman pers. comm. to Guillory *et al.* 2001), which equates to a midpoint of 35% ± 43%.

The percentage of traps lost to ghost fishing is the grand mean calculated from case studies where the parameters were given, which results in 96.9% + 3.1%/- 51.3% of lost traps (96.9% ± 51.3%, with the upper limit truncated at 100%).

The values for the lifespan of ghost fishing traps in this case study was an average of thirteen other case studies, some of which had asymmetrical variances. In the cases where variances were asymmetrical, the average of the variances in each case study was taken and used towards the following formula:

$$Sd((X+Y)/13) = (sqrt(Var(X) + Var(Y)))/13$$

resulting in a mean of 0.417 + 141%/-100% years (0.417 ± 141%, with the lower limit truncated at 0).

The mortality rate is taken as the mean from three values, 53.8 crabs·trap^{-1}year^{-1} ± 34.1%, as explained in the narrative above.

The distribution of ghost fishing mortality as a percentage of the reported landed catch is shown in Figure 3.1.14.

Eastern Bering Sea crab fishery 1993

Parameter list

	Parameter i:	Not provided
	Parameter ii:	Not provided
	Parameter 1:	71,000 traps
×	Parameter 2:	20%
=	Parameter 3:	*14,200 traps*
×	Parameter 4:	96.9% + 3.1%/- 51.3%
=	Parameter 5:	*13,753 traps*
×	Parameter 6:	0.243 ± 33% years
=	Parameter 7:	*3,340 traps*
×	Parameter 8:	9.03 ± 47.4% crabs· trap^{-1}year^{-1}
=	Parameter 9:	*30,176 crabs*
×	Parameter 10:	1.16 ± 21.8% kg
=	Parameter 11:	*42,269 kg*
÷	Parameter 12:	63,282,000 kg
=	Result:	*0.07%*

Narrative

In the eastern Bering Sea crab fishery, 71,000 traps were registered for use in 1993 (D. Tracy, pers. comm. to Stevens 1996), though the target species was not identified. To provide a conservative estimate, it will be assumed that the registered traps were for all crab species. An annual trap loss rate of 20% (W. Nippes, pers. comm. to

Kruse and Kimker 1993) for the Bering Strait/Aleutian Islands region red king crab (*Paralithodes camtschatica*) is applied in the absence of a loss rate for the 71,000 traps, resulting in 14,200 traps lost.

There was no indication of whether all the traps were ghost fishing. To achieve a conservative estimate, it was assumed that not all the lost traps would ghost fish, and a modifier of 96.9% was applied. This modifer was the mean calculated from other case studies where this parameter was specified: 46.5% in the 1987 BC Dungeness crab fishery (Breen 1987); 100% in the 1990 Chiniak Bay red king crab fishery (assumed from R. Meyer, pers comm to Smolowitz 1978a); 100% in the 1976 Atlantic offshore lobster fishery (assumed from Smolowitz 1978b); 100% in the 1969-1989 Gulf of St. Lawrence snow crab fishery (assumed from Vienneau and Moriyasu 1994); 100% in the 1987 Gulf of St. Lawrence snow crab fishery (Mallet *et al.* 1998); 100% in the 1987 New Brunswick snow crab fishery (Mallet *et al.* 1998); 100% in the Louisiana blue crab fishery c. 1993 (Guillory 1999); 100% in the 1988 Louisiana blue crab fishery (Guillory 1999); 100% in the 1993 Louisiana blue crab fishery (Guillory 1999); and 100% in the 1974 Newfoundland snow crab fishery (Miller 1977). The result was13,753 ghost fishing traps.

Since Alaskan legislation requires that all crab fisheries (aside from Dungeness crab fisheries) use 30 thread cotton twine (Kruse and Kimker 1993), the results for 30 thread twine from Kimker's (1990) study of various sizes biodegradable twine was consulted to estimate how long these traps would remain capable of ghost fishing. Eight repetitions in Cook Inlet yielded an average of 89.4 days (with a range of 50-106 days), or 0.245 years, to total twine degradation, and five repetitions in Prince William Sound yielded an average of 87.9 days (with a range of 76-99 days), or 0.241 years, to total twine degradation. No experiment was done in the Bering Sea, so the average (0.243 years) of the values from the two locations was used instead. Assuming that the system was at equilibrium, wherein ghost traps were added at the same rate as they were being rendered inoperable, 3,340 traps are calculated to be ghost fishing annually.

Because the target crab species was not identified for this case study, an average of crab mortalities (9.03 crabs$\cdot$ trap^{-1}year^{-1}) in other case studies situated in Alaska was applied to calculate that 30,176 "crabs" are killed per year by ghost traps. The mortalities from the case studies are: 1.54 tanner crabs per trap in Kodiak, Alaska in the 1990s (Stevens *et al.* 2000); 0.03 red king crabs per trap in Kodiak, Alaska in the 1990s (Stevens *et al.* 2000); 4 "crabs" per trap in Chiniak, Alaska in the 1990s (Stevens 1995); 3.9 king crab per trap in Chiniak, Alaska in the 1990s (Stevens 1996); and 35.7 tanner crabs per trap in Chiniak, Alaska in the 1990s (Stevens 1996).

An average was also taken from weight estimates of commercially targeted crabs in Alaska: snow crab *Chionoecetes opilio* (0.16 kg; Mallet *et al.* 1998); red king crab (6.5 lbs, or 2.95 kg; Kruse and Kimker 1993); and Dungeness crab (0.68 kg; Breen 1987). The weight of crab mortality was therefore estimated to be 42,269 kg, which is 0.07% of the 63,282,000 kg of crab landed in Alaska in 1997 (Reeves and Turnock 1999). 1997 landing information was used because 1993 landings for the Bering Strait were not available.

Monte Carlo simulation

The percentage of traps lost to ghost fishing is the grand mean calculated from case studies where the parameters were given, which results in 96.9% + 3.1%/- 51.3% of lost traps (96.9% ± 51.3%, with the upper limit truncated at 100%).

The value for the lifespan of ghost fishing traps in this case study was an average of two other values that had asymmetrical variances (0.241 years with a range of 0.208 to 0.271 years and 0.245 years with a range of 0.189 to 0.290 years). An average was thus taken of the variances for each case study, and the variance of the mean was obtained from the following formula:

$$Sd((X+Y)/2) = 1/2\text{sqrt}(Var(X) + Var(Y))$$

resulting in a mean of 0.243 years ± 33%.

The mortality rate for this case study is taken from all other Alaskan case studies. Kimker (1990) estimated a mortality of 3.9 red king crabs· $trap^{-1}year^{-1}$ and 35.7 tanner crabs in traps with 30 twine thread, Stevens *et al.* (2000) estimated 0.03 red king crabs· $trap^{-1}year^{-1}$ and 1.54 tanner crabs· $trap^{-1}year^{-1}$, and Stevens (1996) found 4 unspecified species of crab per trap per year. The mean mortality is therefore 9.03 ± 47.4 crabs· $trap^{-1}year^{-1}$.

The species weight was taken as the mean from other Alaskan case studies, where snow crab is 0.16 kg (Mallet *et al.* 1998), red king crab is 2.95 kg (Kruse and Kimker 1993) and Dungeness crab is 0.68 kg (Breen 1987). The mean weight is therefore 1.16 ± 21.8% kg .

The distribution of ghost fishing mortality as a percentage of the reported landed catch is shown in Figure 3.1.15.

Eastern Bering Sea snow crab fishery 1999

Parameter list

	Parameter i:	Not provided
	Parameter ii:	Not provided
	Parameter 1:	50,720 traps
×	Parameter 2:	1%
=	Parameter 3:	*507 traps*
×	Parameter 4:	96.9% + 3.1%/- 51.3%
=	Parameter 5:	*491 traps*
×	Parameter 6:	0.243 ± 33% years
=	Parameter 7:	*119 traps*
×	Parameter 8:	42.7 ± 3.9% crabs· $trap^{-1}year^{-1}$
=	Parameter 9:	*5,089 crabs*
×	Parameter 10:	0.57 ± 0.35% kg
=	Parameter 11:	*2,490 kg*
÷	Parameter 12:	8,808,912 kg
=	Result:	*0.03%*

Narrative

In 1999, 50,720 traps were registered for the Bering Sea snow crab (*Chionoecetes opilio*) fishery (Stevens *et al.* 2000). The rate of trap loss is estimated at 1% of traps used (R. Morrison pers. comm. to Stevens *et al.* 2000), resulting in 507 traps lost annually. Stevens *et al.* (2000) indicate that the estimate of trap loss includes traps that require replacing, so not all lost traps end up ghost fishing. There was no indication of whether all the traps were ghost fishing. To achieve a conservative estimate, it was assumed that not all the lost traps would ghost fish, and a modifier of 96.9% was applied. This modifer was the mean calculated from other case studies where this parameter was specified: 46.5% in the 1987 BC Dungeness crab fishery (Breen 1987); 100% in the 1990 Chiniak Bay red king crab fishery (assumed from R. Meyer, pers comm to Smolowitz 1978a); 100% in the 1976 Atlantic offshore lobster fishery (assumed from Smolowitz 1978b); 100% in the 1969-1989 Gulf of St. Lawrence snow crab fishery (assumed from Vienneau and Moriyasu 1994); 100% in the 1987 Gulf of St. Lawrence snow crab fishery (Mallet *et al.* 1998); 100% in the 1987 New Brunswick snow crab fishery (Mallet *et al.* 1998); 100% in the Louisiana blue crab fishery c. 1993 (Guillory 1999); 100% in the 1988 Louisiana blue crab fishery (Guillory 1999); 100% in the 1993 Louisiana blue crab fishery (Guillory 1999); and 100% in the 1974 Newfoundland snow crab fishery (Miller 1977). The result was491 traps lost to ghost fishing.

Since Alaskan legislation requires that all crab fisheries (aside from Dungeness crab fisheries) use 30 thread cotton twine (Kruse and Kimker 1993), the results for 30 thread twine from Kimker's (1990) study of various sizes biodegradable twine was consulted to estimate how long these traps would remain capable of ghost fishing. Eight repetitions in Cook Inlet yielded an average of 89.4 days (with a range of 50-106 days), or 0.245 years, to total twine degradation, and five repetitions in Prince William Sound yielded an average of 87.9 days (with a range of 76-99 days), or 0.241 years, for total twine degradation. No experiment was done in Kodiak, so the average of the values (0.243 years) from the two locations was used instead. Assuming that the rate of entry of lost traps was equal to the rate of degradation, 119 traps are estimated to be ghost fishing in Kodiak annually.

Since there was no estimate of how many snow crabs each trap catches annually, the values of this parameter from the St Lawrence snow crab fishery was applied instead. Vienneau and Moriyasu (1994) estimate the total mortality rate of crab caught by a lost trap to be 50% of a functioning trap and the average CPUE observed during the spring 1993 fishery was 82 individuals per trap, so the mortality from ghost traps is 41 individuals per trap per year. However, in a trawl survey of the Gulf of St. Lawrence, Mallet *et al.* (1998) found the mean number of crabs found in lost traps at 44.3 crabs per trap. The average of these values (42.7 crabs· $trap^{-1}year^{-1}$) was used in this case study, resulting in 5,089 crabs lost to ghost traps per year. To express the number of crabs caught in the lost traps as a percentage of the reported landings (8,808,912 kg; (Alaska Department of Fish and Game 2004a) the average weight for red king crab (0.57 kg) was obtained from Mallet *et al.* (1998); the weight of king crab mortality from ghost traps was therefore estimated to be 2,920 kg, or 0.03% of the reported landings.

Monte Carlo simulation

The percentage of traps lost to ghost fishing is the grand mean calculated from case studies where the parameters were given, which results in 96.9% + 3.1%/- 51.3% of lost traps (96.9% ± 51.3%, with the upper limit truncated at 100%).

The value for the lifespan of ghost fishing traps in this case study was an average of two other case studies that had asymmetrical variances (0.241 years with a range of 0.208 to 0.271 years and 0.245 years with a range of 0.189 to 0.290 years). An average was thus taken of the variances for each case study, and the variance of the mean was obtained from the following formula:

$$Sd((X+Y)/2) = 1/2\text{sqrt}(Var(X) + Var(Y))$$

resulting in a mean of 0.243 years ± 33%.

The mortality rate is the mean of two other case studies involving snow crabs: Stevens *et al.* (1993) estimated a mortality of 44.3 crabs· $trap^{-1}year^{-1}$ and Pecci *et al.* (1978) estimated a mortality of 41 crabs· $trap^{-1}year^{-1}$. The mean is thus 42.7 ± 3.9% crabs· $trap^{-1}year^{-1}$.

The average weight of snow crabs is the mean of two snow crab case studies in the Gulf of St. Lawrence. Vienneau and Moriyasu (1994) estimated 0.572 kg and Mallet *at al.* (1998) estimated 0.576 kg. The mean is therefore 0.574 kg ± 0.35%.

The distribution of ghost fishing mortality as a percentage of the reported landed catch is shown in Figure 3.1.16.

Florida blue crab fishery 2001

Parameter list

	Parameter i:	855 fishers
×	Parameter ii:	346 traps per fisher
=	Parameter 1:	*295,830 traps*
×	Parameter 2:	40% ± 25%
=	Parameter 3:	*118,332 traps*
×	Parameter 4:	96.9% + 3.1%/- 51.3%
=	Parameter 5:	*114,608 traps ghost fishing*
×	Parameter 6:	0.417 + 141%/-100% years
=	Parameter 7:	*47,820 traps*
×	Parameter 8:	53.8 ± 34.1% crabs· $trap^{-1}year^{-1}$
=	Parameter 9:	*2,572,693 crabs*
×	Parameter 10:	0.16 kg
=	Parameter 11:	*408,441 kg*
÷	Parameter 12:	3,379,000 kg
=	Result:	*12.1%*

Narrative

In the Florida blue crab (*Callinectes sapidus*) fishery in 2001, 855 fishers use an average of 346 traps each annually (A. Jackson, pers. comm. to A. Poon, 2004), resulting in a total of 295,830 traps. A. McMillan-Jackson (pers. comm. to Guillory *et al.* 2001) estimates the trap loss rate in Florida to be 30-50%; for the purposes of this case study, the mean was used, resulting in an estimate of 118,332 traps lost annually. The estimate of trap loss included stolen traps, but there was no indication of the proportion of traps lost to ghost fishing. Hence, a modifier of 96.9% was applied. This modifer was the mean calculated from other case studies where this parameter was specified: 46.5% in the 1987 BC Dungeness crab fishery (Breen 1987); 100% in the 1990 Chiniak Bay red king crab fishery (assumed from R. Meyer, pers comm to Smolowitz 1978a); 100% in the 1976 Atlantic offshore lobster fishery (assumed from Smolowitz 1978b); 100% in the 1969-1989 Gulf of St. Lawrence snow crab fishery (assumed from Vienneau and Moriyasu 1994); 100% in the 1987 Gulf of St. Lawrence snow crab fishery (Mallet *et al.* 1998); 100% in the 1987 New Brunswick snow crab fishery (Mallet *et al.* 1998); 100% in the Louisiana blue crab fishery c. 1993 (Guillory 1999); 100% in the 1988 Louisiana blue crab fishery (Guillory 1999); 100% in the 1993 Louisiana blue crab fishery (Guillory 1999); and 100% in the 1974 Newfoundland snow crab fishery (Miller 1977). The result was114,608 ghost fish traps.

No estimate for the functional lifespan of the traps was available, so an average length of time, 0.417 years, was taken from all case studies in which ghost fishing period was specified. The values from those case studies were: 2.2 years in the 1984 BC Dungeness crab fishery (Breen 1987); 0.418 years in the 1969-70 Alaska red king crab fishery (Kimker 1990); 0.375 years ± 11% in the 1986 California Dungeness crab fishery (Kennedy 1986); 0.245 +44%/-19% years in the 1992 Cook Inlet red king crab fishery (Kimker 1990); and 0.243 ± 33% years. The last value is a composite in itself, obtained from 0.241 +20.8%/-27.1% years (Kimker 1990) and 0.245 +44%/-19% years (Kimker 1990), and used in 9 case studies: 1993 Bering Sea crab fishery; 1993 Bering Sea red king crab fishery; 1990 Bristol Bay red king crab fishery; 1991 Bristol Bay red king crab fishery; 1994 Bristol Bay red king crab fishery; 1996 Bristol Bay red king crab fishery; Chiniak Bay red king crab fishery in the 1990s; and 2 1991 eastern Bering Sea snow crab fisheries. Assuming that the rate of entry of lost traps was equal to the rate of degradation, 47,820 traps are estimated to be ghost fishing in the area annually.

In the absence of mortality rate estimates for the Florida blue crab fishery, the average of mortality rates from Louisiana blue crab fisheries were applied instead. In Guillory's (1993) study of ghost fishing by blue crab traps in Louisiana, an average of 25.8 individuals died per trap. Arcement and Guillory (1993) performed a comparison of mortality of crabs in traps that had escape rings and those that had no escape rings. In the former, an average of 5.3 individuals were killed per trap in a 2-month period. In the latter, an average of 17.3 individuals were killed per trap in a 2-month period. Assuming that mortality rate is uniform throughout the study period and throughout the year, annual mortality is and 31.8 and 103.8 crabs per trap respectively. The average of these three values is 53.8 crabs· $trap^{-1}year^{-1}$.

Applied to the previous parameter, the annual mortality from ghost traps is 2,572,693 crabs. The average weight of blue crabs in October 1999 to November 2000 landings was 0.35 lbs, or 0.16 kg (Murphy *et al.* 2001). The weight of ghost fishing catch is thus 408,441 kg, or 12.1% of the 3,379,000 kg landed in 2001 (A. Jackson, pers. comm. to A. Poon, 2004).

Monte Carlo simulation

A. McMillen-Jackson (pers. comm. to Guillory *et al.* 2001) estimates gear loss to be between 30% and 50%, which is 40% ± 25%.

The percentage of traps lost to ghost fishing is the grand mean calculated from case studies where the parameters were given, which results in 96.9% + 3.1%/- 51.3% of lost traps (96.9% ± 51.3%, with the upper limit truncated at 100%).

The values for the lifespan of ghost fishing traps in this case study was an average of thirteen other case studies, some of which had asymmetrical variances. In the cases where variances were asymmetrical, the average of the variances in each case study was taken and used towards the following formula:

$$Sd((X+Y)/13) = (sqrt(Var(X) + Var(Y)))/13$$

resulting in a mean of 0.417 + 141%/-100% years (0.417 ± 141%, with the lower limit truncated at 0).

The mortality rate is taken as the mean from three values, 53.8 crabs·trap^{-1}year^{-1} ± 34.1%, as explained in the narrative above.

The distribution of ghost fishing mortality as a percentage of the reported landed catch is shown in Figure 3.1.17.

Gulf of Mexico blue crab fishery 1993

Parameter list

	Parameter i:	Not provided
	Parameter ii:	Not provided
	Parameter 1:	605,000 traps
×	Parameter 2:	40% ± 25%
=	Parameter 3:	*242,000 traps*

×	Parameter 4:	96.9% + 3.1%/- 51.3%
=	Parameter 5:	*234,384 traps*
×	Parameter 6:	0.417 + 141%/-100% years
=	Parameter 7:	*97,795 traps*
×	Parameter 8:	53.8 ± 34.1% crabs· $trap^{-1}year^{-1}$
=	Parameter 9:	*5,261,397 crabs*
×	Parameter 10:	0.16 kg
=	Parameter 11:	*835,299 kg*
÷	Parameter 12:	27,722,644 kg
=	Result:	*3.0%*

Narrative

The National Marine Fisheries Service (NMFS) estimated that there were 605,000 traps in use in 1993 in Florida, Alabama, Mississippi, and Louisiana (Guillory *et al.* 2001). A. McMillan-Jackson (pers. comm. to Guillory *et al.* 2001) estimates the trap loss rate in Florida to be 30-50%; for the purposes of this case study, the mean was used, resulting in an estimate of 242,000 traps lost annually.

The estimate of trap loss included stolen traps, but there was no indication of the proportion of traps lost to ghost fishing. Hence, a modifier of 96.9% was applied. This modifer was the mean calculated from other case studies where this parameter was specified: 46.5% in the 1987 BC Dungeness crab fishery (Breen 1987); 100% in the 1990 Chiniak Bay red king crab fishery (assumed from R. Meyer, pers comm to Smolowitz 1978a); 100% in the 1976 Atlantic offshore lobster fishery (assumed from Smolowitz 1978b); 100% in the 1969-1989 Gulf of St. Lawrence snow crab fishery (assumed from Vienneau and Moriyasu 1994); 100% in the 1987 Gulf of St. Lawrence snow crab fishery (Mallet *et al.* 1998); 100% in the 1987 New Brunswick snow crab fishery (Mallet *et al.* 1998); 100% in the Louisiana blue crab fishery c. 1993 (Guillory 1999); 100% in the 1988 Louisiana blue crab fishery (Guillory 1999); 100% in the 1993 Louisiana blue crab fishery (Guillory 1999); and 100% in the 1974 Newfoundland snow crab fishery (Miller 1977). The result was 234,384 ghost fish traps. No estimate for the functional lifespan of the traps was available, so an average length of time, 0.417 years, was taken from all case studies in which ghost fishing period was specified. Assuming that the rate of entry of lost traps was equal to the rate of degradation, 97,795 traps are estimated to be ghost fishing inshore in the Gulf of Mexico annually.

In the absence of mortality rate estimates for the Florida blue crab fishery, the average of mortality rates from Louisiana blue crab fisheries were applied instead. In Guillory's (1993) study of ghost fishing by blue crab traps in Louisiana, an average of 25.8 individuals died per trap. Arcement and Guillory (1993) performed a comparison of mortality of crabs in traps that had escape rings and those that had no escape rings. In the former, an average of 5.3 individuals were killed per trap in a 2-month period. In the latter, an average of 17.3 individuals were killed per trap in a 2-month period. Assuming that mortality rate is uniform throughout the study period and throughout the year, annual mortality is and 31.8 and 103.8 crabs per trap respectively. The average of these three values is 53.8 crabs· $trap^{-1}year^{-1}$.

Applied to the previous parameter, the annual mortality from ghost traps is 5,261,397 crabs. The average weight of blue crabs in October 1999 to November 2000 landings was 0.35 lbs, or 0.16 kg (Murphy *et al.* 2001). The weight of ghost fishing catch is thus 835,299 kg, or 3.0% of the combined landings caught in blue crab traps in Florida, Alabama, Mississippi, and Louisiana in 1993 (27,722,644 kg; National Marine Fisheries Service 2004).

Monte Carlo simulation

Gear loss in this fishery is estimated to be between 30% and 50% (A. McMillan-Jackson pers. comm. to Guillory *et al.* 2001), or 40% ± 25%.

The percentage of traps lost to ghost fishing is the grand mean calculated from case studies where the parameters were given, which results in 96.9% + 3.1%/- 51.3% of lost traps (96.9% ± 51.3%, with the upper limit truncated at 100%).

The values for the lifespan of ghost fishing traps in this case study was an average of thirteen other case studies, some of which had asymmetrical variances. In the cases where variances were asymmetrical, the average of the variances in each case study was taken and used towards the following formula:

$$Sd((X+Y)/13) = (sqrt(Var(X) + Var(Y)))/13$$

resulting in a mean of 0.417 + 141%/-100% years (0.417 ± 141%, with the lower limit truncated at 0).

The mortality rate is taken as the mean from three values, 53.8 crabs·$trap^{-1}year^{-1}$ ± 34.1%, as explained in the narrative above.

The distribution of ghost fishing mortality as a percentage of the reported landed catch is shown in Figure 3.1.18.

Gulf of Mexico blue crab fishery 1999 or 2000

Parameter list

	Parameter i:	5,000 fishers
×	Parameter ii:	200 traps
=	Parameter 1:	*1,000,000 traps*
×	Parameter 2:	25%
=	Parameter 3:	*250,000 traps*
×	Parameter 4:	96.9% + 3.1%/- 51.3%
=	Parameter 5:	*242,132 traps*
×	Parameter 6:	0.417 + 141%/-100% years
=	Parameter 7:	*101,028 traps*
×	Parameter 8:	53.8 ± 34.1% crabs· trap^{-1}year^{-1}
=	Parameter 9:	*5,435,327 crabs*
×	Parameter 10:	0.16 kg
=	Parameter 11:	*862,913 kg*
÷	Parameter 12:	14,757,422 kg
=	Result:	*5.8%*

Narrative

In 1999 or 2000, there were 2,381 licensed commercial blue crab (*Callinectes sapidus*) fishers in the Florida West Coast, 174 in Alabama, 256 in Mississippi, 3,347 in Louisiana, and 25 in Texas (Guillory *et al.* 2001). However, since not all license holders actively fish, Guillory *et al.* (2001) conservatively estimate 5,000 blue crab fishers in the Gulf of Mexico, each fishing an average of 200 traps for a total of 1,000,000 traps. However, the latter number may also be an underestimate, given that Guillory *et al.* (2001) estimated the following percent frequencies of number of traps per fishers based on a survey of commercial blue crab fishers in the Gulf of Mexico:

<200 traps:	33%
200-299 traps:	29%
300-399 traps:	17%
400-499 traps:	9%
>500 traps:	12%.

Guillory *et al.* (2001) then applied an annual trap loss rate of 25%, resulting in an estimate of 250,000 traps lost annually, but acknowledged that not all lost traps continue to fish. A modifier of 96.9% was therefore applied. This modifer was the mean calculated from other case studies where this parameter was specified: 46.5% in the 1987 BC Dungeness crab fishery (Breen 1987); 100% in the 1990 Chiniak Bay red king crab fishery (assumed from R. Meyer, pers comm to Smolowitz 1978a); 100% in the 1976 Atlantic offshore lobster fishery (assumed from Smolowitz 1978b); 100% in the 1969-1989 Gulf of St. Lawrence snow crab fishery (assumed from Vienneau and Moriyasu 1994); 100% in the 1987 Gulf of St. Lawrence snow crab fishery (Mallet *et al.* 1998); 100% in the 1987 New Brunswick snow crab fishery (Mallet *et al.* 1998); 100% in the Louisiana blue crab fishery c. 1993 (Guillory 1999); 100% in the 1988 Louisiana blue crab fishery (Guillory 1999); 100% in the 1993 Louisiana blue crab fishery (Guillory 1999); and 100% in the 1974 Newfoundland snow crab fishery (Miller 1977). The result was 242,132 ghost fish traps.

No estimate for the functional lifespan of the traps was available, so an average length of time, 0.417 years, was taken from all case studies in which ghost fishing period was specified. The values from those case studies were: 2.2 years in the 1984 BC Dungeness crab fishery (Breen 1987); 0.418 years in the 1969-70 Alaska red king crab fishery (Kimker 1990); 0.375 years ± 11% in the 1986 California Dungeness crab fishery (Kennedy 1986); 0.245 +44%/-19% years in the 1992 Cook Inlet red king crab fishery (Kimker 1990); and 0.243 ± 33% years. The last value is a composite in itself, obtained from 0.241 +20.8%/-27.1% years (Kimker 1990) and 0.245 +44%/-19% years (Kimker 1990), and used in 9 case studies: 1993 Bering Sea crab fishery; 1993 Bering Sea red king crab fishery; 1990 Bristol Bay red king crab fishery; 1991 Bristol Bay red king crab fishery; 1994 Bristol Bay red king crab fishery; 1996 Bristol Bay red king crab fishery; Chiniak Bay red king crab fishery in the 1990s; and 2 1991 eastern Bering Sea snow crab fisheries. Assuming that the rate of entry of lost traps was equal to the rate of degradation, 101,028 traps were estimated to be ghost fishing in the Gulf of Mexico annually.

In the absence of mortality rate estimates for the Gulf of Mexico blue crab fisheries in general, the average of mortality rates from Louisiana blue crab fisheries were applied instead. In Guillory's (1993) study of ghost fishing by blue crab traps in Louisiana, an average of 25.8 individuals died per trap. Arcement and Guillory (1993) performed a comparison of mortality of crabs in traps that had escape rings and those that had no escape rings. In the former, an average of 5.3 individuals were killed per trap in a 2-month period. In the latter, an average of 17.3 individuals were killed per trap in a 2-month period. Assuming that mortality rate is uniform throughout the study period and throughout the year, annual mortality is and 31.8 and 103.8 crabs per trap respectively. The average of these three values is 53.8 crabs· $trap^{-1}year^{-1}$.

Applied to the previous parameter, the annual mortality from ghost traps is 5,435,327 crabs. The average weight of blue crabs in Florida's October 1999 to November 2000 landings was 0.35 lbs, or 0.16 kg (Murphy *et al.* 2001). The weight of ghost fishing catch is thus 862,913 kg, or 5.8% of the combined landings of blue crabs (excluding soft crabs and peelers) caught in blue crab traps in Florida, Alabama, Mississippi, and Louisiana in 2001 (14,757,422 kg; National Marine Fisheries Service 2004).

Monte Carlo simulation

The percentage of traps lost to ghost fishing is the grand mean calculated from case studies where the parameters were given, which results in 96.9% + 3.1%/- 51.3% of lost traps (96.9% ± 51.3%, with the upper limit truncated at 100%).

The values for the lifespan of ghost fishing traps in this case study was an average of thirteen other case studies, some of which had asymmetrical variances. In the cases where variances were asymmetrical, the average of the variances in each case study was taken and used towards the following formula:

$$Sd((X+Y)/13) = (sqrt(Var(X) + Var(Y)))/13$$

resulting in a mean of 0.417 + 141%/-100% years (0.417 ± 141%, with the lower limit truncated at 0).

The mortality rate is taken as the mean from three values, 53.8 crabs·trap^{-1}year^{-1} ± 34.1%, as explained in the narrative above.

The distribution of ghost fishing mortality as a percentage of the reported landed catch is shown in Figure 3.1.19.

Gulf of St. Lawrence snow crab fishery 1980

Parameter list

	Parameter i:	130 fishers
×	Parameter ii:	150
=	Parameter 1:	*19,500 traps*
×	Parameter 2:	10.5% ± 90%
=	Parameter 3:	*2,048 traps*
×	Parameter 4:	96.9% + 3.1%/- 51.3%
=	Parameter 5:	*1,983 traps*

×	Parameter 6:	0.417 + 141%/-100% years
=	Parameter 7:	*827 traps*
×	Parameter 8:	41 crabs· $trap^{-1}year^{-1}$
=	Parameter 9:	*33,924 crabs*
×	Parameter 10:	0.572 kg
=	Parameter 11:	*19,405 kg*
÷	Parameter 12:	11,782,000 kg
	Result:	*0.16%*

Narrative

In 1980, there were 130 licensed fishers in the southwestern Gulf of St. Lawrence snow crab (*Chionoecetes opilio*) fishery (Blois 1992). There is no estimate of how many traps they used on average, but each fisher is allowed a maximum of 150 traps (M. Moriyasu, pers. comm. to A. Poon, 2004). Assuming all fishers used the maximum number of traps, 19,500 traps were used. No estimate for annual rate of loss was provided, so the average from case studies (20% in W. Nippes pers. comm. to Kruse and Kimker 1993 and 1% in R. Morrison pers. comm. to Stevens *et al.* 2000) was used for the snow crab fisheries in Alaska was applied, resulting in 2,048 traps lost per year.

Not all lost traps remain capable of ghost fishing, so a modifier of 96.9% was therefore applied. This modifer was the mean calculated from other case studies where this parameter was specified: 46.5% in the 1987 BC Dungeness crab fishery (Breen 1987); 100% in the 1990 Chiniak Bay red king crab fishery (assumed from R. Meyer, pers comm to Smolowitz 1978a); 100% in the 1976 Atlantic offshore lobster fishery (assumed from Smolowitz 1978b); 100% in the 1969-1989 Gulf of St. Lawrence snow crab fishery (assumed from Vienneau and Moriyasu 1994); 100% in the 1987 Gulf of St. Lawrence snow crab fishery (Mallet *et al.* 1998); 100% in the 1987 New Brunswick snow crab fishery (Mallet *et al.* 1998); 100% in the Louisiana blue crab fishery c. 1993 (Guillory 1999); 100% in the 1988 Louisiana blue crab fishery (Guillory 1999); 100% in the 1993 Louisiana blue crab fishery (Guillory 1999); and 100% in the 1974 Newfoundland snow crab fishery (Miller 1977). The result was 1,983 ghost fish traps.

No estimate for the functional lifespan of the traps was available, so an average length of time, 0.417 years, was taken from all case studies in which ghost fishing period was specified. The values from those case studies were: 2.2 years in the 1984 BC Dungeness crab fishery (Breen 1987); 0.418 years in the 1969-70 Alaska red king crab fishery (Kimker 1990); 0.375 years ± 11% in the 1986 California Dungeness crab fishery (Kennedy 1986); 0.245 +44%/-19% years in the 1992 Cook Inlet red king crab fishery (Kimker 1990); and 0.243 ± 33% years. The last value is a composite in itself, obtained from 0.241 +20.8%/-27.1% years (Kimker 1990) and 0.245 +44%/-19% years (Kimker

1990), and used in 9 case studies: 1993 Bering Sea crab fishery; 1993 Bering Sea red king crab fishery; 1990 Bristol Bay red king crab fishery; 1991 Bristol Bay red king crab fishery; 1994 Bristol Bay red king crab fishery; 1996 Bristol Bay red king crab fishery; Chiniak Bay red king crab fishery in the 1990s; and 2 1991 eastern Bering Sea snow crab fisheries.

Assuming that the rate of entry of lost traps was equal to the rate of degradation, 827 traps are estimated to be ghost fishing in the Gulf of St. Lawrence annually. Vienneau and Moriyasu (1994) determined that the mortality rate of crab caught by a lost trap is 50% that of regularly functioning traps; applied to the observed CPUE in the Spring 1993 fishery of 82 individuals per trap, each trap would kill 41 crabs per year. The 827 lost traps thus would kill an average of 33,924 snow crabs each year. Vienneau and Moriyasu (1994), based on unpublished data from Y. Chiasson, DFO Gulf Region, state that the average individual weight is 0.572 kg. The weight of ghost fishing catch is thus 19,405 kg, 0.16% of the reported 11,782,000 kg landed in 1987 (Mallet *et al.* 1998).

Monte Carlo simulation

An estimate of gear loss was not available for this fishery, so the average from other case studies, both in the Bering Sea, was taken. Preliminary information from R. Morrison (pers. comm. to Stevens *et al.* 2000) estimate the gear loss rate at 1%, while Paul *et al.* (1994) estimated the gear loss rate at 20%, which results in a midpoint estimate of 10.5% ± 90%.

The percentage of traps lost to ghost fishing is the grand mean calculated from case studies where the parameters were given, which results in 96.9% + 3.1%/- 51.3% of lost traps (96.9% ± 51.3%, with the upper limit truncated at 100%).

The values for the lifespan of ghost fishing traps in this case study was an average of thirteen other case studies, some of which had asymmetrical variances. In the cases where variances were asymmetrical, the average of the variances in each case study was taken and used towards the following formula:

$$Sd((X+Y)/13) = (\text{sqrt}(Var(X) + Var(Y)))/13$$

resulting in a mean of 0.417 + 141%/-100% years (0.417 ± 141%, with the lower limit truncated at 0).

The distribution of ghost fishing mortality as a percentage of the reported landed catch is shown in Figure 3.1.20.

Louisiana blue crab fishery 1999 or 2000

Parameter list

	Parameter i:	3,347 fishers
×	Parameter ii:	257 traps
	Parameter 1:	Not applicable
	Parameter 2:	Not applicable
=	Parameter 3:	*860,179 traps*
×	Parameter 4:	96.9% + 3.1%/- 51.3%
=	Parameter 5:	*833,109 traps*
×	Parameter 6:	0.417 + 141%/-100% years
=	Parameter 7:	*347,610 traps*
×	Parameter 8:	53.8 ± 34.1% crabs· $trap^{-1}year^{-1}$
=	Parameter 9:	*18,701,417 crabs*
×	Parameter 10:	0.16 kg
=	Parameter 11:	*2,969,037 kg*
÷	Parameter 12:	18,897,136 kg
=	Result:	*15.7%*

Narrative

In 1999 or 2000, there were 3,347 licensed commercial blue crab (*Callinectes sapidus*) fishers, and 257 traps per fisher were lost or stolen (Guillory and Merrell 1998 cited in Guillory *et al.* 2001), resulting in 860,179 lost traps per year. There is no estimate for the proportion of those traps that are actually ghost fishing, so a modifier of 96.9% was applied. This modifer was the mean calculated from other case studies where this parameter was specified: 46.5% in the 1987 BC Dungeness crab fishery (Breen 1987); 100% in the 1990 Chiniak Bay red king crab fishery (assumed from R. Meyer, pers comm to Smolowitz 1978a); 100% in the 1976 Atlantic offshore lobster fishery (assumed from Smolowitz 1978b); 100% in the 1969-1989 Gulf of St. Lawrence snow crab fishery (assumed from Vienneau and Moriyasu 1994); 100% in the 1987 Gulf of St. Lawrence snow crab fishery (Mallet *et al.* 1998); 100% in the 1987 New Brunswick snow crab fishery (Mallet *et al.* 1998); 100% in the Louisiana blue crab fishery c. 1993 (Guillory 1999); 100% in the 1988 Louisiana blue crab fishery (Guillory 1999); 100% in the 1993 Louisiana blue crab fishery (Guillory 1999); and 100% in the 1974 Newfoundland snow crab fishery (Miller 1977). Thus, 833,109 ghost traps are added to Louisiana's blue crab fishing grounds each year.

In the absence of an estimate for the functional life of the ghost traps, an average of ghost fishing period (0.417 years) was taken from all other case studies that had a value for this parameter was used. The values from those case studies were: 2.2 years in the 1984 BC Dungeness crab fishery (Breen 1987); 0.418 years in the 1969-70 Alaska red king crab fishery (Kimker 1990); 0.375 years ± 11% in the 1986 California Dungeness crab fishery (Kennedy 1986); 0.245 +44%/-19% years in the 1992 Cook Inlet red king crab fishery (Kimker 1990); and 0.243 ± 33% years. The last value is a composite in itself, obtained from 0.241 +20.8%/-27.1% years (Kimker 1990) and 0.245 +44%/-19% years (Kimker 1990), and used in 9 case studies: 1993 Bering Sea crab fishery; 1993 Bering Sea red king crab fishery; 1990 Bristol Bay red king crab fishery; 1991 Bristol Bay red king crab fishery; 1994 Bristol Bay red king crab fishery; 1996 Bristol Bay red king crab fishery; Chiniak Bay red king crab fishery in the 1990s; and 2 1991 eastern Bering Sea snow crab fisheries. Assuming that the rate of entry of lost traps was equal to the rate of degradation, 347,610 traps are estimated to be ghost fishing in the area annually.

In Guillory's (1993) study of ghost fishing by blue crab traps in Louisiana, an average of 25.8 individuals died per trap. Arcement and Guillory (1993) performed a comparison of mortality of crabs in traps that had escape rings and those that had no escape rings. In the former, an average of 5.3 individuals were killed per trap in a 2-month period. In the latter, an average of 17.3 individuals were killed per trap in a 2-month period. Assuming that mortality rate is uniform throughout the study period and throughout the year, annual mortality is and 31.8 and 103.8 crabs per trap respectively. The average of these three values is 53.8 crabs· $trap^{-1}year^{-1}$.

Applied to the previous parameter, the annual mortality from ghost traps is 18,701,417 crabs. The average weight of blue crabs in October 1999 to November 2000 landings was 0.35 lbs, or 0.16 kg (Murphy *et al.* 2001). The weight of ghost fishing catch is thus 2,969,037 kg, or 15.7% of the reported 18,897,136 kg landed in 2001 (National Marine Fisheries Service 2004).

Monte Carlo simulation

The percentage of traps lost to ghost fishing is the grand mean calculated from case studies where the parameters were given, which results in 96.9% + 3.1%/- 51.3% of lost traps (96.9% ± 51.3%, with the upper limit truncated at 100%).

The values for the lifespan of ghost fishing traps in this case study was an average of thirteen other case studies, some of which had asymmetrical variances. In the cases where variances were asymmetrical, the average of the variances in each case study was taken and used towards the following formula:

Sd((X+Y)/13) = (sqrt(Var(X) + Var(Y)))/13

resulting in a mean of 0.417 + 141%/-100% years (0.417 ± 141%, with the lower limit truncated at 0).

The mortality rate is taken as the mean from three values, 53.8 crabs·trap^{-1}year^{-1} ± 34.1%, as explained in the narrative above.

The distribution of ghost fishing mortality as a percentage of the reported landed catch is shown in Figure 3.1.21.

Louisiana blue crab fishery 1993

Parameter list

	Parameter i:	2,783 ± 3% fishers
×	Parameter ii:	164 traps
=	Parameter 1:	*453,548 traps*
×	Parameter 2:	10% trap
=	Parameter 3:	*45,355 traps*
×	Parameter 4:	100%
=	Parameter 5:	*45,355 traps*
×	Parameter 6:	0.417 + 141%/-100% years
=	Parameter 7:	*18,924 traps*
×	Parameter 8:	53.8 ± 34.1% crabs· trap^{-1}year^{-1}
=	Parameter 9:	*1,108,112 crabs*
×	Parameter 10:	0.16 kg
=	Parameter 11:	*161,635 kg*
÷	Parameter 12:	20,796,199 kg
=	Result:	*0.78%*

Narrative

In 1993, 2,854 licenses were issued in the Louisiana blue crab (*Callinectes sapidus*) fishery; 2,711 of those were estimated to be in full-time use (Guillory *et al.* 1996). For the purposes of this case study, the mean of the two numbers (2,783) was used to reflect both the full-time and part-time fishers. An average of 163 traps was used by each fisher, taking the total number of traps used that year to 453,548. Guillory (1999) estimates an annual trap loss rate of 10% in the fishery; 45,355 traps would be added to the ghost fishing fleet each year. Guillory (1999) assumes that all these lost traps are ghost fishing, but gives no estimate for the duration of their functional lives, so the average (0.417 years) was taken from other case studies where this parameter was specified and applied. The values from those case studies were: 2.2 years in the 1984 BC Dungeness crab fishery (Breen 1987); 0.418 years in the 1969-70 Alaska red king crab fishery (Kimker 1990); 0.375 years ± 11% in the 1986 California Dungeness crab fishery (Kennedy 1986); 0.245 +44%/-19% years in the 1992 Cook Inlet red king crab fishery (Kimker 1990); and 0.243 ± 33% years. The last value is a composite in itself, obtained from 0.241 +20.8%/-27.1% years (Kimker 1990) and 0.245 +44%/-19% years (Kimker 1990), and used in 9 case studies: 1993 Bering Sea crab fishery; 1993 Bering Sea red king crab fishery; 1990 Bristol Bay red king crab fishery; 1991 Bristol Bay red king crab fishery; 1994 Bristol Bay red king crab fishery; 1996 Bristol Bay red king crab fishery; Chiniak Bay red king crab fishery in the 1990s; and 2 1991 eastern Bering Sea snow crab fisheries. Assuming that the rate of entry of lost traps was equal to the rate of degradation, 18,924 traps are estimated to be ghost fishing in the area annually.

In Guillory's (1993) study of ghost fishing by blue crab traps in Louisiana, an average of 25.8 individuals died per trap. Arcement and Guillory (1993) performed a comparison of mortality of crabs in traps that had escape rings and those that had no escape rings. In the former, an average of 5.3 individuals were killed per trap in a 2-month period. In the latter, an average of 17.3 individuals were killed per trap in a 2-month period. Assuming that mortality rate is uniform throughout the study period and throughout the year, annual mortality is and 31.8 and 103.8 crabs per trap respectively. The average of these three values is 53.8 crabs· $trap^{-1}year^{-1}$.

Applied to the previous parameter, the annual mortality from ghost traps 1,018,112 crabs. The average weight of blue crabs in October 1999 to November 2000 landings was 0.35 lbs, or 0.16 kg (Murphy *et al.* 2001). The weight of ghost fishing catch is thus 161,635 kg, or 0.78% of the reported 20,796,199 kg landed in 1993 (NMFS cited in Guillory *et al.* 1996).

Monte Carlo simulation

Since 2854 licenses were issued in the Louisiana blue crab fishery in 1993 but only 2711 trappers were working full time (Guillory *et al.* 1996), the midpoint (2783) was taken to represent the part-time fishers, with the error (± 3%) representing the lower and upper limits of the value.

The values for the lifespan of ghost fishing traps in this case study was an average of thirteen other case studies, some of which had asymmetrical variances. In the cases where variances were asymmetrical, the average of the variances in each case study was taken and used towards the following formula:

Sd((X+Y)/13) = (sqrt(Var(X) + Var(Y)))/13

resulting in a mean of 0.417 + 141%/-100% years (0.417 ± 141%, with the lower limit truncated at 0).

The mortality rate is taken as the mean from three values, 53.8 crabs·trap^{-1}year^{-1} ± 34.1%, as explained in the narrative above.

The distribution of ghost fishing mortality as a percentage of the reported landed catch is shown in Figure 3.1.22.

Ireland spider crab fishery 2000

Parameter list

	Parameter i:	Not provided
	Parameter ii:	Not provided
	Parameter 1:	10,000 traps
×	Parameter 2:	18.6% ± 6.5%
=	Parameter 3:	*1,862 traps*
×	Parameter 4:	96.9% + 3.1%/- 51.3%
=	Parameter 5:	*1,804 traps*
×	Parameter 6:	0.417 + 141%/-100% years
=	Parameter 7:	*753 traps*
×	Parameter 8:	7.08 crabs· trap^{-1}year^{-1}
=	Parameter 9:	*5,329 crabs*
×	Parameter 10:	0.70 kg
=	Parameter 11:	*3,370 kg*
÷	Parameter 12:	402,700 kg
=	Result:	*0.93%*

Narrative

In 2000, an estimated 10,000 traps fished for spider crabs (*Maja squinado*) in Tralee and Brandon Bays in Ireland (Fahy 2001). No estimate for the rate of loss for traps was available, and since no other case studies in this paper are similar enough to assume a similar rate of loss, the average annual loss rate (18.6%) from all case studies with this parameter was used instead, resulting in 1,862 lost traps per year. The case studies were: 35% ± 43% in the 1999/2000 Alabama blue crab fishery (L. Hartman pers. comm to Guillory *et al.* 2001); 20% used in the 1993 Bering Sea crab fishery (W. Nippes to Kruse and Kimker 1993); 5% ± 33% in the 1993 Bering Sea red king crab fishery (W. Nippes pers. comm. to Stevens *et al.* 1993); 10% in the 1996 Bristol Bay red king crab fishery (Stevens 1996); 1% trap loss rate used in the 1999 Bering Sea snow crab fishery (R. Morrison pers. comm. to Stevens *et al.* 2000); 7.5% ± 33% in the 1987 Atlantic inshore lobster fishery (Krouse 1989 cited in Breen 1990); 25% ± 20% in the 1976 Atlantic offshore lobster fishery (Smolowitz 1979b); 33% in the 1973 Atlantic seacoast inshore lobster fishery (Prudden 1962); 10.9% in the 1984 BC Dungeness crab fishery (Breen 1987); 17.6% in the 1975/1976 Columbia River estuary Dungeness crab fishery (Muir *et al.* 1984); 40% ± 25% in the 2001 Florida blue crab fishery (A. McMillan-Jackson pers. comm. to Guillory *et al.* 2001); 25% in the 2001 Gulf of Mexico blue crab fishery (Guillory *et al.* 2001); 10% in the 1999 Louisiana blue crab fishery (Guillory 1999); 22.5% ± 11% in the 1975 Maine lobster fishery (Sheldon and Dow 1975); 7.5% ± 33% used in the 1992 Maine lobster fishery calculations (Carr and Harris 1987); 25% ± 20% (T. Floyd pers. comm. to Guillory *et al.* 2001); 7.5% ± 33% in the 1987 New England lobster fishery (Breen 1990); 8.3% in the 1974 Newfoundland snow crab fishery (calculated from 1,000 traps lost from 12,000 vessels; Miller 1977); 10% in the 1971/1972 Pacific Coast Dungeness crab fishery (Pacific Marine Fisheries Commission 1978); 12.5% ± 20% used in the 1980 Rhode Island Lobster fishery (Fogarty and Borden 1980 cited in Breen 1990) 42.5% ± 18% in the 1999 or 2000 Texas blue crab fishery (Texas Parks and Wildlife Department unpublished data cited in Guillory *et al.* 2001); 11.9% in the Washington Dungeness crab fishery (Barry pers. comm. to Breen 1990); 15.7% in the 1972 Washington Dungeness crab fishery (Tegelberg 1974); 15.7% in the 1973 Washington Dungeness crab fishery (Tegelberg 1974).

Not all lost traps are capable of ghost fishing; some are lost to vandalism or are stolen, so a modifier of 96.9% was applied. This modifer was the mean calculated from other case studies where this parameter was specified: 46.5% in the 1987 BC Dungeness crab fishery (Breen 1987); 100% in the 1990 Chiniak Bay red king crab fishery (assumed from R. Meyer, pers comm to Smolowitz 1978a); 100% in the 1976 Atlantic offshore lobster fishery (assumed from Smolowitz 1978b); 100% in the 1969-1989 Gulf of St. Lawrence snow crab fishery (assumed from Vienneau and Moriyasu 1994); 100% in the 1987 Gulf of St. Lawrence snow crab fishery (Mallet *et al.* 1998); 100% in the 1987 New Brunswick snow crab fishery (Mallet *et al.* 1998); 100% in the Louisiana blue crab fishery c. 1993 (Guillory 1999); 100% in the 1988 Louisiana blue crab fishery (Guillory 1999); 100% in the 1993 Louisiana blue crab fishery (Guillory 1999); and 100% in the 1974 Newfoundland snow crab fishery (Miller 1977). This results in 1,804 lost traps capable of ghost fishing.

There was no indication of how long the lost traps would remain functional, so an average length of time, 0.417 years, was taken from all case studies in which ghost fishing period was specified. The values from those case studies were: 2.2 years in the

1984 BC Dungeness crab fishery (Breen 1987); 0.418 years in the 1969-70 Alaska red king crab fishery (Kimker 1990); 0.375 years ± 11% in the 1986 California Dungeness crab fishery (Kennedy 1986); 0.245 +44%/-19% years in the 1992 Cook Inlet red king crab fishery (Kimker 1990); and 0.243 ± 33% years. The last value is a composite in itself, obtained from 0.241 +20.8%/-27.1% years (Kimker 1990) and 0.245 +44%/-19% years (Kimker 1990), and used in 9 case studies: 1993 Bering Sea crab fishery; 1993 Bering Sea red king crab fishery; 1990 Bristol Bay red king crab fishery; 1991 Bristol Bay red king crab fishery; 1994 Bristol Bay red king crab fishery; 1996 Bristol Bay red king crab fishery; Chiniak Bay red king crab fishery in the 1990s; and 2 1991 eastern Bering Sea snow crab fisheries. Assuming that the rate of entry of lost traps was equal to the rate of degradation, and that the numbers remained constant since then, 753 traps are estimated to be ghost fishing inshore in the area annually.

In a study of catches from a fleet of 'ghost fishing' traps where traps were deliberately sunk and then retrieved off the coast of Wales, an average of 7.08 spider crabs were caught per trap per year (Bullimore *et al.* 2001). Ghost fishing mortality from all lost traps is thus 5,329 individuals per year. With the average weight of spider crabs at 0.70 kg (Industry Canada 2004), the weight of ghost catches is 3,730 kg, 0.93% of the reported 402,700 kg landed in Tralee and Brandon Bays in 1999 (Fahy 2001).

Monte Carlo simulation

The value for the trap loss rate in this case study was the mean of all other case studies with this parameter. To find the variance of the mean, the following formula was used:

Sd((X+Y)/23) = (sqrt(Var(X) + Var(Y)))/23

resulting in 18.6% ± 6.5%. The variance of the mean appears to be smaller than the individually listed variances because there were numerous case studies for which variances were not given and assumed to be zero.

The value for the lifespan of ghost fishing traps in this case study was an average of thirteen other case studies, some of which had asymmetrical variances. In the cases where variances were asymmetrical, the average of the variances in each case study was taken and used towards the following formula:

Sd((X+Y)/13) = (sqrt(Var(X) + Var(Y)))/13

resulting in a mean of 0.417 + 141%/-100% years (0.417 ± 141%, with the lower limit truncated at 0).

The distribution of ghost fishing mortality as a percentage of the reported landed catch is shown in Figure 3.1.23.

Ireland brown crab fishery 1968-1972

Parameter list

	Parameter i:	28.5 ± 9.6% vessels
×	Parameter ii:	106 ± 11.6% traps
=	Parameter 1:	*3,021 traps*
×	Parameter 2:	18.6 ± 6.5%
=	Parameter 3:	*563 traps*
×	Parameter 4:	96.9% + 3.1%/- 51.3%
=	Parameter 5:	*545 traps*
×	Parameter 6:	0.417 + 141%/-100% years
=	Parameter 7:	*227 traps*
×	Parameter 8:	6.06 crabs· $trap^{-1}year^{-1}$
=	Parameter 9:	*1,378 crabs*
×	Parameter 10:	0.80 kg
=	Parameter 11:	*1,102 kg*
÷	Parameter 12:	7,774,000 kg
=	Result:	*0.01%*

Narrative

In the period between 1968-1972, 26-31 vessels each fished 95-117 brown crab (*Cancer pagurus*) traps in southeast Ireland (Gibson 1973 cited in Fahy *et al.* 2002). If the midranges of those values were taken, a total of 3,021 traps were used per year. No estimate for the rate of loss for traps was available, and since no other case studies in this paper are similar enough to assume a similar rate of loss, the average annual loss rate (18.6%) from all case studies with this parameter was used instead, resulting in 563 lost traps per year. The case studies were: 35% ± 43% in the 1999/2000 Alabama blue crab fishery (L. Hartman pers. comm to Guillory *et al.* 2001); 20% used in the 1993 Bering Sea crab fishery (W. Nippes to Kruse and Kimker 1993); 5% ± 33% in the 1993 Bering Sea red king crab fishery (W. Nippes pers. comm. to Stevens *et al.* 1993); 10% in the 1996 Bristol Bay red king crab fishery (Stevens 1996); 1% trap loss rate used in the 1999 Bering Sea snow crab fishery (R. Morrison pers. comm. to Stevens *et al.* 2000); 7.5% ±

33% in the 1987 Atlantic inshore lobster fishery (Krouse 1989 cited in Breen 1990); 25% ± 20% in the 1976 Atlantic offshore lobster fishery (Smolowitz 1979b); 33% in the 1973 Atlantic seacoast inshore lobster fishery (Prudden 1962); 10.9% in the 1984 BC Dungeness crab fishery (Breen 1987); 17.6% in the 1975/1976 Columbia River estuary Dungeness crab fishery (Muir *et al.* 1984); 40% ± 25% in the 2001 Florida blue crab fishery (A. McMillan-Jackson pers. comm. to Guillory *et al.* 2001); 25% in the 2001 Gulf of Mexico blue crab fishery (Guillory *et al.* 2001); 10% in the 1999 Louisiana blue crab fishery (Guillory 1999); 22.5% ± 11% in the 1975 Maine lobster fishery (Sheldon and Dow 1975); 7.5% ± 33% used in the 1992 Maine lobster fishery calculations (Carr and Harris 1987); 25% ± 20% (T. Floyd pers. comm. to Guillory *et al.* 2001); 7.5% ± 33% in the 1987 New England lobster fishery (Breen 1990); 8.3% in the 1974 Newfoundland snow crab fishery (calculated from 1,000 traps lost from 12,000 vessels; Miller 1977); 10% in the 1971/1972 Pacific Coast Dungeness crab fishery (Pacific Marine Fisheries Commission 1978); 12.5% ± 20% used in the 1980 Rhode Island Lobster fishery (Fogarty and Borden 1980 cited in Breen 1990) 42.5% ± 18% in the 1999 or 2000 Texas blue crab fishery (Texas Parks and Wildlife Department unpublished data cited in Guillory *et al.* 2001); 11.9% in the Washington Dungeness crab fishery (Barry pers. comm. to Breen 1990); 15.7% in the 1972 Washington Dungeness crab fishery (Tegelberg 1974); 15.7% in the 1973 Washington Dungeness crab fishery (Tegelberg 1974)

Not all lost traps are capable of ghost fishing; some are lost to vandalism or are stolen, so a modifier of 96.9% was applied. This modifer was the mean calculated from other case studies where this parameter was specified: 46.5% in the 1987 BC Dungeness crab fishery (Breen 1987); 100% in the 1990 Chiniak Bay red king crab fishery (assumed from R. Meyer, pers comm to Smolowitz 1978a); 100% in the 1976 Atlantic offshore lobster fishery (assumed from Smolowitz 1978b); 100% in the 1969-1989 Gulf of St. Lawrence snow crab fishery (assumed from Vienneau and Moriyasu 1994); 100% in the 1987 Gulf of St. Lawrence snow crab fishery (Mallet *et al.* 1998); 100% in the 1987 New Brunswick snow crab fishery (Mallet *et al.* 1998); 100% in the Louisiana blue crab fishery c. 1993 (Guillory 1999); 100% in the 1988 Louisiana blue crab fishery (Guillory 1999); 100% in the 1993 Louisiana blue crab fishery (Guillory 1999); and 100% in the 1974 Newfoundland snow crab fishery (Miller 1977). This results in 545 lost traps capable of ghost fishing.

There was no indication of how long the lost traps would remain functional, so an average length of time, 0.417 years, was taken from all case studies in which ghost fishing period was specified. The values from those case studies were: 2.2 years in the 1984 BC Dungeness crab fishery (Breen 1987); 0.418 years in the 1969-70 Alaska red king crab fishery (Kimker 1990); 0.375 years ± 11% in the 1986 California Dungeness crab fishery (Kennedy 1986); 0.245 +44%/-19% years in the 1992 Cook Inlet red king crab fishery (Kimker 1990); and 0.243 ± 33% years. The last value is a composite in itself, obtained from 0.241 +20.8%/-27.1% years (Kimker 1990) and 0.245 +44%/-19% years (Kimker 1990), and used in 9 case studies: 1993 Bering Sea crab fishery; 1993 Bering Sea red king crab fishery; 1990 Bristol Bay red king crab fishery; 1991 Bristol Bay red king crab fishery; 1994 Bristol Bay red king crab fishery; 1996 Bristol Bay red king crab fishery; Chiniak Bay red king crab fishery in the 1990s; and 2 1991 eastern Bering Sea snow crab fisheries. Assuming that the rate of entry of lost traps was equal to the rate of degradation, and that the numbers remained constant since then, 227 traps are estimated to be ghost fishing inshore in the area annually.

In a study of catches from a fleet of 'ghost fishing' traps where traps were deliberately sunk and then retrieved off the coast of Wales, an average of 6.06 brown crabs were caught per trap per year (Bullimore *et al.* 2001). Ghost fishing mortality from all lost traps is thus 1,378 individuals per year. With the average weight of brown crabs at 0.80 kg (R. De Forges, pers. comm. to A. Poon, 2004), the weight of ghost catches is 1,102 kg, 0.01% of the reported 7,774,000 kg landed in southeast Ireland in 1999. Bullimore's traps caught 0.44 lobsters per trap per year as bycatch; applied to the southeast Irish fleet, this results in 93 individuals or 55 kg (with the average weight of lobsters at 0.585 kg (Mercer 2002) per year; 0.44% of the reported 13,412 kg landed per year in Norfolk in the late from 1969-1973 (Brown 1979).

Monte Carlo simulation

Total gear was calculated from the midranges of 26-31 vessels and 95-117 traps per vessel. The result was 3,021 traps ± 19%, wherein the variance was calculated with the following formula:

Sd(X*Y)=(X*Y)(SdX/X + SdY/Y)

The value for the trap loss rate in this case study was the mean of all other case studies with this parameter. To find the variance of the mean, the following formula was used:

Sd((X+Y)/23) = (sqrt(Var(X) + Var(Y)))/23

resulting in 18.6% ± 6.5 %. The variance of the mean appears to be smaller than the individually listed variances because there were numerous case studies for which variances were not given and assumed to be zero.

The percentage of traps lost to ghost fishing is the grand mean calculated from case studies where the parameters were given, which results in 96.9% + 3.1%/- 51.3% of lost traps (96.9% ± 51.3%, with the upper limit truncated at 100%).

The values for the lifespan of ghost fishing traps in this case study was an average of thirteen other case studies, some of which had asymmetrical variances. In the cases where variances were asymmetrical, the average of the variances in each case study was taken and used towards the following formula:

$$Sd((X+Y)/13) = (sqrt(Var(X) + Var(Y)))/13$$

resulting in a mean of 0.417 + 141%/-100% years (0.417 ± 141%, with the lower limit truncated at 0).

The distribution of ghost fishing mortality as a percentage of the reported landed catch is shown in Figure 3.1.24.

Texas blue crab fishery 1999 or 2000

Parameter list

	Parameter i:	259 fishers
×	Parameter ii:	200 traps
=	Parameter 1:	*51,800 traps*
×	Parameter 2:	42.5% ± 18%
=	Parameter 3:	*22,105 traps*
×	Parameter 4:	96.9% + 3.1%/- 51.3%
=	Parameter 5:	*21,322 traps*
×	Parameter 6:	0.417 + 141%/-100% years
=	Parameter 7:	*8,897 traps ghost fishing annually*
×	Parameter 8:	53.8 ± 34.1% crabs· $trap^{-1}year^{-1}$
=	Parameter 9:	*478,635 crabs*
×	Parameter 10:	0.16 kg
=	Parameter 11:	*75,988 kg*
÷	Parameter 12:	2,341,997 kg
=	Result:	*3.2%*

Narrative

In the Texas blue crab (*Callinectes sapidus*) fishery, 259 licensed fishers each fished an average of 200 traps (Hammerschmidt *et al.* 1998 cited in Guillory *et al.* 2001) for a total of 51,800 traps. The annual trap loss rate is 35%-50% (Texas Parks and

Wildlife Department unpublished data cited in Guillory *et al.* 2001), which corresponds to 22,015 lost traps if the midrange were applied to the number of traps used.

It was unclear whether all lost traps were capable of ghost fishing or whether some were stolen or broken, so a modifier of 96.9% was applied. This modifer was the mean calculated from other case studies where this parameter was specified: 46.5% in the 1987 BC Dungeness crab fishery (Breen 1987); 100% in the 1990 Chiniak Bay red king crab fishery (assumed from R. Meyer, pers comm to Smolowitz 1978a); 100% in the 1976 Atlantic offshore lobster fishery (assumed from Smolowitz 1978b); 100% in the 1969-1989 Gulf of St. Lawrence snow crab fishery (assumed from Vienneau and Moriyasu 1994); 100% in the 1987 Gulf of St. Lawrence snow crab fishery (Mallet *et al.* 1998); 100% in the 1987 New Brunswick snow crab fishery (Mallet *et al.* 1998); 100% in the Louisiana blue crab fishery c. 1993 (Guillory 1999); 100% in the 1988 Louisiana blue crab fishery (Guillory 1999); 100% in the 1993 Louisiana blue crab fishery (Guillory 1999); and 100% in the 1974 Newfoundland snow crab fishery (Miller 1977). This results in 21,322 lost traps capable of ghost fishing.

There was no indication of how long the lost traps would remain functional, so an average length of time, 0.417 years, was taken from all case studies in which ghost fishing period was specified. The values from those case studies were: 2.2 years in the 1984 BC Dungeness crab fishery (Breen 1987); 0.418 years in the 1969-70 Alaska red king crab fishery (Kimker 1990); 0.375 years ± 11% in the 1986 California Dungeness crab fishery (Kennedy 1986); 0.245 +44%/-19% years in the 1992 Cook Inlet red king crab fishery (Kimker 1990); and 0.243 ± 33% years. The last value is a composite in itself, obtained from 0.241 +20.8%/-27.1% years (Kimker 1990) and 0.245 +44%/-19% years (Kimker 1990), and used in 9 case studies: 1993 Bering Sea crab fishery; 1993 Bering Sea red king crab fishery; 1990 Bristol Bay red king crab fishery; 1991 Bristol Bay red king crab fishery; 1994 Bristol Bay red king crab fishery; 1996 Bristol Bay red king crab fishery; Chiniak Bay red king crab fishery in the 1990s; and 2 1991 eastern Bering Sea snow crab fisheries. Assuming that the rate of entry of lost traps was equal to the rate of degradation, and that the numbers remained constant, 8,897 traps are estimated to be ghost fishing inshore in the area annually.

In Guillory's (1993) study of ghost fishing by blue crab traps in Louisiana, an average of 25.8 individuals died per trap. Arcement and Guillory (1993) performed a comparison of mortality of crabs in traps that had escape rings and those that had no escape rings. In the former, an average of 5.3 individuals were killed per trap in a 2-month period. In the latter, an average of 17.3 individuals were killed per trap in a 2-month period. Assuming that mortality rate is uniform throughout the study period and throughout the year, annual mortality is and 31.8 and 103.8 crabs per trap respectively. The average of these three values is 53.8 crabs· $trap^{-1}year^{-1}$.

Applied to the previous parameter, the annual mortality from ghost traps is 478,635 crabs. The average weight of blue crabs in October 1999 to November 2000 landings was 0.35 lbs, or 0.16 kg (Murphy *et al.* 2001). The weight of ghost fishing catch of blue crabs is thus 75,988 kg, 3.2% of the reported 2,341,997 kg landed in Texas in 2001 (National Marine Fisheries Service 2004).

Monte Carlo simulation

Gear loss in this fishery was estimated to be between 35% and 50% (TPWD in Guillory *et al.* 2001), which equates to 42.5% ± 18%.

The percentage of traps lost to ghost fishing is the grand mean calculated from case studies where the parameters were given, which results in 96.9% + 3.1%/- 51.3% of lost traps (96.9% ± 51.3%, with the upper limit truncated at 100%).

The values for the lifespan of ghost fishing traps in this case study was an average of thirteen other case studies, some of which had asymmetrical variances. In the cases where variances were asymmetrical, the average of the variances in each case study was taken and used towards the following formula:

$$Sd((X+Y)/13) = (sqrt(Var(X) + Var(Y)))/13$$

resulting in a mean of 0.417 + 141%/-100% years (0.417 ± 141%, with the lower limit truncated at 0).

The mortality rate is taken as the mean from three values, 53.8 crabs·trap^{-1}year^{-1} ± 34.1%, as explained in the narrative above.

The distribution of ghost fishing mortality as a percentage of the reported landed catch is shown in Figure 3.1.25.

Case studies with 4 missing parameters:

Mississippi blue crab fishery 1999 or 2000

Parameter list

	Parameter i:	256 fishers
×	Parameter ii:	346 traps per fisher
=	Parameter 1:	*88,576 traps*
×	Parameter 2:	25% ± 20%

=	Parameter 3:	*22,144 traps*
×	Parameter 4:	96.9% + 3.1%/- 51.3%
=	Parameter 5:	*21,447 traps*
×	Parameter 6:	0.417 + 141%/-100% years
=	Parameter 7:	*8,949 traps*
×	Parameter 8:	53.8 ± 34.1% crabs· trap^{-1}year^{-1}
=	Parameter 9:	*481,440 crabs*
×	Parameter 10:	0.16 kg
=	Parameter 11:	*75,433 kg*
÷	Parameter 12:	337,981 kg
=	Result:	*20.2%*

Narrative

In 1999 or 2000, 256 blue crab (*Callinectes sapidus*) fishers were licensed in Mississippi (Guillory *et al.* 2001). No estimate for the average number of traps per fisher was available, so the value for this parameter from the Florida fishery was applied instead (346 traps/fisher; A. Jackson 2004 pers. comm. to A. Poon). This results in 88,576 traps used annually, assuming the numbers remain consistent. Annual trap loss rate is 20%-30% in Mississippi (T. Floyd pers. comm. to Guillory *et al.* 2001); taking the midrange results in an estimate of 22,144 traps lost annually.

It is unclear what proportion of lost traps contribute to ghost fishing as opposed to being stolen or rendered inoperable, so a modifier of 96.9% was applied. This modifer was the mean calculated from other case studies where this parameter was specified: 46.5% in the 1987 BC Dungeness crab fishery (Breen 1987); 100% in the 1990 Chiniak Bay red king crab fishery (assumed from R. Meyer, pers comm to Smolowitz 1978a); 100% in the 1976 Atlantic offshore lobster fishery (assumed from Smolowitz 1978b); 100% in the 1969-1989 Gulf of St. Lawrence snow crab fishery (assumed from Vienneau and Moriyasu 1994); 100% in the 1987 Gulf of St. Lawrence snow crab fishery (Mallet *et al.* 1998); 100% in the 1987 New Brunswick snow crab fishery (Mallet *et al.* 1998); 100% in the Louisiana blue crab fishery c. 1993 (Guillory 1999); 100% in the 1988 Louisiana blue crab fishery (Guillory 1999); 100% in the 1993 Louisiana blue crab fishery (Guillory 1999); and 100% in the 1974 Newfoundland snow crab fishery (Miller 1977). The number of traps lost to ghost fishing, then, is 21,447.

In the absence of an estimate for the functional life of the ghost traps, an average of ghost fishing period (0.417 years) was taken from all other case studies that had a value for this parameter was used. Assuming that the rate of entry of lost traps was equal to the rate of degradation, 8,949 traps are estimated to be ghost fishing in the area annually. In Guillory's (1993) study of ghost fishing by blue crab traps in Louisiana, an average of 25.8 individuals died per trap. Arcement and Guillory (1993) performed a comparison of mortality of crabs in traps that had escape rings and those that had no escape rings. In the former, an average of 5.3 individuals were killed per trap in a 2-month period. In the latter, an average of 17.3 individuals were killed per trap in a 2-month period. Assuming that mortality rate is uniform throughout the study period and throughout the year, annual mortality is and 31.8 and 103.8 crabs per trap respectively. The average of these three values is 53.8 crabs· $trap^{-1}year^{-1}$.

Applied to the previous parameter, the annual mortality from ghost traps is 481,440 crabs. The average weight of blue crabs in October 1999 to November 2000 landings was 0.35 lbs, or 0.16 kg (Murphy *et al.* 2001). The weight of ghost fishing catch is thus 76,433 kg, or 20.2% of the reported 337,981 kg landed in 2000 (National Marine Fisheries Service 2004).

Monte Carlo simulation

Floyd (in Guillory *et al.* 2001) estimated the gear loss in this fishery to be between 20% and 30%, which is a midpoint of 25% ± 20%.

The percentage of traps lost to ghost fishing is the grand mean calculated from case studies where the parameters were given, which results in 96.9% + 3.1%/- 51.3% of lost traps (96.9% ± 51.3%, with the upper limit truncated at 100%).

The values for the lifespan of ghost fishing traps in this case study was an average of thirteen other case studies, some of which had asymmetrical variances. In the cases where variances were asymmetrical, the average of the variances in each case study was taken and used towards the following formula:

$$Sd((X+Y)/13) = (sqrt(Var(X) + Var(Y)))/13$$

resulting in a mean of 0.417 + 141%/-100% years (0.417 ± 141%, with the lower limit truncated at 0).

The mortality rate is taken as the mean from three values, 53.8 crabs·$trap^{-1}year^{-1}$ ± 34.1%, as explained in the narrative above.

The distribution of ghost fishing mortality as a percentage of the reported landed catch is shown in Figure 3.1.26.

South Carolina blue crab fishery c. 1979

Parameter list

	Parameter i:	743 fishers
×	Parameter ii:	75 ± 33% traps per fisher
=	Parameter 1:	*55,725 traps*
×	Parameter 2:	18.6% ± 6.5%
=	Parameter 3:	*10,378 traps*
×	Parameter 4:	96.9% + 3.1%/- 51.3%
=	Parameter 5:	*10,052 traps*
×	Parameter 6:	0.417 + 141%/-100% years
=	Parameter 7:	*4,194 traps*
×	Parameter 8:	53.8 ± 34.1% crabs· $trap^{-1}year^{-1}$
=	Parameter 9:	*225,639 crabs*
×	Parameter 10:	0.16 kg
=	Parameter 11:	*35,822 kg*
÷	Parameter 12:	2,980,000 kg
=	Result:	*1.2%*

Narrative

In the South Carolina blue crab (*Callinectes sapidus*) fishery in 1982, 743 crabbers (Bishop 1983) fished an average of 50-100 traps (Whitaker 1979 in Guillory 1999). If the midrange for traps per fisher were used, 55,725 traps would be used in total in that fishery. No estimate for the rate of loss for traps was available, and since no other case studies in this paper are similar enough to assume a similar rate of loss, the average annual loss rate (18.6%) from all case studies with this parameter was used instead, resulting in 10,378 lost traps per year. The values from the case studies were: 35% ± 43% in the 1999/2000 Alabama blue crab fishery (L. Hartman pers. comm to Guillory *et al.* 2001); 20% used in the 1993 Bering Sea crab fishery (W. Nippes to Kruse and Kimker 1993); 5% ± 33% in the 1993 Bering Sea red king crab fishery (W. Nippes pers. comm. to Stevens *et al.* 1993); 10% in the 1996 Bristol Bay red king crab fishery (Stevens 1996); 1% trap loss rate used in the 1999 Bering Sea snow crab fishery (R. Morrison pers. comm. to Stevens *et al.* 2000); 7.5% ± 33% in the 1987 Atlantic inshore lobster fishery (Krouse 1989 cited in Breen 1990); 25% ± 20% in the 1976 Atlantic offshore lobster fishery (Smolowitz 1979b); 33% in the 1973 Atlantic seacoast inshore lobster fishery (Prudden 1962); 10.9% in the 1984 BC Dungeness crab fishery (Breen

1987); 17.6% in the 1975/1976 Columbia River estuary Dungeness crab fishery (Muir *et al.* 1984); 40% ± 25% in the 2001 Florida blue crab fishery (A. McMillan-Jackson pers. comm. to Guillory *et al.* 2001); 25% in the 2001 Gulf of Mexico blue crab fishery (Guillory *et al.* 2001); 10% in the 1999 Louisiana blue crab fishery (Guillory 1999); 22.5% ± 11% in the 1975 Maine lobster fishery (Sheldon and Dow 1975); 7.5% ± 33% used in the 1992 Maine lobster fishery calculations (Carr and Harris 1987); 25% ± 20% (T. Floyd pers. comm. to Guillory *et al.* 2001); 7.5% ± 33% in the 1987 New England lobster fishery (Breen 1990); 8.3% in the 1974 Newfoundland snow crab fishery (calculated from 1,000 traps lost from 12,000 vessels; Miller 1977); 10% in the 1971/1972 Pacific Coast Dungeness crab fishery (Pacific Marine Fisheries Commission 1978); 12.5% ± 20% used in the 1980 Rhode Island Lobster fishery (Fogarty and Borden 1980 cited in Breen 1990) 42.5% ± 18% in the 1999 or 2000 Texas blue crab fishery (Texas Parks and Wildlife Department unpublished data cited in Guillory *et al.* 2001); 11.9% in the Washington Dungeness crab fishery (Barry pers. comm. to Breen 1990); 15.7% in the 1972 Washington Dungeness crab fishery (Tegelberg 1974); 15.7% in the 1973 Washington Dungeness crab fishery (Tegelberg 1974).

Not all lost traps are capable of ghost fishing; some are lost to vandalism or are stolen, so a modifier of 96.9% was applied. This modifer was the mean calculated from other case studies where this parameter was specified: 46.5% in the 1987 BC Dungeness crab fishery (Breen 1987); 100% in the 1990 Chiniak Bay red king crab fishery (assumed from R. Meyer, pers comm to Smolowitz 1978a); 100% in the 1976 Atlantic offshore lobster fishery (assumed from Smolowitz 1978b); 100% in the 1969-1989 Gulf of St. Lawrence snow crab fishery (assumed from Vienneau and Moriyasu 1994); 100% in the 1987 Gulf of St. Lawrence snow crab fishery (Mallet *et al.* 1998); 100% in the 1987 New Brunswick snow crab fishery (Mallet *et al.* 1998); 100% in the Louisiana blue crab fishery c. 1993 (Guillory 1999); 100% in the 1988 Louisiana blue crab fishery (Guillory 1999); 100% in the 1993 Louisiana blue crab fishery (Guillory 1999); and 100% in the 1974 Newfoundland snow crab fishery (Miller 1977). This results in 10,052 lost traps capable of ghost fishing.

There was no indication of how long the lost traps would remain functional, so an average length of time, 0.417 years, was taken from all case studies in which ghost fishing period was specified. The values from those case studies were: 2.2 years in the 1984 BC Dungeness crab fishery (Breen 1987); 0.418 years in the 1969-70 Alaska red king crab fishery (Kimker 1990); 0.375 years ± 11% in the 1986 California Dungeness crab fishery (Kennedy 1986); 0.245 +44%/-19% years in the 1992 Cook Inlet red king crab fishery (Kimker 1990); and 0.243 ± 33% years. The last value is a composite in itself, obtained from 0.241 +20.8%/-27.1% years (Kimker 1990) and 0.245 +44%/-19% years (Kimker 1990), and used in 9 case studies: 1993 Bering Sea crab fishery; 1993 Bering Sea red king crab fishery; 1990 Bristol Bay red king crab fishery; 1991 Bristol

Bay red king crab fishery; 1994 Bristol Bay red king crab fishery; 1996 Bristol Bay red king crab fishery; Chiniak Bay red king crab fishery in the 1990s; and 2 1991 eastern Bering Sea snow crab fisheries. Assuming that the rate of entry of lost traps was equal to the rate of degradation, and that the numbers remained constant since then, 4,194 traps are estimated to be ghost fishing inshore in the area annually.

In the absence of an estimate for mortality rate of blue crabs in lost traps in this fishery, an average from other case studies was used instead. In Guillory's (1993) study of ghost fishing by blue crab traps in Louisiana, an average of 25.8 individuals died per trap. Arcement and Guillory (1993) performed a comparison of mortality of crabs in traps that had escape rings and those that had no escape rings. In the former, an average of 5.3 individuals were killed per trap in a 2-month period. In the latter, an average of 17.3 individuals were killed per trap in a 2-month period. Assuming that mortality rate is uniform throughout the study period and throughout the year, annual mortality is and 31.8 and 103.8 crabs per trap respectively. The average of these three values is 53.8 crabs· $trap^{-1}year^{-1}$.

Applied to the previous parameter, the annual mortality from ghost traps is 225,639 crabs. The average weight of blue crabs in October 1999 to November 2000 landings was 0.35 lbs, or 0.16 kg (Murphy *et al.* 2001). The weight of ghost fishing catch is thus 35,822 kg, 1.2% of the reported landings of 2,980,000 kg per year, averaged over 35 years (Whitaker *et al.* 1998). Terrapin is a bycatch of the blue crab fishery, and over a two month period, terrapin mortality was estimated at 285 terrapins for the 743 commercial crabbers in the fishery (Bishop 1983). Assuming a constant rate of catch, annual terrapin mortality is 1,710 terrapins; a high number for a closed fishery.

Monte Carlo simulation

Whitaker (1979 in Guillory 1999) estimates that each fisher in this fishery uses between 50 and100 traps, which equates to 75 ± 33% traps per fisher.

The value for the trap loss rate in this case study was the mean of all other case studies with this parameter. To find the variance of the mean, the following formula was used:

$$Sd((X+Y)/23) = (sqrt(Var(X) + Var(Y)))/23$$

resulting in 18.6% ± 6.5%. The variance of the mean appears to be smaller than the individually listed variances because there were numerous case studies for which variances were not given and assumed to be zero.

The percentage of traps lost to ghost fishing is the grand mean calculated from case studies where the parameters were given, which results in 96.9% + 3.1%/- 51.3% of lost traps (96.9% ± 51.3%, with the upper limit truncated at 100%).

The values for the lifespan of ghost fishing traps in this case study was an average of thirteen other case studies, some of which had asymmetrical variances. In the cases where variances were asymmetrical, the average of the variances in each case study was taken and used towards the following formula:

$$Sd((X+Y)/13) = (sqrt(Var(X) + Var(Y)))/13$$

resulting in a mean of 0.417 + 141%/-100% years (0.417 ± 141%, with the lower limit truncated at 0).

The mortality rate is taken as the mean from three values, 53.8 crabs·trap^{-1}year^{-1} ± 34.1%, as explained in the narrative above.

The distribution of ghost fishing mortality as a percentage of the reported landed catch is shown in Figure 3.1.27.

Texas blue crab fishery c. 1997

Parameter list

	Parameter i:	259 fishers
	Parameter ii:	Not applicable
	Parameter 1:	Not applicable
×	Parameter 2:	103 traps lost per fisher
=	Parameter 3:	*26,667 traps*
×	Parameter 4:	96.9% + 3.1%/- 51.3%
=	Parameter 5:	*25,837 traps*
×	Parameter 6:	0.417 + 141%/-100% years
=	Parameter 7:	*10,781 traps*
×	Parameter 8:	53.8 ± 34.1% crabs· trap^{-1}year^{-1}
=	Parameter 9:	*579,993 crabs*
×	Parameter 10:	0.16 kg
=	Parameter 11:	*92,080 kg*
÷	Parameter 12:	2,341,997 kg
=	Result:	*3.9%*

Narrative

In the Texas blue crab (*Callinectes sapidus*) fishery, fishers lose an average of 103 traps per year each (Shively 1997 cited in Guillory *et al.* 2001). In 1999 or 2000 there were 259 licensed fishers in Texas (Guillory *et al.* 2001), so in that season, 26,667 traps were lost.

It was unclear whether all lost traps were capable of ghost fishing or whether some were stolen or broken, so a modifier of 96.9% was applied. This modifer was the mean calculated from other case studies where this parameter was specified: 46.5% in the 1987 BC Dungeness crab fishery (Breen 1987); 100% in the 1990 Chiniak Bay red king crab fishery (assumed from R. Meyer, pers comm to Smolowitz 1978a); 100% in the 1976 Atlantic offshore lobster fishery (assumed from Smolowitz 1978b); 100% in the 1969-1989 Gulf of St. Lawrence snow crab fishery (assumed from Vienneau and Moriyasu 1994); 100% in the 1987 Gulf of St. Lawrence snow crab fishery (Mallet *et al.* 1998); 100% in the 1987 New Brunswick snow crab fishery (Mallet *et al.* 1998); 100% in the Louisiana blue crab fishery c. 1993 (Guillory 1999); 100% in the 1988 Louisiana blue crab fishery (Guillory 1999); 100% in the 1993 Louisiana blue crab fishery (Guillory 1999); and 100% in the 1974 Newfoundland snow crab fishery (Miller 1977). This results in 25,837 lost traps capable of ghost fishing.

There was no indication of how long the lost traps would remain functional, so an average length of time, 0.417 years, was taken from all case studies in which ghost fishing period was specified. The values from those case studies were: 2.2 years in the 1984 BC Dungeness crab fishery (Breen 1987); 0.418 years in the 1969-70 Alaska red king crab fishery (Kimker 1990); 0.375 years ± 11% in the 1986 California Dungeness crab fishery (Kennedy 1986); 0.245 +44%/-19% years in the 1992 Cook Inlet red king crab fishery (Kimker 1990); and 0.243 ± 33% years. The last value is a composite in itself, obtained from 0.241 +20.8%/-27.1% years (Kimker 1990) and 0.245 +44%/-19% years (Kimker 1990), and used in 9 case studies: 1993 Bering Sea crab fishery; 1993 Bering Sea red king crab fishery; 1990 Bristol Bay red king crab fishery; 1991 Bristol Bay red king crab fishery; 1994 Bristol Bay red king crab fishery; 1996 Bristol Bay red king crab fishery; Chiniak Bay red king crab fishery in the 1990s; and 2 1991 eastern Bering Sea snow crab fisheries. Assuming that the rate of entry of lost traps was equal to the rate of degradation, and that the numbers remained constant, 10,781 traps are estimated to be ghost fishing inshore in the area annually.

In Guillory's (1993) study of ghost fishing by blue crab traps in Louisiana, an average of 25.8 individuals died per trap. Arcement and Guillory (1993) performed a comparison of mortality of crabs in traps that had escape rings and those that had no escape rings. In the former, an average of 5.3 individuals were killed per trap in a 2-

month period. In the latter, an average of 17.3 individuals were killed per trap in a 2-month period. Assuming that mortality rate is uniform throughout the study period and throughout the year, annual mortality is and 31.8 and 103.8 crabs per trap respectively. The average of these three values is 53.8 crabs· $trap^{-1}year^{-1}$.

Applied to the previous parameter, the annual mortality from ghost traps is 579,993 crabs. The average weight of blue crabs in October 1999 to November 2000 landings was 0.35 lbs, or 0.16 kg (Murphy *et al.* 2001). The weight of ghost fishing catch of blue crabs is thus 92,080 kg, 3.9% of the reported 2,341,997 kg landed in Texas in 2001 (National Marine Fisheries Service 2004).

Monte Carlo simulation

The percentage of traps lost to ghost fishing is the grand mean calculated from case studies where the parameters were given, which results in 96.9% + 3.1%/- 51.3% of lost traps (96.9% ± 51.3%, with the upper limit truncated at 100%).

The values for the lifespan of ghost fishing traps in this case study was an average of thirteen other case studies, some of which had asymmetrical variances. In the cases where variances were asymmetrical, the average of the variances in each case study was taken and used towards the following formula:

$$Sd((X+Y)/13) = (sqrt(Var(X) + Var(Y)))/13$$

resulting in a mean of 0.417 + 141%/-100% years (0.417 ± 141%, with the lower limit truncated at 0).

The mortality rate is taken as the mean from three values, 53.8 crabs·$trap^{-1}year^{-1}$ ± 34.1%, as explained in the narrative above.

The distribution of ghost fishing mortality as a percentage of the reported landed catch is shown in Figure 3.1.28.

Monte Carlo figures

Distributions of Monte Carlo simulations; x-axis denotes ghost fishing as a percentage of reported landings (%) and y-axis denotes frequency. Unless noted otherwise, scale of the x-axis begins at 0. The verticle line represents the result obtained from the calculation of midrange values.

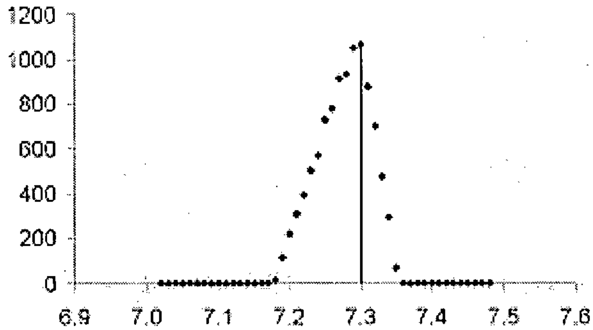

Figure 3.1.1 – British Columbia Dungeness crab fishery 1984.

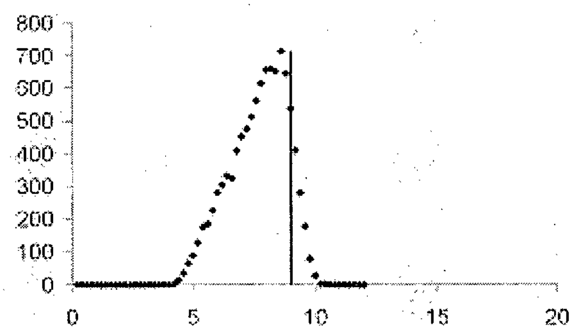

Figure 3.1.2 – California Dungeness crab fishery 1986

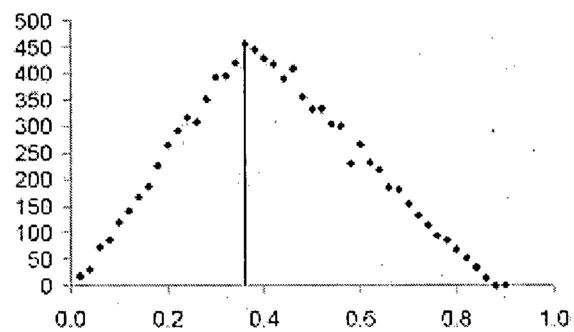

Figure 3.1.3 – New Brunswick snow crab fishery 1987

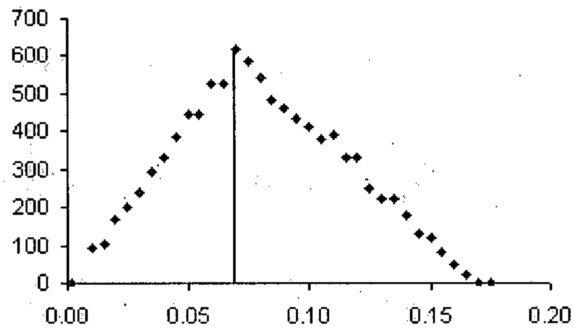

Figure 3.1.4 – Gulf of St. Lawrence snow crab fishery 1966-1989

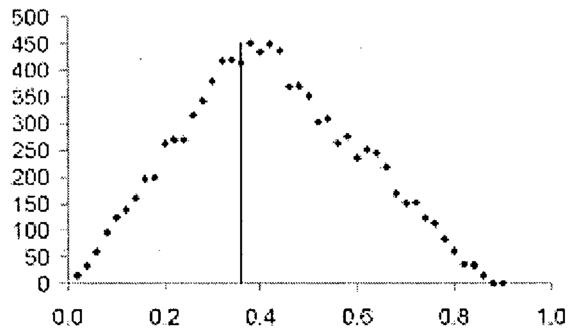

Figure 3.1.5 – Gulf of St. Lawrence snow crab fishery 1987

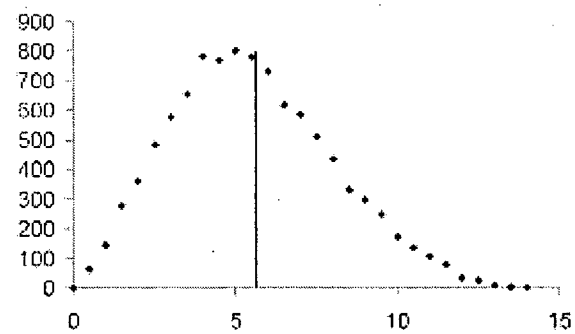

Figure 3.1.6 – Washington State Dungeness crab fishery 1975-1976

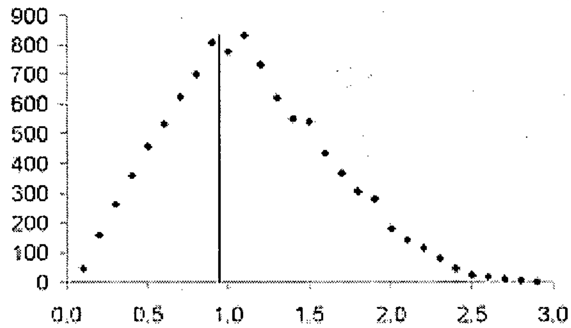

Figure 3.1.7 – Louisiana blue crab fishery c. 1999

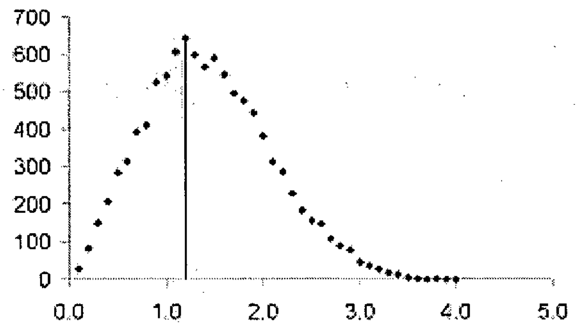

Figure 3.1.8 – Louisiana blue crab fishery c. 1993

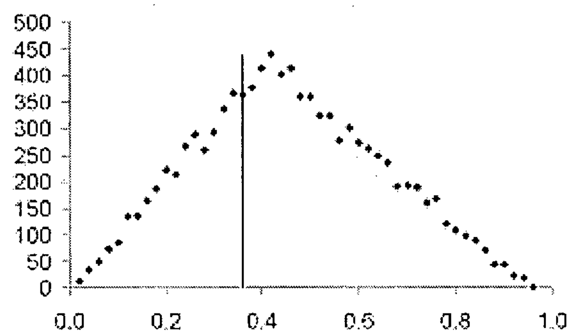

Figure 3.1.9 – Louisiana blue crab fishery 1988

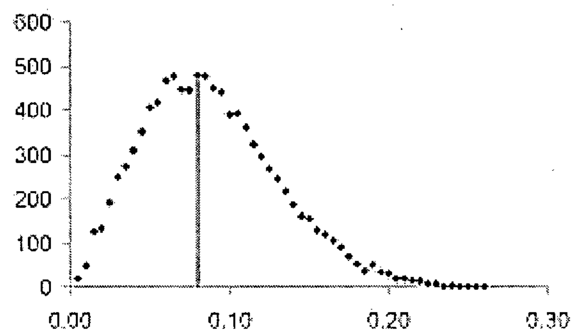

Figure 3.1.10 – Newfoundland snow crab fishery 1974

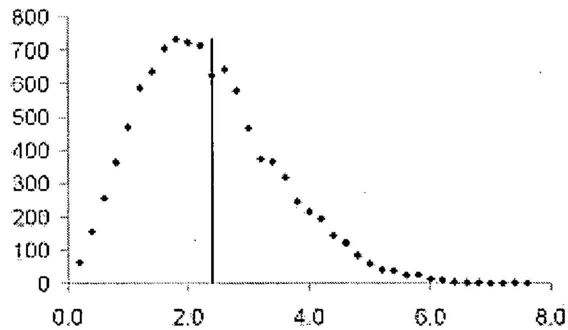

Figure 3.1.11 – Pacific Coast Dungeness crab fishery 1971-1972

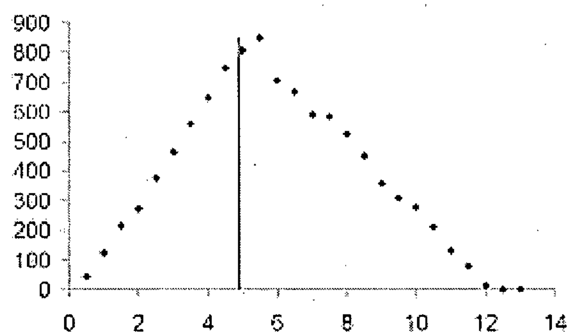

Figure 3.1.12 – Washington State Dungeness crab fishery 1972

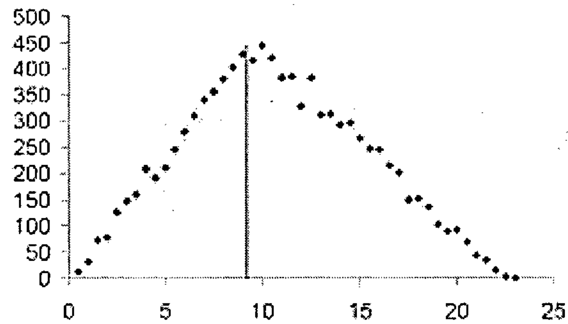

Figure 3.1.13 – Washington State Dungeness crab fishery 1973

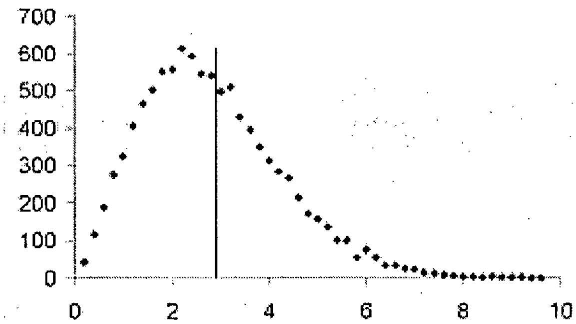

Figure 3.1.14 – Alabama blue crab fishery 1999-2000

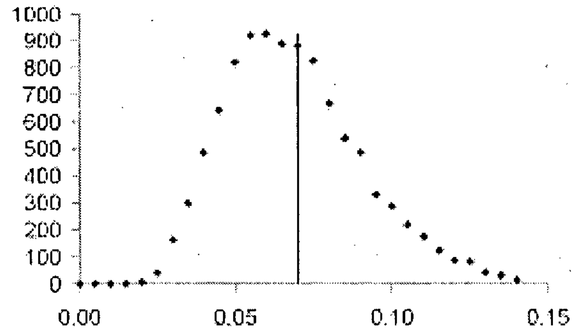

Figure 3.1.15 – Eastern Bering Sea crab fishery 1993

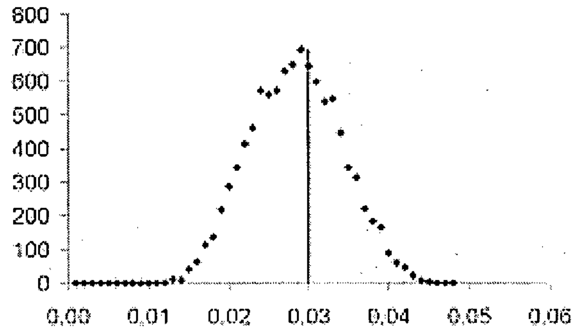

Figure 3.1.16 – Eastern Bering Sea snow crab fishery 1999

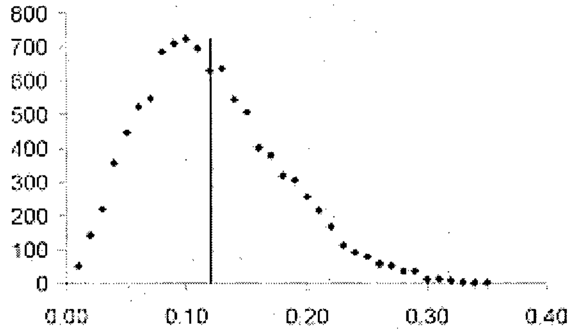

Figure 3.1.17 – Florida blue crab fishery 2001

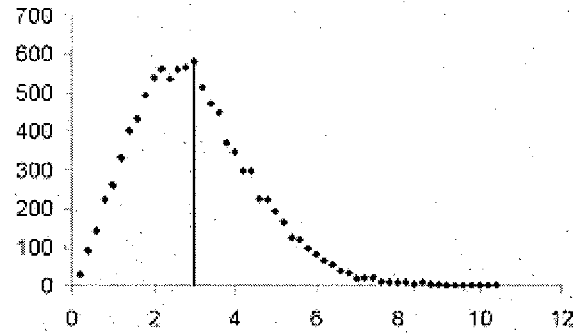

Figure 3.1.18 – Gulf of Mexico blue crab fishery 1993

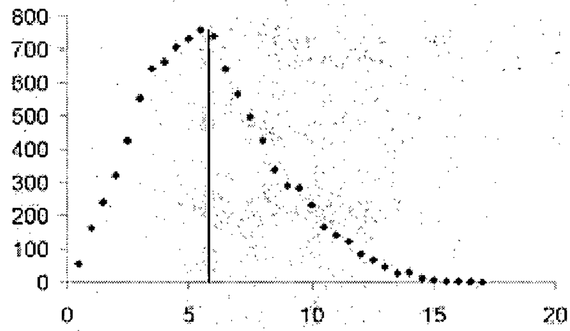

Figure 3.1.19 – Gulf of Mexico blue crab fishery 1999 or 2000

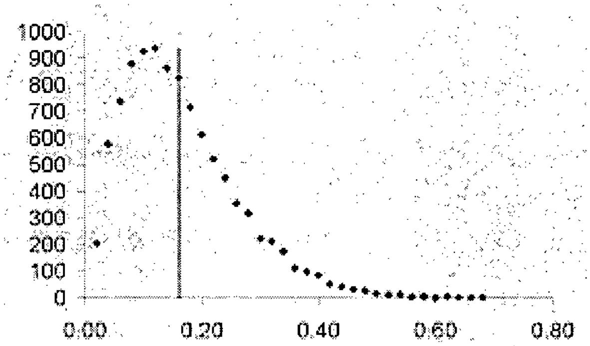

Figure 3.1.20 – Gulf of St. Lawrence snow crab fishery 1980

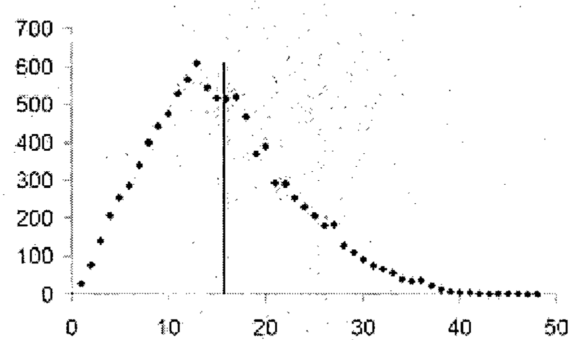

Figure 3.1.21 – Louisiana blue crab fishery 1999 or 2000

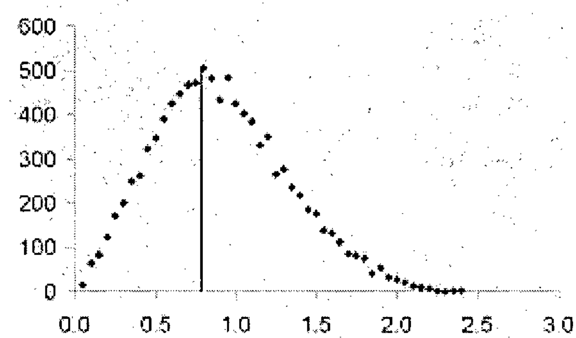

Figure 3.1.22 Louisana blue crab fishery 1993

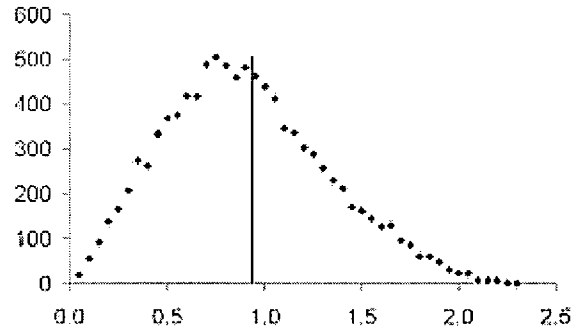

Figure 3.1.23 – Ireland spider crab fishery 2000

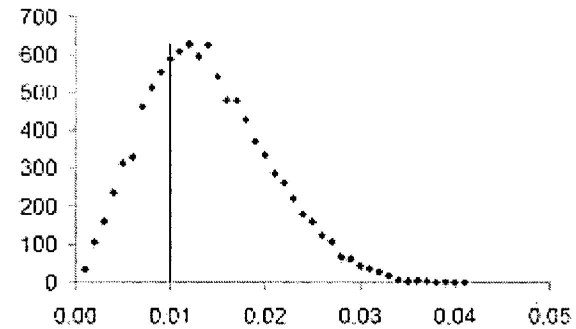

Figure 3.1.24 – Ireland brown crab fishery 1968-1972

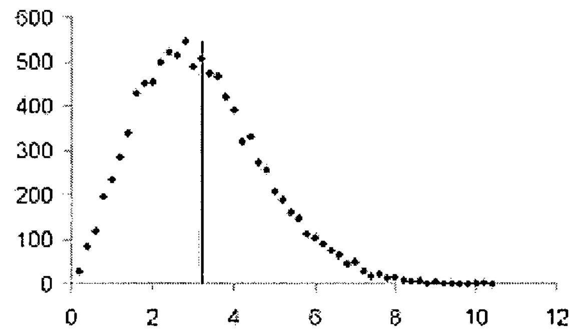

Figure 3.1.25 – Texas blue crab fishery 1999 or 2000

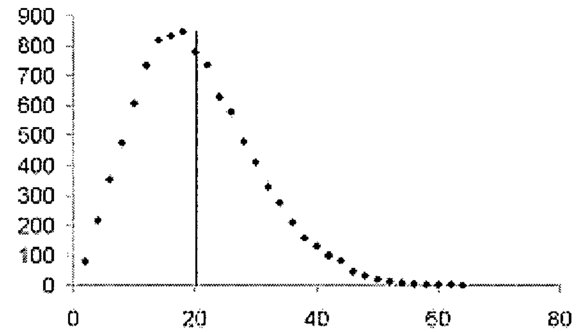

Figure 3.1.26 – Mississippi blue crab fishery 1999 or 2000

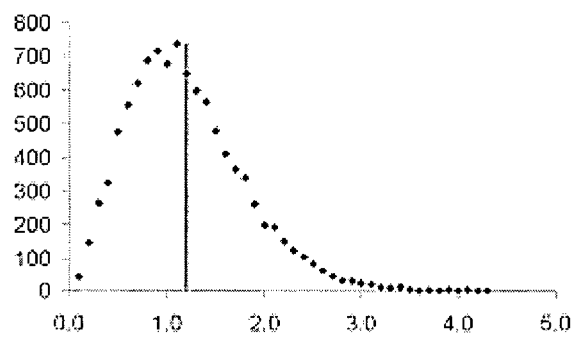

Figure 3.1.27 – South Carolina blue crab fishery c. 1979

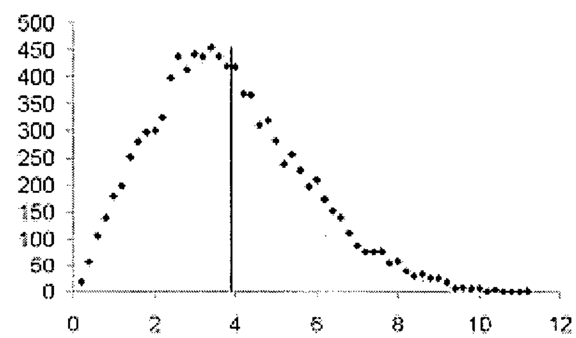

Figure 3.1.28 – Texas blue crab fishery c. 1997

3.2 King crabs

Case studies with 1 missing parameter:

Chiniak Bay red king crab fishery c. 1990s

Parameter list

	Parameter i:	Not provided
	Parameter ii:	Not provided
	Parameter 1:	Not provided
	Parameter 2:	Not provided
	Parameter 3:	3,000 traps
×	Parameter 4:	100%
=	Parameter 5:	*3,000 traps*
×	Parameter 6:	0.243 ± 33% years
=	Parameter 7:	*729 traps*
×	Parameter 8:	0.036 crabs· $trap^{-1}year^{-1}$
=	Parameter 9:	*26 crabs*
×	Parameter 10:	0.16 kg
=	Parameter 11:	*77 kg*
÷	Parameter 12:	3,946,320 kg
=	Result:	*0.002%*

Narrative

No estimate of fishing effort or trap loss rate was given for the red king crab (*Paralithodes camtschatica*) fishery in Chiniak Bay in Alaska, so the total number of traps lost annually from Kodiak Island (R. Meyer pers. comm. to Smolowitz 1978a) was used instead. It was not specified that the estimated 3,000 lost traps were capable of ghost fishing (as opposed to being stolen or falling to degradation) but the context in which the estimate was given suggested that all the traps lost were ghost fishing: "This durability made it more urgent to answer the question of whether or not lost pots continued to fish and for how long, especially when gear loss numbers were estimated at over 3,000 pots annually."

Since Alaskan legislation requires that all crab fisheries (aside from Dungeness crab fisheries) use 30 thread cotton twine (Kruse and Kimker 1993), the results for 30 thread twine from Kimker's (1990) study of various sizes biodegradable twine was consulted to estimate how long these traps would remain capable of ghost fishing. Eight repetitions in Cook Inlet yielded an average of 89.4 days (with a range of 50-106 days), or 0.245 years, to total twine degradation, and five repetitions in Prince William Sound yielded an average of 87.9 days (with a range of 76-99 days), or 0.241 years, for total twine degradation. No experiment was done in Chiniak Bay, so the average of the values from the two locations was used instead. Assuming that the rate of entry of lost traps was equal to the rate of degradation, 729 traps are estimated to be ghost fishing in Chiniak Bay that year.

Several steps were taken to estimate mortality in the traps. Four crabs were found in 8 pots recovered by dragging in a survey of Chiniak Bay (Stevens 1996). Since the species of crab were unspecified, it was necessary to determine the probability that the crabs were king crabs. To do so, catches for were obtained from the NMFS online catch statistics database for all species of crabs landed in Alaska in 1994. The proportion of king crab catches was applied to the 0.5 catch rate of the traps for crabs in Chiniak Bay, resulting in 0.036 crabs caught per trap, or 26 for all traps over the year.

Landings of red king crab in Chiniak Bay were unavailable, so the closest available landings - 3,946,320 kg in Kodiak in the 1982/1983 season, which had the lowest landings in 23 years (Kodiak Chamber of Commerce 2001) - were used instead. To express the number of crabs caught in the lost traps as a percentage of reported landings, the average weight for red king crab (6.5 lbs, or 2.95 kg) was obtained from Kruse and Kimker (1993); the weight of king crab mortality from ghost traps was therefore estimated to be 77 kg, or 0.002% of the reported landings.

Monte Carlo Simulation

The value for the lifespan of ghost fishing traps in this case study was an average of two other values that had asymmetrical variances (0.241 years with a range of 0.208 to 0.271 years and 0.245 years with a range of 0.189 to 0.290 years). An average was thus taken of the variances for each case study, and the variance of the mean was obtained from the following formula:

$$Sd((X+Y)/2) = 1/2\text{sqrt}(Var(X) + Var(Y))$$

resulting in a mean of 0.243 years ± 33%.

The distribution of ghost fishing mortality as a percentage of the reported landed catch is shown in Figure 3.2.1.

Case studies with 2 missing parameters:

Eastern Bering Sea red king crab fishery c. 1993

Parameter list

	Parameter i:	Not provided
	Parameter ii:	Not provided
	Parameter 1:	100,000 traps
×	Parameter 2:	15% ± 33%
=	Parameter 3:	*15,000 traps*
×	Parameter 4:	96.9% + 3.1%/- 51.3%
=	Parameter 5:	*14,528 traps*
×	Parameter 6:	0.243 ± 33% years
=	Parameter 7:	*3,528 traps*
×	Parameter 8:	1.97 ± 98% crabs· $trap^{-1}year^{-1}$
=	Parameter 9:	*6,933 crabs*
×	Parameter 10:	2.95 kg
=	Parameter 11:	*20,443 kg*
÷	Parameter 12:	9,200,000 kg)
=	Result:	*0.22%*

Narrative

In the early 1990s, an estimated 100,000 red king crab (*Paralithodes camtschatica*) pots were in use in the Bering Sea (Stevens *et al.* 1993), with an annual trap loss rate between 10 and 20% (W. Nippes, pers. comm. to Stevens *et al.* 1993). The midrange, 15%, is used in the calculation to estimate 15,000 traps lost per year in that scenario. It is not specified whether the trap loss rate included traps that had been stolen or were otherwise incapable of ghost fishing. To achieve a conservative estimate, it was assumed that not all the lost traps would ghost fish, so a modifier of 96.9% was applied. This modifer was the mean calculated from other case studies where this parameter was specified: 46.5% in the 1987 BC Dungeness crab fishery (Breen 1987); 100% in the 1990 Chiniak Bay red king crab fishery (assumed from R. Meyer, pers comm to Smolowitz 1978a); 100% in the 1976 Atlantic offshore lobster fishery (assumed from Smolowitz 1978b); 100% in the 1969-1989 Gulf of St. Lawrence snow crab fishery (assumed from Vienneau and Moriyasu 1994); 100% in the 1987 Gulf of St. Lawrence snow crab fishery (Mallet *et al.* 1998); 100% in the 1987 New Brunswick snow crab fishery (Mallet *et al.* 1998); 100% in the Louisiana blue crab fishery c. 1993 (Guillory 1999); 100% in the 1988 Louisiana blue crab fishery (Guillory 1999); 100% in the 1993 Louisiana blue crab fishery (Guillory 1999); and 100% in the 1974 Newfoundland snow crab fishery (Miller 1977). The result was 14,528 ghost fishing traps.

Since Alaskan legislation requires that all crab fisheries (aside from Dungeness crab fisheries) use 30 thread cotton twine (Kruse and Kimker 1993), the results for 30 thread twine from Kimker's (1990) study of various sizes biodegradable twine was consulted to estimate how long these traps would remain capable of ghost fishing. Eight repetitions in Cook Inlet yielded an average of 89.4 days (with a range of 50-106 days), or 0.245 years, to total twine degradation, and five repetitions in Prince William Sound yielded an average of 87.9 days (with a range of 76-99 days), or 0.241 years, to total twine degradation. No experiment was done in the Bering Sea, so the average of the values from the two locations was used instead. Assuming that the system was at equilibrium, wherein ghost traps were added at the same rate as they were being rendered inoperable, 3,528 traps were calculated to be ghost fishing annually. There was no estimate of mortality per trap in Alaska's king crab fishery, so an average was taken from mortalities from regional case studies in Alaska. 3.9 crabs· $trap^{-1}year^{-1}$ was from estimated Kimker (1990) and 0.03 crabs· $trap^{-1}year^{-1}$ was estimated from Stevens *et al.* (2000) for an average of 1.97 crabs· $trap^{-1}year^{-1}$. The number of crabs killed by ghost traps was thus 10,083. An estimate of the average weight of red king crabs (6.5 lbs, or 2.95 kg) was obtained (Kruse and Kimker 1993); the weight of king crab mortality from ghost traps is therefore estimated to be 29,728 kg, or 0.22% of the 9,200,000 kg landed in Alaska in 1993 (Reeves and Turnock 1999).

Monte Carlo Simulation

Gear loss for this fishery was estimated to be between 10% and 20% (Stevens *et al.* 1993), which equates to 15% ± 33%.

The percentage of traps lost to ghost fishing is the grand mean calculated from case studies where the parameters were given, which results in 96.9% + 3.1%/- 51.3% of lost traps (96.9% ± 51.3%, with the upper limit truncated at 100%).

The value for the lifespan of ghost fishing traps in this case study was an average of two other values that had asymmetrical variances (0.241 years with a range of 0.208 to 0.271 years and 0.245 years with a range of 0.189 to 0.290 years). An average was thus taken of the variances for each case study, and the variance of the mean was obtained from the following formula:

$$Sd((X+Y)/2) = 1/2\text{sqrt}(Var(X) + Var(Y))$$

resulting in a mean of 0.243 years ± 33%.

The mortality rate for this case study is taken from other Alaskan red king crab case studies. Kimker (1990) estimated a mortality of 3.9 crabs· $trap^{-1}year^{-1}$ in traps with 30 twine thread, while Stevens *et al.* (2000) estimated 0.03 crabs per tanner crab trap. This results in an average mortality rate of 1.97 crabs per trap ± 98%.

The distribution of ghost fishing mortality as a percentage of the reported landed catch is shown in Figure 3.2.2.

Bristol Bay red king crab fishery c. 1994

Parameter list

	Parameter i:	Not provided
	Parameter ii:	Not provided
	Parameter 1:	Not provided
	Parameter 2:	Not provided
	Parameter 3:	20,000 traps
×	Parameter 4:	96.9% + 3.1%/- 51.3%
=	Parameter 5:	*19,371 traps*
×	Parameter 6:	0.243 ± 33% years
=	Parameter 7:	*4,705 traps*
×	Parameter 8:	1.97 ± 98% crabs· $trap^{-1}year^{-1}$
=	Parameter 9:	*9,245 crabs*
×	Parameter 10:	2.95 kg
=	Parameter 11:	*27,257 kg*
÷	Parameter 12:	1,025,720 kg
=	Result:	*2.6%*

Narrative

No data on fishing effort was given for one case study for the red king crab (*Paralithodes camtschatica*) fisheries in Bristol Bay, Alaska, around 1994; however, the number of lost traps was estimated to be 20,000 per year (Paul *et al.* 1994). It was not specified whether this number referred to traps capable of ghost fishing or to traps lost due to various causes, including those which render them incapable of functioning. To achieve a conservative estimate, it was assumed that not all the lost traps would ghost fish. A modifier of 96.9% was applied. This modifer was the mean calculated from other case studies where this parameter was specified: 46.5% in the 1987 BC Dungeness crab fishery (Breen 1987); 100% in the 1990 Chiniak Bay red king crab fishery (assumed from R. Meyer, pers comm to Smolowitz 1978a); 100% in the 1976 Atlantic offshore lobster fishery (assumed from Smolowitz 1978b); 100% in the 1969-1989 Gulf of St. Lawrence snow crab fishery (assumed from Vienneau and Moriyasu 1994); 100% in the 1987 Gulf of St. Lawrence snow crab fishery (Mallet *et al.* 1998); 100% in the 1987 New Brunswick snow crab fishery (Mallet *et al.* 1998); 100% in the Louisiana blue crab fishery c. 1993 (Guillory 1999); 100% in the 1988 Louisiana blue crab fishery (Guillory 1999); 100% in the 1993 Louisiana blue crab fishery (Guillory 1999); and 100% in the 1974 Newfoundland snow crab fishery (Miller 1977). The result was 19,371 ghost fishing traps.

Since Alaskan legislation requires that all crab fisheries (aside from Dungeness crab fisheries) use 30-thread cotton twine (Kruse and Kimker 1993), the results for 30 thread twine from Kimker's (1990) study of various sizes biodegradable twine was consulted to estimate how long these traps would remain capable of ghost fishing. Eight repetitions in Cook Inlet yielded an average of 89.4 days (with a range of 50-106 days), or 0.245 years, to total twine degradation, and five repetitions in Prince William Sound yielded an average of 87.9 days (with a range of 76-99 days), or 0.241 years, to total twine degradation. No experiment was done in Bristol Bay, so the average of the values from the two locations was used instead. Assuming the rate of entry of lost traps is equal to the rate of degradation, 4,705 traps are estimated to be ghost fishing in Bristol Bay per year.

No estimate of mortality was given for crabs caught in the traps, so an average was taken from mortalities from other regional case studies in Alaska. 3.9 crabs· $trap^{-1}year^{-1}$ was from estimated Kimker (1990) and 0.03 crabs· $trap^{-1}year^{-1}$ was estimated from Stevens *et al.* (2000) for a mean of 1.97 crabs· $trap^{-1}year^{-1}$, giving a result of 13,444 crabs lost to ghost fishing annually To express this as a percentage of reported landings (1,025,720; Granath 2002) in the Bristol Bay fishery in 1993, the average weight for red king crab (6.5 lbs, or 2.95 kg) was obtained from Kruse and Kimker (1993); the weight of king crab mortality from ghost traps was therefore estimated to be 39,639 kg, 2.6% of the reported landings.

Monte Carlo Simulation

The percentage of traps lost to ghost fishing is the grand mean calculated from case studies where the parameters were given, which results in 96.9% + 3.1%/- 51.3% of lost traps (96.9% ± 51.3%, with the upper limit truncated at 100%).

The value for the lifespan of ghost fishing traps in this case study was an average of two other values that had asymmetrical variances (0.241 years with a range of 0.208 to 0.271 years and 0.245 years with a range of 0.189 to 0.290 years). An average was thus taken of the variances for each case study, and the variance of the mean was obtained from the following formula:

$$Sd((X+Y)/2) = 1/2sqrt(Var(X) + Var(Y))$$

resulting in a mean of 0.243 years ± 33%.

The mortality rate for this case study is taken from other Alaskan red king crab case studies. Kimker (1990) estimated a mortality of 3.9 crabs· $trap^{-1}year^{-1}$ in traps with 30 twine thread, while Stevens *et al.* (2000) estimated 0.03 crabs per tanner crab trap. This results in an average mortality rate of 1.97 crabs per trap ± 98%.

The distribution of ghost fishing mortality as a percentage of the reported landed catch is shown in Figure 3.2.3.

Bristol Bay red king crab fishery c. 1996

Parameter list

	Parameter i:	Not provided
	Parameter ii:	Not provided
	Parameter 1:	70,000 traps
×	Parameter 2:	10%
=	Parameter 3:	*7,000 traps*
×	Parameter 4:	96.9% + 3.1%/- 51.3%
=	Parameter 5:	*6,780 traps ghost fishing*
×	Parameter 6:	0.243 ± 33% years
=	Parameter 7:	*1,647 traps*
×	Parameter 8:	1.97 ± 98% crabs· $trap^{-1}year^{-1}$
=	Parameter 9:	*3,236 crabs*
×	Parameter 10:	2.95 kg
=	Parameter 11:	*9,540 kg*
÷	Parameter 12:	3,812,787 kg
=	Result:	*0.25%*

Narrative

In another case study for Bristol Bay, Alaska, Stevens (1996) used a rough approximation of W. Nippes's (pers. comm. to Stevens *et al.* 1993) estimate of 70,000 traps used annually in the area's red king crab (*Paralithodes camtschatica*) fisheries and applied a trap loss rate of 10%, resulting in 7,000 traps lost per year. Since it was unclear whether this rate applied only to traps lost in the water and capable of ghost fishing, a conservative approach was taken. A modifier of 96.9% was applied. This modifer was the mean calculated from other case studies where this parameter was specified: 46.5% in the 1987 BC Dungeness crab fishery (Breen 1987); 100% in the 1990 Chiniak Bay red king crab fishery (assumed from R. Meyer, pers comm to Smolowitz 1978a); 100% in the 1976 Atlantic offshore lobster fishery (assumed from Smolowitz 1978b); 100% in the 1969-1989 Gulf of St. Lawrence snow crab fishery (assumed from Vienneau and Moriyasu 1994); 100% in the 1987 Gulf of St. Lawrence snow crab fishery (Mallet *et al.* 1998); 100% in the 1987 New Brunswick snow crab fishery (Mallet *et al.* 1998); 100% in the Louisiana blue crab fishery c. 1993 (Guillory 1999); 100% in the 1988 Louisiana blue crab fishery (Guillory 1999); 100% in the 1993 Louisiana blue crab fishery (Guillory 1999); and 100% in the 1974 Newfoundland snow crab fishery (Miller 1977). The result was 6,780 ghost fishing traps.

Since Alaskan legislation requires that all crab fisheries (aside from Dungeness crab fisheries) use 30 thread cotton twine (Kruse and Kimker 1993), the results for 30 thread twine from Kimker's (1990) study of various sizes biodegradable twine was consulted to estimate how long these traps would remain capable of ghost fishing. Eight repetitions in Cook Inlet yielded an average of 89.4 days (with a range of 50-106 days), or 0.245 years, for total twine degradation, and five repetitions in Prince William Sound yielded an average of 87.9 days (with a range of 76-99 days), or 0.241 years, for total twine degradation. No experiment was done in Bristol Bay, so the average of the values from the two locations was used instead. Assuming that the rate of entry of lost traps was equal to the rate of degradation, 1,647 traps are estimated to be ghost fishing in Bristol Bay per year.

No estimate of mortality was given for crabs caught in the traps, so an average was taken from mortalities from other regional case studies in Alaska. 3.9 crabs· $trap^{-1}year^{-1}$ was from estimated Kimker (1990) and 0.03 crabs· $trap^{-1}year^{-1}$ was estimated from Stevens *et al.* (2000) for a mean of 1.97 crabs· $trap^{-1}year^{-1}$, giving a result of 4,705 crabs lost to ghost fishing annually. To express this as a percentage of reported landings (3,812,787 kg; (Alaska Department of Fish and Game 2004b) in the Bristol Bay fishery in 1996, the average weight for red king crab (6.5 lbs, or 2.95 kg) was obtained from Kruse and Kimker (1993); the weight of king crab mortality from ghost traps is therefore estimated to be 13,873 kg, 0.364% of the reported landings.

Monte Carlo Simulation

The percentage of traps lost to ghost fishing is the grand mean calculated from case studies where the parameters were given, which results in 96.9% + 3.1%/- 51.3% of lost traps (96.9% ± 51.3%, with the upper limit truncated at 100%).

The value for the lifespan of ghost fishing traps in this case study was an average of two other values that had asymmetrical variances (0.241 years with a range of 0.208 to 0.271 years and 0.245 years with a range of 0.189 to 0.290 years). An average was thus taken of the variances for each case study, and the variance of the mean was obtained from the following formula:

$$Sd((X+Y)/2) = 1/2sqrt(Var(X) + Var(Y))$$

resulting in a mean of 0.243 years ± 33%.

The mortality rate for this case study is taken from other Alaskan red king crab case studies. Kimker (1990) estimated a mortality of 3.9 crabs· $trap^{-1}year^{-1}$ in traps with 30 twine thread, while Stevens *et al.* (2000) estimated 0.03 crabs per tanner crab trap. This results in an average mortality rate of 1.97 crabs per trap ± 98%.

The distribution of ghost fishing mortality as a percentage of the reported landed catch is shown in Figure 3.2.4.

Bristol Bay red king crab fishery 1990

Parameter list

	Parameter i:	Not provided
	Parameter ii:	Not provided
	Parameter 1:	68,000 traps
×	Parameter 2:	20% trap loss rate
=	Parameter 3:	*7,000 traps*
×	Parameter 4:	96.9% + 3.1%/- 51.3%
=	Parameter 5:	*13,172 traps*
×	Parameter 6:	0.243 ± 33% years
=	Parameter 7:	*3,199 traps*
×	Parameter 8:	1.97 ± 98% crabs· $trap^{-1}year^{-1}$
=	Parameter 9:	*6,286 crabs*
×	Parameter 10:	2.95 kg
=	Parameter 11:	*18,535 kg*
÷	Parameter 12:	9,236,358 kg
=	Result:	*0.20%*

Narrative

In 1990, 68,000 traps were registered for use in the Alaska Bristol Bay red king crab (*Paralithodes camtschatica*) fishery (Griffin and Ward 1992 cited in Kruse and Kimker 1993). If 20% of those traps are assumed to be lost as W. Nippes (pers. comm.to Kruse and Kimker 1993) suggests, 13,600 traps were lost in the fishery. It is unclear if the trap loss rate refers solely to traps that end up ghost fishing; to produce a conservative estimate, it was assumed that it did not. Therefore, the average of values for other case studies where this parameter was specified was applied. This modifier, 96.9%, was the mean calculated from other case studies where this parameter was specified: 46.5% in the 1987 BC Dungeness crab fishery (Breen 1987); 100% in the 1990 Chiniak Bay red king crab fishery (assumed from R. Meyer, pers comm to Smolowitz 1978a); 100% in the 1976 Atlantic offshore lobster fishery (assumed from Smolowitz 1978b); 100% in the 1969-1989 Gulf of St. Lawrence snow crab fishery (assumed from Vienneau and Moriyasu 1994); 100% in the 1987 Gulf of St. Lawrence snow crab fishery (Mallet *et al.* 1998); 100% in the 1987 New Brunswick snow crab fishery (Mallet *et al.* 1998); 100% in the Louisiana blue crab fishery c. 1993 (Guillory 1999); 100% in the 1988 Louisiana blue crab fishery (Guillory 1999); 100% in the 1993 Louisiana blue crab fishery (Guillory 1999); and 100% in the 1974 Newfoundland snow crab fishery (Miller 1977). The result was 13,172 lost traps assumed to be ghost fishing.

Since Alaskan legislation requires that all crab fisheries (aside from Dungeness crab fisheries) use 30 thread cotton twine (Kruse and Kimker 1993), the results for 30 thread twine from Kimker's (1990) study of various sizes biodegradable twine was consulted to estimate how long these traps would remain capable of ghost fishing. Eight repetitions in Cook Inlet yielded an average of 89.4 days (with a range of 50-106 days), or 0.245 years, to total twine degradation, and five repetitions in Prince William Sound yielded an average of 87.9 days (with a range of 76-99 days), or 0.241 years, for total twine degradation. No experiment was done in Bristol Bay, so the average of the values from the two locations was used instead. Assuming that the rate of entry of lost traps was equal to the rate of degradation, 3,199 traps are estimated to be ghost fishing in Bristol Bay.

No estimate of mortality was given for crabs caught in the traps, so an average was taken from mortalities from other regional case studies in Alaska. 3.9 crabs· $trap^{-1}year^{-1}$ was from estimated Kimker (1990) and 0.03 crabs· $trap^{-1}year^{-1}$ was estimated from Stevens *et al.* (2000) for a mean of 1.97 crabs· $trap^{-1}year^{-1}$, giving a result of 9,142 crabs lost to ghost fishing annually. To express this as a percentage of reported landings (9,236,358 kg; (Alaska Department of Fish and Game 2004b) in the Bristol Bay fishery in 1990, the average weight for red king crab (6.5 lbs, or 2.95 kg) was obtained from

Kruse and Kimker (1993); the weight of king crab mortality from ghost traps was therefore estimated to be 26,953 kg, or 0.292% of the reported landings.

Monte Carlo Simulation

The percentage of traps lost to ghost fishing is the grand mean calculated from case studies where the parameters were given, which results in 96.9% + 3.1%/- 51.3% of lost traps (96.9% ± 51.3%, with the upper limit truncated at 100%).

The value for the lifespan of ghost fishing traps in this case study was an average of two other values that had asymmetrical variances (0.241 years with a range of 0.208 to 0.271 years and 0.245 years with a range of 0.189 to 0.290 years). An average was thus taken of the variances for each case study, and the variance of the mean was obtained from the following formula:

$$Sd((X+Y)/2) = 1/2\text{sqrt}(Var(X) + Var(Y))$$

resulting in a mean of 0.243 years ± 33%.

The mortality rate for this case study is taken from other Alaskan red king crab case studies. Kimker (1990) estimated a mortality of 3.9 crabs· $trap^{-1}year^{-1}$ in traps with 30 twine thread, while Stevens *et al.* (2000) estimated 0.03 crabs per tanner crab trap. This results in an average mortality rate of 1.97 crabs per trap ± 98%.

The distribution of ghost fishing mortality as a percentage of the reported landed catch is shown in Figure 3.2.5.

Bristol Bay red king crab fishery 1991

Parameter list

	Parameter i:	Not provided
	Parameter ii:	Not provided
	Parameter 1:	90,000 traps
×	Parameter 2:	20%
=	Parameter 3:	*18,000 traps*
×	Parameter 4:	96.9% + 3.1%/- 51.3%
=	Parameter 5:	*17,434 traps*
×	Parameter 6:	0.243 ± 33% years
=	Parameter 7:	*4,234 traps*
×	Parameter 8:	1.97 ± 98% crabs· $trap^{-1}year^{-1}$

=	Parameter 9:	*8,320 crabs*
×	Parameter 10:	2.95 kg
=	Parameter 11:	*24,531 kg*
÷	Parameter 12:	7,791,893 kg
=	Result:	*0.32%*

Narrative

In 1991, 90,000 traps were registered for use in the Alaska Bristol Bay red king crab (*Paralithodes camtschatica*) fishery (Griffin and Ward in Kruse and Kimker 1993). If 20% of those traps are assumed to be lost as W. Nippes (pers. comm.to Kruse and Kimker 1993) suggests, 18,000 traps were lost in the fishery. The trap loss rate doesn't specify whether it refers solely to traps that end up ghost fishing; to produce a conservative estimate, it was assumed that it did not. Therefore, the average of values for other case studies where this parameter was specified was applied. This modifier, 96.9%, was the mean calculated from other case studies where this parameter was specified: 46.5% in the 1987 BC Dungeness crab fishery (Breen 1987); 100% in the 1990 Chiniak Bay red king crab fishery (assumed from R. Meyer, pers comm to Smolowitz 1978a); 100% in the 1976 Atlantic offshore lobster fishery (assumed from Smolowitz 1978b); 100% in the 1969-1989 Gulf of St. Lawrence snow crab fishery (assumed from Vienneau and Moriyasu 1994); 100% in the 1987 Gulf of St. Lawrence snow crab fishery (Mallet *et al.* 1998); 100% in the 1987 New Brunswick snow crab fishery (Mallet *et al.* 1998); 100% in the Louisiana blue crab fishery c. 1993 (Guillory 1999); 100% in the 1988 Louisiana blue crab fishery (Guillory 1999); 100% in the 1993 Louisiana blue crab fishery (Guillory 1999); and 100% in the 1974 Newfoundland snow crab fishery (Miller 1977). The result was 17,434 lost traps assumed to be ghost fishing.

Since Alaskan legislation requires that all crab fisheries (aside from Dungeness crab fisheries) use 30 thread cotton twine (Kruse and Kimker 1993), the results for 30 thread twine from Kimker's (1990) study of various sizes biodegradable twine was consulted to estimate how long these traps would remain capable of ghost fishing. Eight repetitions in Cook Inlet yielded an average of 89.4 days (with a range of 50-106 days), or 0.245 years, to total twine degradation, and five repetitions in Prince William Sound yielded an average of 87.9 days (with a range of 76-99 days), or 0.241 years, for total twine degradation. No experiment was done in Bristol Bay, so the average of the values from the two locations was used instead. Assuming that the rate of entry of lost traps was equal to the rate of degradation, 4,234 traps are estimated to be ghost fishing in Bristol Bay.

No estimate of mortality was given for crabs caught in the traps, so an average was taken from mortalities from other regional case studies in Alaska. 3.9 crabs· trap⁻

^{1}year^{-1} was from estimated Kimker (1990) and 0.03 crabs· trap^{-1}year^{-1} was estimated from Stevens *et al.* (2000) for a mean of 1.97 crabs· trap^{-1}year^{-1}, giving a result of 12,099 crabs lost to ghost fishing annually. To express this as a percentage of reported landings (7,791,893 kg; (Alaska Department of Fish and Game 2004b) in the Bristol Bay fishery in 1991, the average weight for red king crab (6.5 lbs, or 2.95 kg) was obtained from Kruse and Kimker (1993); the weight of king crab mortality from ghost traps is therefore estimated to be 35,673 kg, or 0.458% of the reported landings.

Monte Carlo Simulation

The percentage of traps lost to ghost fishing is the grand mean calculated from case studies where the parameters were given, which results in 96.9% + 3.1%/- 51.3% of lost traps (96.9% ± 51.3%, with the upper limit truncated at 100%).

The value for the lifespan of ghost fishing traps in this case study was an average of two other values that had asymmetrical variances (0.241 years with a range of 0.208 to 0.271 years and 0.245 years with a range of 0.189 to 0.290 years). An average was thus taken of the variances for each case study, and the variance of the mean was obtained from the following formula:

$$\mathrm{Sd}((X+Y)/2) = 1/2\mathrm{sqrt}(\mathrm{Var}(X) + \mathrm{Var}(Y))$$

resulting in a mean of 0.243 years ± 33%.

The mortality rate for this case study is taken from other Alaskan red king crab case studies. Kimker (1990) estimated a mortality of 3.9 crabs· trap^{-1}year^{-1} in traps with 30 twine thread, while Stevens *et al.* (2000) estimated 0.03 crabs per tanner crab trap. This results in an average mortality rate of 1.97 crabs per trap ± 98%.

The distribution of ghost fishing mortality as a percentage of the reported landed catch is shown in Figure 3.2.6.

Case studies with 3 missing parameters:

Alaska red king crab fishery 1969-1970

Parameter list

	Parameter i:	354 fishers
×	Parameter ii:	70 traps per
=	Parameter 1:	*24,780 traps*

×	Parameter 2:	10%
=	Parameter 3:	*2,478 traps*
×	Parameter 4:	96.9% + 3.1%/- 51.3%
=	Parameter 5:	*2,400 traps*
×	Parameter 6:	0.418 years
=	Parameter 7:	*1,004 traps*
×	Parameter 8:	1.97 ± 98% crabs· $trap^{-1}year^{-1}$
=	Parameter 9:	*1,973 crabs*
×	Parameter 10:	2.95 kg
=	Parameter 11:	*5,817 kg*
÷	Parameter 12:	26,186,237 kg
=	Result:	*0.02%*

Narrative

In the 1969-1970 season in the Alaska red king crab (*Paralithodes camtschatica*) fishery, an estimated 354 fishers fished 70 traps each (R. Kaiser pers. comm. to High and Worlund 1979), resulting in calculated total of 24,780 traps. As no estimate for trap loss rate is available for Alaska in general, a loss rate of "about" 10% is applied from a case study in the western Gulf of Alaska (High 1985). The case study only indicated that traps were lost "as a result of various mishaps" and not whether they were capable of ghost fishing or were simply destroyed or stolen. Therefore, of the 2,478 traps calculated to be lost, 96.9% of those were assumed to be capable of ghost fishing. This modifer was the mean calculated from other case studies where this parameter was specified: 46.5% in the 1987 BC Dungeness crab fishery (Breen 1987); 100% in the 1990 Chiniak Bay red king crab fishery (assumed from R. Meyer, pers comm to Smolowitz 1978a); 100% in the 1976 Atlantic offshore lobster fishery (assumed from Smolowitz 1978b); 100% in the 1969-1989 Gulf of St. Lawrence snow crab fishery (assumed from Vienneau and Moriyasu 1994); 100% in the 1987 Gulf of St. Lawrence snow crab fishery (Mallet *et al.* 1998); 100% in the 1987 New Brunswick snow crab fishery (Mallet *et al.* 1998); 100% in the Louisiana blue crab fishery c. 1993 (Guillory 1999); 100% in the 1988 Louisiana blue crab fishery (Guillory 1999); 100% in the 1993 Louisiana blue crab fishery (Guillory 1999); and 100% in the 1974 Newfoundland snow crab fishery (Miller 1977). When that is applied, the number of traps lost to ghost fishing is calculated to be 2,400.

An experiment on the durability of crab traps using various biodegradable twine sizes in Prince William Sound was done between October 1989 and March 1990. From 1978 to the early 1990s, Alaska had a 120 thread regulation (Kimker 1990). Since the largest thread size used in the experiment was 96, those results (153 days, or 0.418 years, to degradation) are used for the calculation of active ghost fishing period of lost traps in this case study. This is an underestimate of the time necessary for the traps to be rendered inoperable, as 14 of the 15 traps using 96 size twine remained intact after the study was completed. Furthermore, the 120 thread regulation did not come into effect until almost a decade after this case study.

The number of traps ghost fishing is thus calculated to be 1,004, assuming the system is at equilibrium and that the numbers have remained constant since then. There is no estimate of mortality per trap in Alaska's king crab fishery in general, so the average of mortalities from regional case studies in Alaska is used instead. 3.9 crabs· $trap^{-1}year^{-1}$ was from estimated Kimker (1990) and 0.03 crabs· $trap^{-1}year^{-1}$ was estimated from Stevens *et al.* (2000) for a mean of 1.97 crabs· $trap^{-1}year^{-1}$. The number of crabs killed by ghost traps is thus 2,869. A generic estimate of the average weight of red king crabs is 6.5 lbs, or 2.95 kg (Kruse and Kimker 1993); the weight of king crab mortality from ghost traps is therefore estimated to be 8,459 kg, which is 0.032% of the 26,186,237 kg landed in Alaska in 1969 (National Marine Fisheries Service 2004).

Monte Carlo simulation

The percentage of traps lost to ghost fishing is the grand mean calculated from case studies where the parameters were given, which results in 96.9% + 3.1%/- 51.3% of lost traps (96.9% ± 51.3%, with the upper limit truncated at 100%).

The mortality rate for this case study is taken from other Alaskan red king crab case studies. Kimker (1990) estimated a mortality of 3.9 crabs· $trap^{-1}year^{-1}$ in traps with 30 twine thread, while Stevens *et al.* (2000) estimated 0.03 crabs per tanner crab trap. This results in an average mortality rate of 1.97 crabs per trap ± 98%.

The distribution of ghost fishing mortality as a percentage of the reported landed catch is shown in Figure 3.2.7.

Monte Carlo figures

Distributions of Monte Carlo simulations; x-axis denotes ghost fishing as a percentage of reported landings (%) and y-axis denotes frequency. Unless noted otherwise, scale of the x-axis begins at 0. The verticle line represents the result obtained from the calculation of midrange values.

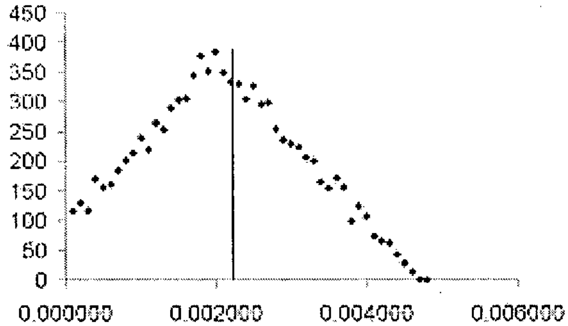

Figure 3.2.1 – Chiniak Bay red king crab fishery c. 1990s

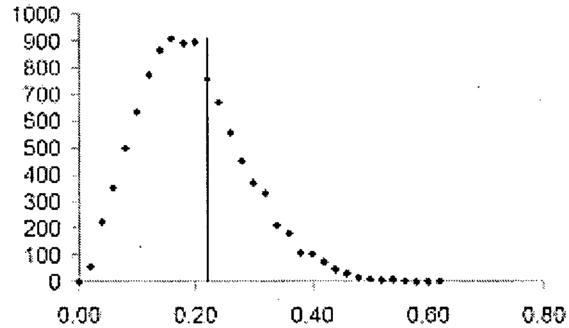

Figure 3.2.2 – Bristol Bay red king crab fishery c. 1993

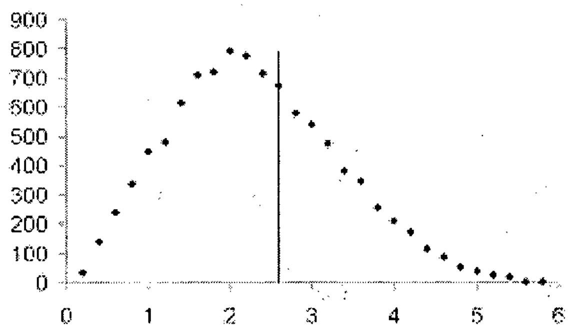

Figure 3.2.3 – Bristol Bay red king crab fishery c. 1994

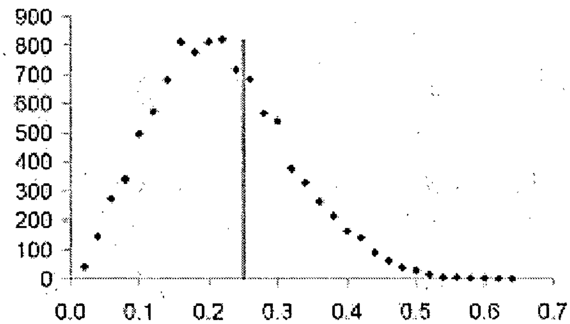

Figure 3.2.4 – Bristol Bay red king crab fishery 1996

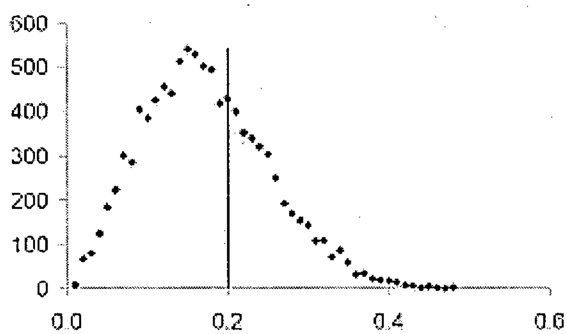

Figure 3.2.5 – Bristol Bay red king crab fishery 1990

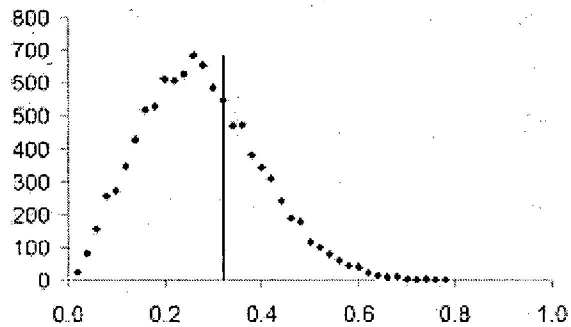

Figure 3.2.6 – Bristol Bay red king crab fishery 1991

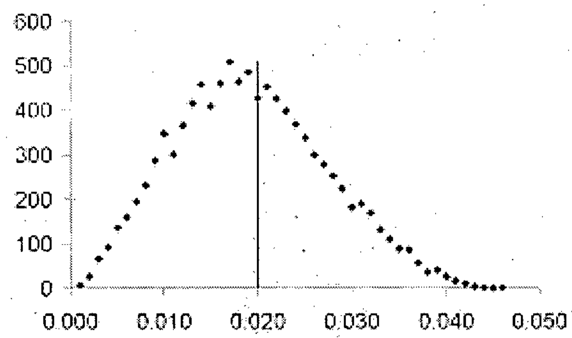

Figure 3.2.7 – Alaska red king crab fishery 1969-1970

3.3 Lobsters

Case studies with 2 missing parameters:

Atlantic offshore lobster fishery 1976

Parameter list

	Parameter i:	Not provided
	Parameter ii:	Not provided
	Parameter 1:	72,000 traps
×	Parameter 2:	25% ± 20%
=	Parameter 3:	*18,000 traps*
×	Parameter 4:	100%
=	Parameter 5:	*18,000 traps*
×	Parameter 6:	0.417 + 141%/-100% years
=	Parameter 7:	*7,510 traps*
×	Parameter 8:	14.7 ± 32% lobsters· trap^{-1}year^{-1}
=	Parameter 9:	*110,534 lobsters*
×	Parameter 10:	0.585 kg
=	Parameter 11:	*64,678 kg*
÷	Parameter 12:	1,899,000 kg
=	Result:	*3.4%*

Narrative

In the Atlantic offshore lobster (*Homarus americanus*) fishery, an estimated 72,000 traps were used in 1976 (NMFS unpublished data cited in Smolowitz 1978b), with a trap loss rate of 20-30%. If the median, 25%, were used to calculate the number of traps lost, the result would be 18,000. Smolowitz (1978b) suggests that all these traps were capable of ghost fishing when lost, since they were lost in offshore grounds.

There was no indication of how long the lost traps would remain functional *in situ*, so an average length of time, 0.417 years, was taken from all case studies in which ghost fishing period was specified. The values from those case studies were: 2.2 years in the 1984 BC Dungeness crab fishery (Breen 1987); 0.418 years in the 1969-70 Alaska red king crab fishery (Kimker 1990); 0.375 years ± 11% in the 1986 California Dungeness crab fishery (Kennedy 1986); 0.245 +44%/-19% years in the 1992 Cook Inlet red king crab fishery (Kimker 1990); and 0.243 ± 33% years. The last value is a composite in itself, obtained from 0.241 +20.8%/-27.1% years (Kimker 1990) and 0.245 +44%/-19% years (Kimker 1990), and used in 9 case studies: 1993 Bering Sea crab fishery; 1993 Bering Sea red king crab fishery; 1990 Bristol Bay red king crab fishery; 1991 Bristol Bay red king crab fishery; 1994 Bristol Bay red king crab fishery; 1996 Bristol Bay red king crab fishery; Chiniak Bay red king crab fishery in the 1990s; and 2 1991 eastern Bering Sea snow crab fisheries. Assuming that the rate of entry of lost traps was equal to the rate of degradation, 7,510 traps are estimated to be ghost fishing offshore in the Atlantic annually.

No estimate of annual mortality was given, so an average was taken from other case studies where this parameter was available. Laist (1996) found 24 lobsters in18 pots weighing 156.5 lbs in total. If each pot averaged 8.7 lbs, then it would contain 6.93 lobsters. Smolowitz (1978a) estimated 0.44 lobsters· $trap^{-1}year^{-1}$, Prudden (1962) estimated 48 lobsters· $trap^{-1}year^{-1}$, and R. Dow (1961 cited in in Sheldon and Dow 1975) estimated 3.5 lobsters· $trap^{-1}year^{-1}$. The mean is therefore 14.7 lobsters·$trap^{-1}year^{-1}$ and the total mortality from ghost fishing is 110,534 lobsters per year. To express the number of lobsters caught in the lost traps as a percentage of the reported landings, the average weight for American lobster (1.29 lbs, or 0.585 kg) was obtained (Mercer 2002); the weight of lobster mortality from ghost traps was therefore estimated to be 64,678 kg, or 3.4% of the reported landings for the Atlantic states (1,899,000 kg; Smolowitz 1978b).

Monte Carlo simulation

Smolowitz (1978b) estimated the gear loss for this fishery to be between 20% and 30%, which equates to a midpoint of 25% ± 20%.

The values for the lifespan of ghost fishing traps in this case study was an average of thirteen other case studies, some of which had asymmetrical variances. In the cases where variances were asymmetrical, the average of the variances in each case study was taken and used towards the following formula:

Sd((X+Y)/13) = (sqrt(Var(X) + Var(Y)))/13

resulting in a mean of 0.417 + 141%/-100% years (0.417 ± 141%, with the lower limit truncated at 0).

Mortality rate was obtained from averaging those of other lobster case studies. Laist (1996) estimated a mortality of 6.93 lobsters· $trap^{-1}year^{-1}$ (from 24 lobsters in 18 pots weighing 156.5 lbs in total; each pot averaged 8.7 lbs). Smolowitz (1978a) estimated 0.44, Prudden (1962) estimated 48, and Dow (in Sheldon and Dow 1975) estimated 3.5. The mean mortality is therefore 14.7 ± 32% lobsters· $trap^{-1}year^{-1}$.

The distribution of ghost fishing mortality as a percentage of the reported landed catch is shown in Figure 3.3.1.

Atlantic seacoast inshore lobster fishery 1973

Parameter list

	Parameter i:	Not provided
	Parameter ii:	Not provided
	Parameter 1:	2,100,000 traps
×	Parameter 2:	33%
=	Parameter 3:	*693,000 traps*
×	Parameter 4:	100%
=	Parameter 5:	*693,000 traps*
×	Parameter 6:	0.417 + 141%/-100% years
=	Parameter 7:	*289,150 traps*
×	Parameter 8:	14.7 ± 32% lobsters·$trap^{-1}year^{-1}$
=	Parameter 9:	*4,255,571 lobsters*
×	Parameter 10:	0.585 kg
=	Parameter 11:	*2,490,122 kg*
÷	Parameter 12:	11,615,400 kg
=	Result:	*21.4%*

Narrative

In 1973, at least 2,100,000 lobster (*Homarus americanus*) traps were used inshore on the Atlantic seacoast (Smolowitz 1978b). Prudden (1962) estimated the annual trap loss rate in the fishery to be 33%, so a total of 693,000 traps would have been lost that year. Since this estimate of trap loss referred to those lost in storms, it is assumed that all traps remained in the water and were capable of ghost fishing.

Because there was no estimation of how long the traps would remain capable of ghost fishing, an average (0.417 years) was taken of the values from other case studies where such a number was given. The values from those case studies were: 2.2 years in the 1984 BC Dungeness crab fishery (Breen 1987); 0.418 years in the 1969-70 Alaska red king crab fishery (Kimker 1990); 0.375 years ± 11% in the 1986 California Dungeness crab fishery (Kennedy 1986); 0.245 +44%/-19% years in the 1992 Cook Inlet red king crab fishery (Kimker 1990); and 0.243 ± 33% years. The last value is a composite in itself, obtained from 0.241 +20.8%/-27.1% years (Kimker 1990) and 0.245 +44%/-19% years (Kimker 1990), and used in 9 case studies: 1993 Bering Sea crab fishery; 1993 Bering Sea red king crab fishery; 1990 Bristol Bay red king crab fishery; 1991 Bristol Bay red king crab fishery; 1994 Bristol Bay red king crab fishery; 1996 Bristol Bay red king crab fishery; Chiniak Bay red king crab fishery in the 1990s; and 2 1991 eastern Bering Sea snow crab fisheries. Assuming that the rate of entry of lost traps was equal to the rate of degradation, 289,150 traps are estimated to be ghost fishing offshore in the Atlantic inshore annually.

No estimate of annual mortality was given, so an average was taken from other case studies where this parameter was available. Laist (1996) found 24 lobsters in18 pots weighing 156.5 lbs in total. If each pot averaged 8.7 lbs, then it would contain 6.93 lobsters. Smolowitz (1978a) estimated 0.44 lobsters· $trap^{-1}year^{-1}$, Prudden (1962) estimated 48 lobsters· $trap^{-1}year^{-1}$, and R. Dow (1961 cited in in Sheldon and Dow 1975) estimated 3.5 lobsters· $trap^{-1}year^{-1}$. The mean is 14.7 lobsters·$trap^{-1}year^{-1}$ and the total mortality from ghost fishing is therefore 4,255,571 lobsters per year. To express the number of lobsters caught in the lost traps as a percentage of the reported landings, the average weight for American lobster (1.29 lbs, or 0.585 kg) was obtained (Mercer 2002); the weight of lobster mortality from ghost traps was therefore estimated to be 2,490,122 kg, or 21.4% of the reported landings for the Atlantic states (11,615,400 kg; Smolowitz 1978b).

Monte Carlo simulation

The values for the lifespan of ghost fishing traps in this case study was an average of thirteen other case studies, some of which had asymmetrical variances. In the cases where variances were asymmetrical, the average of the variances in each case study was taken and used towards the following formula:

$$Sd((X+Y)/13) = (sqrt(Var(X) + Var(Y)))/13$$

resulting in a mean of 0.417 + 141%/-100% years (0.417 ± 141%, with the lower limit truncated at 0).

Mortality rate was obtained from averaging those of other lobster case studies. Laist (1996) estimated a mortality of 6.93 lobsters· $trap^{-1}year^{-1}$ (from 24 lobsters in 18 pots weighing 156.5 lbs in total; each pot averaged 8.7 lbs). Smolowitz (1978a) estimated 0.44, Prudden (1962) estimated 48, and Dow (in Sheldon and Dow 1975) estimated 3.5. The mean mortality is therefore 14.7 ± 32% lobsters· $trap^{-1}year^{-1}$.

The distribution of ghost fishing mortality as a percentage of the reported landed catch is shown in Figure 3.3.2.

Maine lobster fishery 1960

Parameter list

	Parameter i:	Not provided
	Parameter ii:	Not provided
	Parameter 1:	745,000 traps
×	Parameter 2:	15% ± 50% trap loss rate
=	Parameter 3:	*111,750 traps*
×	Parameter 4:	96.9% + 3.1%/- 51.3%
=	Parameter 5:	*108,233 traps*
×	Parameter 6:	0.417 + 141%/-100% years
=	Parameter 7:	*45,160 traps*
×	Parameter 8:	48 lobsters·$trap^{-1}year^{-1}$
=	Parameter 9:	*2,167,665 lobsters*
×	Parameter 10:	0.585 kg per lobster
=	Parameter 11:	*1,268,396 kg*
÷	Parameter 12:	24,000,000 kg
=	Result:	*5.3%*

Narrative

In 1960, 745,000 traps were in use in the Maine lobster (*Homarus americanus*) fishery (Prudden 1962). No estimate of trap loss rate was available for that particular fishery, so the average of values (15%) from other case studies in Maine was used instead. Those values from the case studies were 7.5% ± 33% (Carr and Harris 1997) and 22.5% ± 11% (Sheldon and Dow 1975). This results in 111,750 traps lost annually.

There is no estimate for the proportion of those traps that are actually ghost fishing, so a modifier of 96.9% was applied. This modifer was the mean calculated from other case studies where this parameter was specified: 46.5% in the 1987 BC Dungeness crab fishery (Breen 1987); 100% in the 1990 Chiniak Bay red king crab fishery (assumed from R. Meyer, pers comm to Smolowitz 1978a); 100% in the 1976 Atlantic offshore lobster fishery (assumed from Smolowitz 1978b); 100% in the 1969-1989 Gulf of St. Lawrence snow crab fishery (assumed from Vienneau and Moriyasu 1994); 100% in the 1987 Gulf of St. Lawrence snow crab fishery (Mallet *et al.* 1998); 100% in the 1987 New Brunswick snow crab fishery (Mallet *et al.* 1998); 100% in the Louisiana blue crab fishery c. 1993 (Guillory 1999); 100% in the 1988 Louisiana blue crab fishery (Guillory 1999); 100% in the 1993 Louisiana blue crab fishery (Guillory 1999); and 100% in the 1974 Newfoundland snow crab fishery (Miller 1977). The number of traps lost to ghost fishing, then, is 108,233.

In the absence of an estimate for the functional life of the ghost traps, an average of ghost fishing period (0.417 years) was taken from all other case studies that had a value for this parameter was used. The values from those case studies were: 2.2 years in the 1984 BC Dungeness crab fishery (Breen 1987); 0.418 years in the 1969-70 Alaska red king crab fishery (Kimker 1990); 0.375 years ± 11% in the 1986 California Dungeness crab fishery (Kennedy 1986); 0.245 +44%/-19% years in the 1992 Cook Inlet red king crab fishery (Kimker 1990); and 0.243 ± 33% years. The last value is a composite in itself, obtained from 0.241 +20.8%/-27.1% years (Kimker 1990) and 0.245 +44%/-19% years (Kimker 1990), and used in 9 case studies: 1993 Bering Sea crab fishery; 1993 Bering Sea red king crab fishery; 1990 Bristol Bay red king crab fishery; 1991 Bristol Bay red king crab fishery; 1994 Bristol Bay red king crab fishery; 1996 Bristol Bay red king crab fishery; Chiniak Bay red king crab fishery in the 1990s; and 2 1991 eastern Bering Sea snow crab fisheries. Assuming that the rate of entry of lost traps was equal to the rate of degradation, 45,160 traps are estimated to be ghost fishing in the area annually.

The annual mortality per trap is 48 lobsters (Prudden 1962). The annual ghost fishing mortality is therefore 2,167,665 individuals per year. To express the number of lobsters caught in the lost traps as a percentage of the reported landings, the average weight for American lobster (1.29 lbs, or 0.585 kg) was obtained (Mercer 2002); the weight of lobster mortality from ghost traps was therefore estimated to be 1,268,396 kg, or 5.3% of the estimated 24,000,000 kg landed annually in the Atlantic states in the 1960s (Prudden 1962).

Monte Carlo simulation

Gear loss for this case study is an average (15% ± 50%) from other Maine lobster fisheries: 7.5% ± 33% (Carr and Harris 1997) and 22.5% ± 11% (Sheldon and Dow 1975). Since those case studies have their own uncertainties, the following formula was used to obtain the variance of the mean:

Sd((X+Y)/2) = 1/2sqrt(Var(X) + Var(Y)).

The percentage of traps lost to ghost fishing is the grand mean calculated from case studies where the parameters were given, which results in 96.9% + 3.1%/- 51.3% of lost traps (96.9% ± 51.3%, with the upper limit truncated at 100%).

The values for the lifespan of ghost fishing traps in this case study was an average of thirteen other case studies, some of which had asymmetrical variances. In the cases where variances were asymmetrical, the average of the variances in each case study was taken and used towards the following formula:

Sd((X+Y)/13) = (sqrt(Var(X) + Var(Y)))/13

resulting in a mean of 0.417 + 141%/-100% years (0.417 ± 141%, with the lower limit truncated at 0).

The distribution of ghost fishing mortality as a percentage of the reported landed catch is shown in Figure 3.3.3.

New England lobster fishery 1987

Parameter list

	Parameter i:	Not provided
	Parameter ii:	Not provided
	Parameter 1:	1,870,000 traps
×	Parameter 2:	7.5% ± 33%
=	Parameter 3:	*140,250 traps*
×	Parameter 4:	96.9% + 3.1%/- 51.3%
=	Parameter 5:	*135,836 traps*
×	Parameter 6:	0.417 + 141%/-100% years
=	Parameter 7:	*56,677 traps*
×	Parameter 8:	6.93 lobsters·trap^{-1}year^{-1}
=	Parameter 9:	*392,960 lobsters*
×	Parameter 10:	0.585 kg
=	Parameter 11:	*229,938 kg*
÷	Parameter 12:	18,999,188
=	Result:	*1.2%*

Narrative

In 1987, an estimated 1,870,000 lobster (*Homarus americanus*) traps were used in New England, 5%-10% of which were lost (Krouse 1989 cited in Breen 1990). If the midrange were used to calculate the number of traps lost, The result was140,250 traps. However, it is unclear what proportion of those traps are capable of ghost fishing as opposed to being stolen or destroyed; therefore, a modifier of 96.9% was applied. This modifer was the mean calculated from other case studies where this parameter was specified: 46.5% in the 1987 BC Dungeness crab fishery (Breen 1987); 100% in the 1990 Chiniak Bay red king crab fishery (assumed from R. Meyer, pers comm to Smolowitz 1978a); 100% in the 1976 Atlantic offshore lobster fishery (assumed from Smolowitz 1978b); 100% in the 1969-1989 Gulf of St. Lawrence snow crab fishery (assumed from Vienneau and Moriyasu 1994); 100% in the 1987 Gulf of St. Lawrence snow crab fishery (Mallet *et al.* 1998); 100% in the 1987 New Brunswick snow crab fishery (Mallet *et al.* 1998); 100% in the Louisiana blue crab fishery c. 1993 (Guillory 1999); 100% in the 1988 Louisiana blue crab fishery (Guillory 1999); 100% in the 1993 Louisiana blue crab fishery (Guillory 1999); and 100% in the 1974 Newfoundland snow crab fishery (Miller 1977). The number of traps lost to ghost fishing, then, is 135,836.

In the absence of an estimate for the functional life of the ghost traps, an average of ghost fishing period (0.417 years) was taken from all other case studies that had a value for this parameter was used. The values from those case studies were: 2.2 years in the 1984 BC Dungeness crab fishery (Breen 1987); 0.418 years in the 1969-70 Alaska red king crab fishery (Kimker 1990); 0.375 years ± 11% in the 1986 California Dungeness crab fishery (Kennedy 1986); 0.245 +44%/-19% years in the 1992 Cook Inlet red king crab fishery (Kimker 1990); and 0.243 ± 33% years. The last value is a composite in itself, obtained from 0.241 +20.8%/-27.1% years (Kimker 1990) and 0.245 +44%/-19% years (Kimker 1990), and used in 9 case studies: 1993 Bering Sea crab fishery; 1993 Bering Sea red king crab fishery; 1990 Bristol Bay red king crab fishery; 1991 Bristol Bay red king crab fishery; 1994 Bristol Bay red king crab fishery; 1996 Bristol Bay red king crab fishery; Chiniak Bay red king crab fishery in the 1990s; and 2 1991 eastern Bering Sea snow crab fisheries. Assuming that the rate of entry of lost traps was equal to the rate of degradation, 56,677 traps are estimated to be ghost fishing in the area annually.

In the New England fishery in 1968, 24 lobsters were found in 18 recovered pots, giving an average catch rate of 1.33 lobsters per trap. The pots had been lost for 10 weeks. Assuming that the catch rate is uniform throughout the year and is the same now as it was then, and being caught results in mortality, the mortality from lost traps is 6.93

individuals per trap per year. The annual mortality from all ghost fishing traps is thus 392,960 individuals. To express the number of lobsters caught in the lost traps as a percentage of the reported landings, the average weight for American lobster (1.29 lbs, or 0.585 kg) was obtained (Mercer 2002); the weight of lobster mortality from ghost traps was therefore estimated to be 229,938 kg, or 1.2% of the estimated 18,999,188 kg landed in the inshore and offshore lobster fisheries of New England in 1987 (National Marine Fisheries Service 2004).

Monte Carlo simulation

The percentage of traps lost to ghost fishing is the grand mean calculated from case studies where the parameters were given, which results in 96.9% + 3.1%/- 51.3% of lost traps (96.9% ± 51.3%, with the upper limit truncated at 100%).

The values for the lifespan of ghost fishing traps in this case study was an average of thirteen other case studies, some of which had asymmetrical variances. In the cases where variances were asymmetrical, the average of the variances in each case study was taken and used towards the following formula:

$$Sd((X+Y)/13) = (sqrt(Var(X) + Var(Y)))/13$$

resulting in a mean of 0.417 + 141%/-100% years (0.417 ± 141%, with the lower limit truncated at 0).

The distribution of ghost fishing mortality as a percentage of the reported landed catch is shown in Figure 3.3.4.

Case studies with 3 missing parameters:

Maine lobster fishery 1975

Parameter list

	Parameter i:	Not provided
	Parameter ii:	Not provided
	Parameter 1:	1,250,000 traps
×	Parameter 2:	22.5% ± 11%
=	Parameter 3:	*281,250 traps*
×	Parameter 4:	96.9% + 3.1%/- 51.3%
=	Parameter 5:	*272,399 traps*
×	Parameter 6:	0.417 + 141%/-100% years

=	Parameter 7:	*113,657 traps*
×	Parameter 8:	3.5 lobsters·trap^{-1}year^{-1}
=	Parameter 9:	*397,799 lobsters*
×	Parameter 10:	0.585 kg
=	Parameter 11:	*232,770 kg*
÷	Parameter 12:	7,670,000 kg
=	Result:	*3.0%*

Narrative

In the early 1970s, approximately 1.25 million lobster (*Homarus americanus*) traps were used in Maine, with an average annual loss rate of 20 to 25% (Sheldon and Dow 1975). If the midrange of the loss rate were to be used, 281,250 traps would be lost annually. However, the causes of loss include storms, accidents or vandalism; an estimate of the proportion of lost traps that are capable of ghost fishing is not given. Therefore, a modifier of 96.9% was applied. This modifer was the mean calculated from other case studies where this parameter was specified: 46.5% in the 1987 BC Dungeness crab fishery (Breen 1987); 100% in the 1990 Chiniak Bay red king crab fishery (assumed from R. Meyer, pers comm to Smolowitz 1978a); 100% in the 1976 Atlantic offshore lobster fishery (assumed from Smolowitz 1978b); 100% in the 1969-1989 Gulf of St. Lawrence snow crab fishery (assumed from Vienneau and Moriyasu 1994); 100% in the 1987 Gulf of St. Lawrence snow crab fishery (Mallet *et al.* 1998); 100% in the 1987 New Brunswick snow crab fishery (Mallet *et al.* 1998); 100% in the Louisiana blue crab fishery c. 1993 (Guillory 1999); 100% in the 1988 Louisiana blue crab fishery (Guillory 1999); 100% in the 1993 Louisiana blue crab fishery (Guillory 1999); and 100% in the 1974 Newfoundland snow crab fishery (Miller 1977). The number of traps lost to ghost fishing, then, is 272,399.

In the absence of an estimate for the functional life of the ghost traps, an average of ghost fishing period (0.417 years) was taken from all other case studies that had a value for this parameter was used. The values from those case studies were: 2.2 years in the 1984 BC Dungeness crab fishery (Breen 1987); 0.418 years in the 1969-70 Alaska red king crab fishery (Kimker 1990); 0.375 years ± 11% in the 1986 California Dungeness crab fishery (Kennedy 1986); 0.245 +44%/-19% years in the 1992 Cook Inlet red king crab fishery (Kimker 1990); and 0.243 ± 33% years. The last value is a composite in itself, obtained from 0.241 +20.8%/-27.1% years (Kimker 1990) and 0.245 +44%/-19% years (Kimker 1990), and used in 9 case studies: 1993 Bering Sea crab fishery; 1993 Bering Sea red king crab fishery; 1990 Bristol Bay red king crab fishery; 1991 Bristol Bay red king crab fishery; 1994 Bristol Bay red king crab fishery; 1996 Bristol Bay red king crab fishery; Chiniak Bay red king crab fishery in the 1990s; and 2

1991 eastern Bering Sea snow crab fisheries. Assuming that the rate of entry of lost traps was equal to the rate of degradation, 113,657 traps are estimated to be ghost fishing in the area annually.

R. Dow (1961 cited in Sheldon and Dow 1975) states that lost traps catch an average of 3.1 lobsters each; assuming that this is an annual mortality, the annual mortality from all ghost fishing traps is 397,799 individuals. To express the number of lobsters caught in the lost traps as a percentage of the reported landings, the average weight for American lobster (1.29 lbs, or 0.585 kg) was obtained (Mercer 2002); the weight of lobster mortality from ghost traps was therefore estimated to be 232,770 kg, or 3.0% of the estimated 7,670,000 kg landed in Maine at the time of Sheldon and Dow's (1975) publication.

Monte Carlo simulation

Sheldon and Dow (1975) estimate the gear loss in this fishery to be 20-25%, which is 22.5% ± 11%.

The percentage of traps lost to ghost fishing is the grand mean calculated from case studies where the parameters were given, which results in 96.9% + 3.1%/- 51.3% of lost traps (96.9% ± 51.3%, with the upper limit truncated at 100%).

The values for the lifespan of ghost fishing traps in this case study was an average of thirteen other case studies, some of which had asymmetrical variances. In the cases where variances were asymmetrical, the average of the variances in each case study was taken and used towards the following formula:

Sd((X+Y)/13) = (sqrt(Var(X) + Var(Y)))/13

resulting in a mean of 0.417 + 141%/-100% years (0.417 ± 141%, with the lower limit truncated at 0).

The distribution of ghost fishing mortality as a percentage of the reported landed catch is shown in Figure 3.3.5.

Maine lobster fishery 1992

Parameter list

Parameter i: Not provided
Parameter ii: Not provided

	Parameter 1:	2,000,000 traps
×	Parameter 2:	7.5% ± 33%
=	Parameter 3:	*150,000 traps*
×	Parameter 4:	96.9% + 3.1%/- 51.3%
=	Parameter 5:	*145,279 traps*
×	Parameter 6:	0.417 + 141%/-100% years
=	Parameter 7:	*60,617 traps*
×	Parameter 8:	14.7 ± 32% lobsters·trap^{-1}year^{-1}
=	Parameter 9:	*892,131 lobsters*
×	Parameter 10:	0.585 kg
=	Parameter 11:	*522,025 kg*
÷	Parameter 12:	12,170,291
=	Result:	*4.3%*

Narrative

In 1992, an estimated 2,000,000 traps were in use in the Maine lobster (*Homarus americanus*) fishery, 5%-10% of which were lost (Krouse 1994 cited in Carr and Harris 1997). If the midrange of the loss rate were to be used, 150,000 traps would be lost annually. However, the causes of loss include storms, accidents or vandalism; an estimate of the proportion of lost traps that are capable of ghost fishing is not given. Therefore, a modifier of 96.9% was applied. This modifer was the mean calculated from other case studies where this parameter was specified: 46.5% in the 1987 BC Dungeness crab fishery (Breen 1987); 100% in the 1990 Chiniak Bay red king crab fishery (assumed from R. Meyer, pers comm to Smolowitz 1978a); 100% in the 1976 Atlantic offshore lobster fishery (assumed from Smolowitz 1978b); 100% in the 1969-1989 Gulf of St. Lawrence snow crab fishery (assumed from Vienneau and Moriyasu 1994); 100% in the 1987 Gulf of St. Lawrence snow crab fishery (Mallet *et al.* 1998); 100% in the 1987 New Brunswick snow crab fishery (Mallet *et al.* 1998); 100% in the Louisiana blue crab fishery c. 1993 (Guillory 1999); 100% in the 1988 Louisiana blue crab fishery (Guillory 1999); 100% in the 1993 Louisiana blue crab fishery (Guillory 1999); and 100% in the 1974 Newfoundland snow crab fishery (Miller 1977). The number of traps lost to ghost fishing, then, is 145,279.

In the absence of an estimate for the functional life of the ghost traps, an average of ghost fishing period (0.417 years) was taken from all other case studies that had a value for this parameter was used. The values from those case studies were: 2.2 years in the 1984 BC Dungeness crab fishery (Breen 1987); 0.418 years in the 1969-70 Alaska red king crab fishery (Kimker 1990); 0.375 years ± 11% in the 1986 California Dungeness crab fishery (Kennedy 1986); 0.245 +44%/-19% years in the 1992 Cook Inlet red king crab fishery (Kimker 1990); and 0.243 ± 33% years. The last value is a composite in itself, obtained from 0.241 +20.8%/-27.1% years (Kimker 1990) and 0.245 +44%/-19% years (Kimker 1990), and used in 9 case studies: 1993 Bering Sea crab fishery; 1993 Bering Sea red king crab fishery; 1990 Bristol Bay red king crab fishery; 1991 Bristol Bay red king crab fishery; 1994 Bristol Bay red king crab fishery; 1996 Bristol Bay red king crab fishery; Chiniak Bay red king crab fishery in the 1990s; and 2 1991 eastern Bering Sea snow crab fisheries. Assuming that the rate of entry of lost traps was equal to the rate of degradation, 60,617 traps are estimated to be ghost fishing in the area annually.

No estimate of annual mortality was given, so an average was taken from other case studies where this parameter was available. Laist (1996) found 24 lobsters in18 pots weighing 156.5 lbs in total. If each pot averaged 8.7 lbs, then it would contain 6.93 lobsters. Smolowitz (1978a) estimated 0.44 lobsters· $trap^{-1}year^{-1}$, Prudden (1962) estimated 48 lobsters· $trap^{-1}year^{-1}$, and R. Dow (1961 cited in in Sheldon and Dow 1975) estimated 3.5 lobsters· $trap^{-1}year^{-1}$. The mean is thus 14.7 lobsters·$trap^{-1}year^{-1}$ and the total annual mortality from all ghost fishing traps is 892,131 individuals. To express the number of lobsters caught in the lost traps as a percentage of the reported landings, the average weight for American lobster (1.29 lbs, or 0.585 kg) was obtained (Mercer 2002); the weight of lobster mortality from ghost traps was therefore estimated to be 522,025 kg, or 4.3% of the 12,170,291 kg landed in 1992 in the inshore and offshore fisheries of Maine (National Marine Fisheries Service 2004).

Monte Carlo simulation

Carr and Harris (1997) estimate the gear loss in this fishery at 5%-10%, which is 7.5% ± 33%.

The percentage of traps lost to ghost fishing is the grand mean calculated from case studies where the parameters were given, which results in 96.9% + 3.1%/- 51.3% of lost traps (96.9% ± 51.3%, with the upper limit truncated at 100%).

The values for the lifespan of ghost fishing traps in this case study was an average of thirteen other case studies, some of which had asymmetrical variances. In the cases where variances were asymmetrical, the average of the variances in each case study was taken and used towards the following formula:

$$Sd((X+Y)/13) = (sqrt(Var(X) + Var(Y)))/13$$

resulting in a mean of 0.417 + 141%/-100% years (0.417 ± 141%, with the lower limit truncated at 0).

Mortality rate was obtained from averaging those of other lobster case studies. Laist (1996) estimated a mortality of 6.93 lobsters· $trap^{-1}year^{-1}$ (from 24 lobsters in 18 pots weighing 156.5 lbs in total; each pot averaged 8.7 lbs). Smolowitz (1978a) estimated 0.44, Prudden (1962) estimated 48, and Dow (in Sheldon and Dow 1975) estimated 3.5. The mean mortality is therefore 14.7 ± 32% lobsters· $trap^{-1}year^{-1}$.

The distribution of ghost fishing mortality as a percentage of the reported landed catch is shown in Figure 3.3.6.

Case studies with 4 missing parameters:

Maine and Massachusetts lobster fishery 1991

Parameter list

	Parameter i:	Not provided
	Parameter ii:	Not provided
	Parameter 1:	2,500,924 traps
×	Parameter 2:	15% ± 50%
=	Parameter 3:	*375,139 traps*
×	Parameter 4:	96.9% + 3.1%/- 51.3%
=	Parameter 5:	*363,333 traps*
×	Parameter 6:	0.417 + 141%/-100% years
=	Parameter 7:	*151,599 traps*
×	Parameter 8:	14.7 ± 32% lobsters·$trap^{-1}year^{-1}$
=	Parameter 9:	*2,231,152 lobsters*
×	Parameter 10:	0.585 kg
=	Parameter 11:	*1,305,545 kg*
÷	Parameter 12:	20,920,780 kg
=	Result:	*6.2%*

Narrative

In 1991, 2,500,924 lobster (*Homarus americanus*) traps were used in Massachusetts and Maine (Carr and Harris 1997). No estimate of trap loss rate was available for that particular fishery, so the average of values (15%) from other case studies in Maine was used instead. Those values from the case studies were 7.5% ± 33% (Carr and Harris 1997) and 22.5% ± 11% (Sheldon and Dow 1975). Therefore, 375,139 traps would be lost annually.

However, the causes of loss include storms, accidents or vandalism; an estimate of the proportion of lost traps that are capable of ghost fishing is not given. Therefore, a modifier of 96.9% was applied. This modifer was the mean calculated from other case studies where this parameter was specified: 46.5% in the 1987 BC Dungeness crab fishery (Breen 1987); 100% in the 1990 Chiniak Bay red king crab fishery (assumed from R. Meyer, pers comm to Smolowitz 1978a); 100% in the 1976 Atlantic offshore lobster fishery (assumed from Smolowitz 1978b); 100% in the 1969-1989 Gulf of St. Lawrence snow crab fishery (assumed from Vienneau and Moriyasu 1994); 100% in the 1987 Gulf of St. Lawrence snow crab fishery (Mallet *et al.* 1998); 100% in the 1987 New Brunswick snow crab fishery (Mallet *et al.* 1998); 100% in the Louisiana blue crab fishery c. 1993 (Guillory 1999); 100% in the 1988 Louisiana blue crab fishery (Guillory 1999); 100% in the 1993 Louisiana blue crab fishery (Guillory 1999); and 100% in the 1974 Newfoundland snow crab fishery (Miller 1977). The number of traps lost to ghost fishing, then, is 363,333.

In the absence of an estimate for the functional life of the ghost traps, an average of ghost fishing period (0.417 years) was taken from all other case studies that had a value for this parameter was used. The values from those case studies were: 2.2 years in the 1984 BC Dungeness crab fishery (Breen 1987); 0.418 years in the 1969-70 Alaska red king crab fishery (Kimker 1990); 0.375 years ± 11% in the 1986 California Dungeness crab fishery (Kennedy 1986); 0.245 +44%/-19% years in the 1992 Cook Inlet red king crab fishery (Kimker 1990); and 0.243 ± 33% years. The last value is a composite in itself, obtained from 0.241 +20.8%/-27.1% years (Kimker 1990) and 0.245 +44%/-19% years (Kimker 1990), and used in 9 case studies: 1993 Bering Sea crab fishery; 1993 Bering Sea red king crab fishery; 1990 Bristol Bay red king crab fishery; 1991 Bristol Bay red king crab fishery; 1994 Bristol Bay red king crab fishery; 1996 Bristol Bay red king crab fishery; Chiniak Bay red king crab fishery in the 1990s; and 2 1991 eastern Bering Sea snow crab fisheries. Assuming that the rate of entry of lost traps was equal to the rate of degradation, 151,599 traps are estimated to be ghost fishing in the area annually.

No estimate of annual mortality was given, so an average was taken from other case studies where this parameter was available. Laist (1996) found 24 lobsters in18 pots weighing 156.5 lbs in total. If each pot averaged 8.7 lbs, then it would contain 6.93 lobsters. Smolowitz (1978a) estimated 0.44 lobsters· $trap^{-1}year^{-1}$, Prudden (1962) estimated 48 lobsters· $trap^{-1}year^{-1}$, and R. Dow (1961 cited in in Sheldon and Dow 1975) estimated 3.5 lobsters· $trap^{-1}year^{-1}$. The mean is thus 14.7 lobsters·$trap^{-1}year^{-1}$ and the total mortality is 2,231,152 individuals. To express the number of lobsters caught in the lost traps as a percentage of the reported landings, the average weight for American lobster (1.29 lbs, or 0.585 kg) was obtained (Mercer 2002); the weight of lobster mortality from ghost traps was therefore estimated to be 1,305,545 kg, or 6.2% of the estimated 20,920,780 kg landed in the inshore and offshore lobster fisheries of Maine and Massachusetts in 1991.

Monte Carlo simulation

Gear loss for this case study is an average (15% ± 50%) from other Maine lobster fisheries: 7.5% ± 33% (Carr and Harris 1997) and 22.5% ± 11% (Sheldon and Dow 1975). Since those case studies have their own uncertainties, the following formula was used to obtain the variance of the mean:

Sd((X+Y)/2) = 1/2sqrt(Var(X) + Var(Y)).

The percentage of traps lost to ghost fishing is the grand mean calculated from case studies where the parameters were given, which results in 96.9% + 3.1%/- 51.3% of lost traps (96.9% ± 51.3%, with the upper limit truncated at 100%).

The values for the lifespan of ghost fishing traps in this case study was an average of thirteen other case studies, some of which had asymmetrical variances. In the cases where variances were asymmetrical, the average of the variances in each case study was taken and used towards the following formula:

Sd((X+Y)/13) = (sqrt(Var(X) + Var(Y)))/13

resulting in a mean of 0.417 + 141%/-100% years (0.417 ± 141%, with the lower limit truncated at 0).

Mortality rate was obtained from averaging those of other lobster case studies. Laist (1996) estimated a mortality of 6.93 lobsters· $trap^{-1}year^{-1}$ (from 24 lobsters in 18 pots weighing 156.5 lbs in total; each pot averaged 8.7 lbs). Smolowitz (1978a) estimated 0.44, Prudden (1962) estimated 48, and Dow (in Sheldon and Dow 1975) estimated 3.5. The mean mortality is therefore 14.7 ± 32% lobsters· $trap^{-1}year^{-1}$.

The distribution of ghost fishing mortality as a percentage of the reported landed catch is shown in Figure 3.3.7.

Atlantic lobster fishery 1988

Parameter list

Parameter i: Not provided
Parameter ii: Not provided

	Parameter 1:	Not provided
	Parameter 2:	Not provided
	Parameter 3:	500,000 traps
×	Parameter 4:	96.9% + 3.1%/- 51.3%
=	Parameter 5:	*484,265 traps*
×	Parameter 6:	0.417 + 141%/-100% years
=	Parameter 7:	*202,057 traps*
×	Parameter 8:	14.7 ± 32% lobsters·trap^{-1}year^{-1}
=	Parameter 9:	*2,973,771 lobsters*
×	Parameter 10:	0.585 kg
=	Parameter 11:	*1,740,084 kg*
÷	Parameter 12:	24,853,304 kg
=	Result:	*7.0%*

Narrative

An unpublished study by the Center for Environmental Education (1987 cited in Breen 1990) estimated an annual trap loss of 500,000 in the Atlantic lobster (*Homarus americanus*) fishery. It was not specified whether the trap loss rate referred to traps capable of ghost fishing or to traps lost due to various causes, including those that render them incapable of functioning. To achieve a conservative estimate, it was assumed that not all the lost traps would ghost fish. A modifier of 96.9% was applied. This modifer was the mean calculated from other case studies where this parameter was specified: 46.5% in the 1987 BC Dungeness crab fishery (Breen 1987); 100% in the 1990 Chiniak Bay red king crab fishery (assumed from R. Meyer, pers comm to Smolowitz 1978a); 100% in the 1976 Atlantic offshore lobster fishery (assumed from Smolowitz 1978b); 100% in the 1969-1989 Gulf of St. Lawrence snow crab fishery (assumed from Vienneau and Moriyasu 1994); 100% in the 1987 Gulf of St. Lawrence snow crab fishery (Mallet *et al.* 1998); 100% in the 1987 New Brunswick snow crab fishery (Mallet *et al.* 1998); 100% in the Louisiana blue crab fishery c. 1993 (Guillory 1999); 100% in the 1988 Louisiana blue crab fishery (Guillory 1999); 100% in the 1993 Louisiana blue crab fishery (Guillory 1999); and 100% in the 1974 Newfoundland snow crab fishery (Miller 1977). The result was 484,265 ghost fish traps.

There was no indication of how long the lost traps would remain functional *in situ*, so an average length of time, 0.417 years, was taken from all case studies in which ghost fishing period was specified. The values from those case studies were: 2.2 years in the 1984 BC Dungeness crab fishery (Breen 1987); 0.418 years in the 1969-70 Alaska red king crab fishery (Kimker 1990); 0.375 years ± 11% in the 1986 California Dungeness crab fishery (Kennedy 1986); 0.245 +44%/-19% years in the 1992 Cook Inlet red king crab fishery (Kimker 1990); and 0.243 ± 33% years. The last value is a composite in itself, obtained from 0.241 +20.8%/-27.1% years (Kimker 1990) and 0.245 +44%/-19% years (Kimker 1990), and used in 9 case studies: 1993 Bering Sea crab fishery; 1993 Bering Sea red king crab fishery; 1990 Bristol Bay red king crab fishery; 1991 Bristol Bay red king crab fishery; 1994 Bristol Bay red king crab fishery; 1996 Bristol Bay red king crab fishery; Chiniak Bay red king crab fishery in the 1990s; and 2 1991 eastern Bering Sea snow crab fisheries. Assuming that the rate of entry of lost traps was equal to the rate of degradation, 202,057 traps are estimated to be ghost fishing inshore in the Atlantic annually.

No estimate of annual mortality was given, so an average (14.7 lobsters·trap^{-1}year^{-1}) was taken from other case studies where this parameter was available. Laist (1996) found 24 lobsters in18 pots weighing 156.5 lbs in total. If each pot averaged 8.7 lbs, then it would contain 6.93 lobsters. Smolowitz (1978a) estimated 0.44 lobsters· trap^{-1}year^{-1}, Prudden (1962) estimated 48 lobsters· trap^{-1}year^{-1}, and R. Dow (1961 cited in in Sheldon and Dow 1975) estimated 3.5 lobsters· trap^{-1}year^{-1}. The mean is therefore 14.7 lobsters·trap^{-1}year^{-1} and the total mortality from ghost fishing is 2,973,771 lobsters per year. To express the number of lobsters caught in the lost traps as a percentage of the reported landings, the average weight for American lobster (1.29 lbs, or 0.585 kg) was obtained (Mercer 2002); the weight of lobster mortality from ghost traps was therefore estimated to be 1,740,084 kg, or 7.0% of the reported landings for the Atlantic inshore in 2001 (24,853,304 kg; National Marine Fisheries Service 2004).

Monte Carlo simulation

The percentage of traps lost to ghost fishing is the grand mean calculated from case studies where the parameters were given, which results in 96.9% + 3.1%/- 51.3% of lost traps (96.9% ± 51.3%, with the upper limit truncated at 100%).

The values for the lifespan of ghost fishing traps in this case study was an average of thirteen other case studies, some of which had asymmetrical variances. In the cases where variances were asymmetrical, the average of the variances in each case study was taken and used towards the following formula:

$$Sd((X+Y)/13) = (sqrt(Var(X) + Var(Y)))/13$$

resulting in a mean of 0.417 + 141%/-100% years (0.417 ± 141%, with the lower limit truncated at 0).

Mortality rate was obtained from averaging those of other lobster case studies. Laist (1996) estimated a mortality of 6.93 lobsters· trap^{-1}year^{-1} (from 24 lobsters in 18 pots weighing 156.5 lbs in total; each pot averaged 8.7 lbs). Smolowitz (1978a) estimated 0.44, Prudden (1962) estimated 48, and Dow (in Sheldon and Dow 1975) estimated 3.5. The mean mortality is therefore 14.7 ± 32% lobsters· trap^{-1}year^{-1}.

The distribution of ghost fishing mortality as a percentage of the reported landed catch is shown in Figure 3.3.8.

Monte Carlo figures

Distributions of Monte Carlo simulations; x-axis denotes ghost fishing as a percentage of reported landings (%) and y-axis denotes frequency. Unless noted otherwise, scale of the x-axis begins at 0. The verticle line represents the result obtained from the calculation of midrange values.

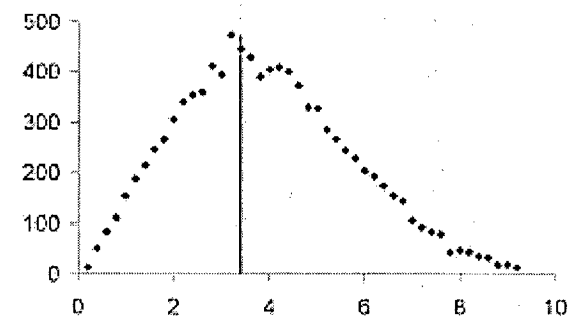

Figure 3.3.1 – Atlantic offshore lobster fishery 1976

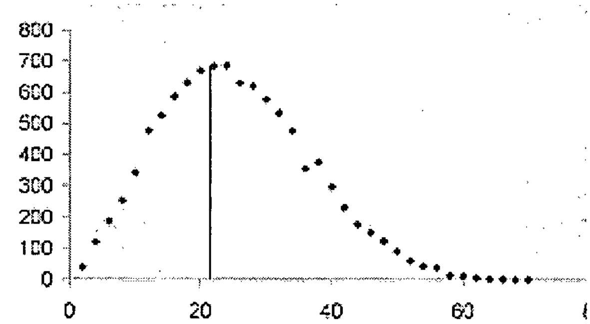

Figure 3.3.2 – Atlantic seacoast inshore lobster fishery 1973

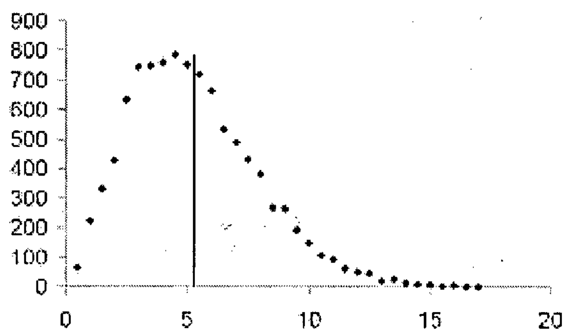

Figure 3.3.3 – Maine lobster fishery 1960

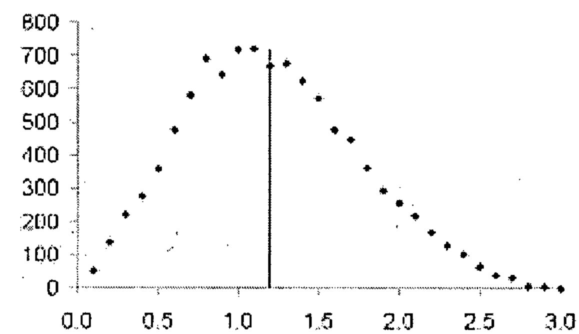

Figure 3.3.4 – New England lobster fishery 1987

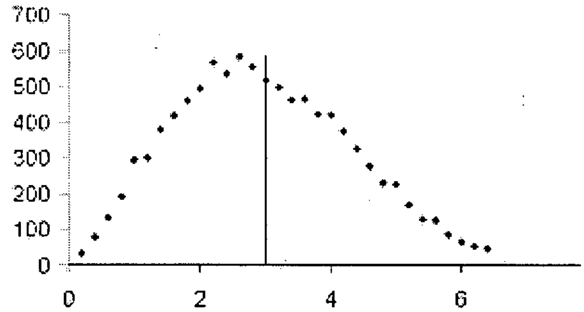

Figure 3.3.5 – Maine lobster fishery 1975

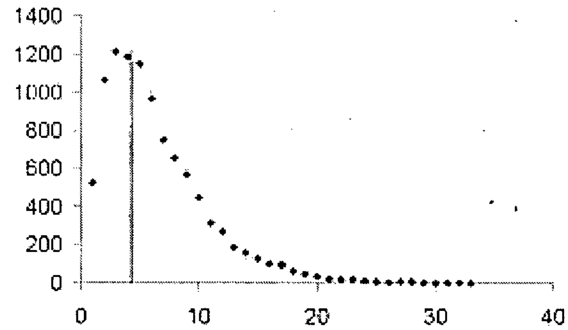

Figure 3.3.6 – Maine lobster fishery 1992

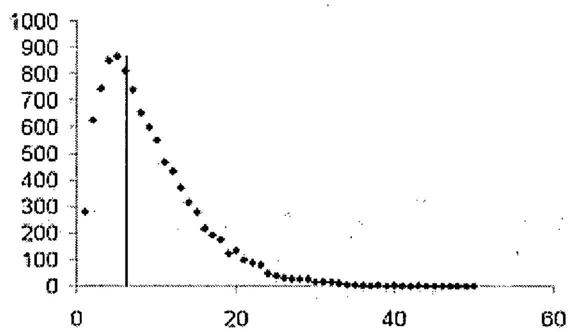

Figure 3.3.7 – Maine and Massachusetts lobster fishery 1991

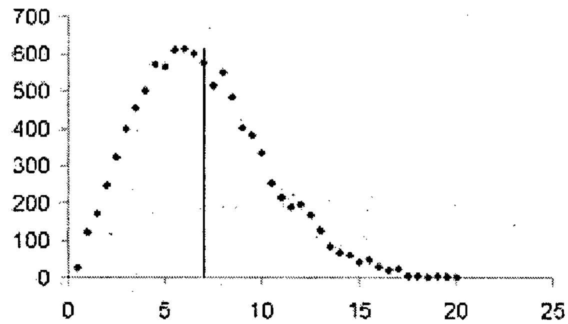

Figure 3.3.8 – Atlantic lobster fishery 1988

3.4 Spiny lobsters

Case studies with 3 missing parameters

Hawaiian spiny lobster fishery 1989

Parameter list

	Parameter i:	Not provided
	Parameter ii:	Not provided
	Parameter 1:	1,000,000 traps
	Parameter 2:	Not provided
	Parameter 3:	1,084 traps lost
×	Parameter 4:	96.9% + 3.1%/- 51.3%
=	Parameter 5:	*1,050 traps*
×	Parameter 6:	0.417 + 141%/-100% years
=	Parameter 7:	*438 traps*
×	Parameter 8:	0.304 lobsters·trap^{-1}year^{-1}

= Parameter 9: *133 lobsters*

× Parameter 10: 0.47 +185%/-74% kg per lobster

= Parameter 11: *62.1 kg*

÷ Parameter 12: 261,274 kg

= Result: *0.024%*

Narrative

In 1989, more than 1,000,000 spiny lobster (*Panulirus marginatus*) traps were set in the Northwestern Hawaiian Islands (Parrish and Kazama 1992), and 1,084 traps were lost (Landgraf *et al.* 1990). This estimate of trap loss may be an underestimate, since it is highly unlikely that the rate of trap loss could be so small compared to the number of traps.

Because there was no indication whether all the lost traps were lost to ghost fishing, a modifier of 96.9% was applied. This modifer was the mean calculated from other case studies where this parameter was specified: 46.5% in the 1987 BC Dungeness crab fishery (Breen 1987); 100% in the 1990 Chiniak Bay red king crab fishery (assumed from R. Meyer, pers comm to Smolowitz 1978a); 100% in the 1976 Atlantic offshore lobster fishery (assumed from Smolowitz 1978b); 100% in the 1969-1989 Gulf of St. Lawrence snow crab fishery (assumed from Vienneau and Moriyasu 1994); 100% in the 1987 Gulf of St. Lawrence snow crab fishery (Mallet *et al.* 1998); 100% in the 1987 New Brunswick snow crab fishery (Mallet *et al.* 1998); 100% in the Louisiana blue crab fishery c. 1993 (Guillory 1999); 100% in the 1988 Louisiana blue crab fishery (Guillory 1999); 100% in the 1993 Louisiana blue crab fishery (Guillory 1999); and 100% in the 1974 Newfoundland snow crab fishery (Miller 1977). This results in 1,050 traps capable of ghost fishing.

No estimate for the functional lifespan of the traps was available, so an average length of time, 0.417 years, was taken from all case studies in which an estimate of ghost fishing period was given, and applied to the ghost fishing traps. The values from those case studies were: 2.2 years in the 1984 BC Dungeness crab fishery (Breen 1987); 0.418 years in the 1969-70 Alaska red king crab fishery (Kimker 1990); 0.375 years ± 11% in the 1986 California Dungeness crab fishery (Kennedy 1986); 0.245 +44%/-19% years in the 1992 Cook Inlet red king crab fishery (Kimker 1990); and 0.243 ± 33% years. The last value is a composite in itself, obtained from 0.241 +20.8%/-27.1% years (Kimker 1990) and 0.245 +44%/-19% years (Kimker 1990), and used in 9 case studies: 1993 Bering Sea crab fishery; 1993 Bering Sea red king crab fishery; 1990 Bristol Bay red king crab fishery; 1991 Bristol Bay red king crab fishery; 1994 Bristol Bay red king crab fishery; 1996 Bristol Bay red king crab fishery; Chiniak Bay red king crab fishery in the 1990s; and 2 1991 eastern Bering Sea snow crab fisheries. Assuming that the rate of entry of lost traps was equal to the rate of degradation, 438 traps are estimated to be ghost fishing in the area annually.

Parrish and Kazama (1992) state that mortality from ghost fishing traps is 0.22 that of fully functioning traps, so obtain an estimate of the mortality per ghost trap, 0.22 of the catch per unit effort in 1989 (1.38; Landgraf *et al.* 1990) was taken and divided by the number of traps set, resulting in a mortality of 0.304 individuals per trap. The number of lobsters lost to ghost fishing is thus 133 per year. The average weight of spiny lobsters is 0.47 kg, taken from a mean carapace length of 80.9 mm (DeMartini *et al.* 2003) and a bodyweight to carapace length model of $BW=0.00090CL^{2.9952}$ (Uchida and Tagami 1984 cited in DeMartini *et al.* 2003). The weight of catches from ghost fishing traps is thus 62.1 kg, or 0.024% of the reported landings for the Northwestern Hawaiian Islands in 1989 (261,274 kg; Landgraf *et al.* 1990).

Monte Carlo simulation

The percentage of traps lost to ghost fishing is the grand mean calculated from case studies where the parameters were given, which results in 96.9% + 3.1%/- 51.3% of lost traps (96.9% ± 51.3%, with the upper limit truncated at 100%).

The values for the lifespan of ghost fishing traps in this case study was an average of thirteen other case studies, some of which had asymmetrical variances. In the cases where variances were asymmetrical, the average of the variances in each case study was taken and used towards the following formula:

Sd((X+Y)/13) = (sqrt(Var(X) + Var(Y)))/13

resulting in a mean of 0.417 + 141%/-100% years (0.417 ± 141%, with the lower limit truncated at 0).

The values for spiny lobster weight were obtained from DeMartini *et al.*'s (2003) study, where the carapace lengths ranged from 51.9 mm to 114.7 mm with a mean of 80.9 mm. Using Uchida and Tagami's (1984) bodyweight to carapace length model, this equates to 0.123 kg and 1.33 kg, or 0.467 +185%/-74% kg per lobster.

The distribution of ghost fishing mortality as a percentage of the reported landed catch is shown in Figure 3.4.1.

Monte Carlo Figures

Distributions of Monte Carlo simulations; x-axis denotes ghost fishing as a percentage of reported landings and y-axis denotes frequency. The verticle line represents the result obtained from the calculation of midrange values.

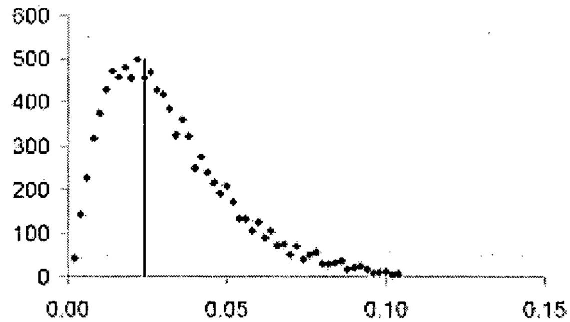

Figure 3.4.1 – Hawaiian spiny lobster fishery

Chapter IV Discussion and Conclusion

When examining the results of this study, several sources of uncertainty must be acknowledged: in the sampling, calculations, and the Monte Carlo analysis.

Sampling Uncertainty

Estimates of fishing effort

Estimates of fishing effort, including number of gear in use and trap loss rate, were mainly obtained from surveys and license registrations. Each method has inherent uncertainties. Low response rates on surveys make it difficult to obtain a clear idea of the situation in the fishery as a whole, and responders may give deliberately misleading answers if they feel that there is a political agenda behind the survey. In case studies where fishing effort is estimated from the number of licensed fishers or boats, it is assumed that all fishers are working full time, which may be an overestimate since some fishers only work part time.

Effectiveness of traps over time

Although traps could be buried in storms, corroded over time or destroyed by woodborers (Breen 1990), Breen (1987) found that there was no difference between the catch rate of traps at the beginning and after one year. With the exception of one case study, the operative span of traps was estimated at less than 1 year in the calculations, so it was assumed that the effectiveness of the traps in catching crustaceans was constant throughout its lifespan.

Behaviour and Anatomy

Because different species of crustaceans behave differently, they are often targetted by different types of traps, which affects the catch rate. True crabs move in a distinctive sideways scuttle while king crabs are more spider-like in their locomotion due to their long, spiny legs. Lobsters and spiny lobsters crawl sideways and forwards with their legs but swim backwards with flaps of their tails if bursts of speed are needed, although spiny lobsters are more closely related to crayfish and do not have large front claws.

Case studies were sorted into four taxonomic groups for ease of comparison (Figure 3.1). In case studies where mortality rate was a missing parameter and had to be calculated as a mean of other mortality rates, values were applied from another fishery that targeted the same species if available.

One example of the difference in behaviour is whether caught individuals attract or repel others of the same species, although that cannot be necessarily attributed to taxon-specific behaviour. In the Infraorder Brachyura, blue crabs are cannibalistic and are attracted to traps that already hold other blue crabs (Guillory 2001). On the other hand, behavioural interactions between Dungeness crabs inside and outside traps result in reduced catch (Miller 1979 cited in Breen 1990). Similarly, dead King crabs in a trap usually repel other King crabs (High 1985). Live lobsters in traps attract additional lobsters even after the bait is gone (Paul 1984).

Measures of mortality

Although the unit used for mortality was individuals·trap^{-1}year^{-1}, some studies were done over a period of several weeks or months. In that case, the mortality was extrapolated to a year, under the assumption that mortality is constant throughout the year. This may not be an accurate representation of the situation, as Breen (1987) noted that the number of crabs in pots varied throughout the year and that the number of crabs found in a trap is not a reliable indicator of the fishing rate of the trap because of turnover and deaths. One of his arguments for this case is that crabs might enter and then escape from a trap between observations; in this thesis, it was assumed that the ingress and egress rates were equal, putting the number of captured individuals at equilibrium. Only direct mortality is taken into account in this thesis; it should be noted that the indirect mortality or decreased fitness of crustaceans as a result of wounds obtained from escaping a trap was not examined.

Calculation Uncertainty

There are numerous potential sources for error in the equations and parameters used in the calculation of ghost fishing mortality. The linear nature of the calculations means that a change in one parameter directly affects all derived parameters. Halving the operating lifespan of a trap, for example, results in half the ghost fishing mortality.

Other than Breen's (1987) study of the BC Dungeness crab fishery, no case study had all the required parameters. As a result, values from different articles and studies for varying years and fisheries were put together to form one case study. The closest matches to the fisheries in question were used, but the values used may not reflect the situation in the fisheries because they may be from different years, different locations, or a smaller geographic area than the one dealt with in the case study.

In some references, authors gave values but did not specify the location or year to which the values applied; in some cases, they did not even supply units. In such cases, guesses had to be made based on context and the publication dates of the references. In other cases, values were given in units that were not appropriate for the case study calculations, so a corresponding number had to be inferred. For example, Parrish and Kazama (1992) expressed the mortality rate of ghost traps as 0.22 that of working traps rather than as individuals caught per trap per year, so the value was adjusted using the reported landings and the number of traps in use.

In most case studies, one mean species weight was used for all case studies involving the same species. This is not an accurate representation, as mean weights of crustaceans are different in each fishery, depending on how heavily they are fished.

Monte Carlo Uncertainty

The quantity of parameters available for a case study does not affect the level of ghost fishing activity; it does, however, affect the range of possible results. At 10,000 runs, the shape of the distribution can be seen clearly, but in many case studies, the range of possible values is large due to the uncertainty in the parameters.

Parameters with uncertainty were assumed to have symmetrical triangular distributions, but in some cases, the distributions may not have been symmetrical. In a study of degradation time of traps in Alaska, the mean time for degradation was not the midrange (Kimker 1990).

Conclusion

Despite the potential sources of error, a number of conclusions can be drawn from this study. My estimates suggest that ghostfishing as a percentage of reported landings ranges from 0.002% to 21% with 19 of 44 case studies below 1%. The mean of all estimates is 3.8%. The highest incidence of ghost fishing occurs in the 1973 Atlantic inshore lobster fishery, where a combination of high fishing effort and high rate of loss take the ghost fishing mortality to 21.4%. Figure 4.1 shows the frequency of percentage classes resulting from the case studies.

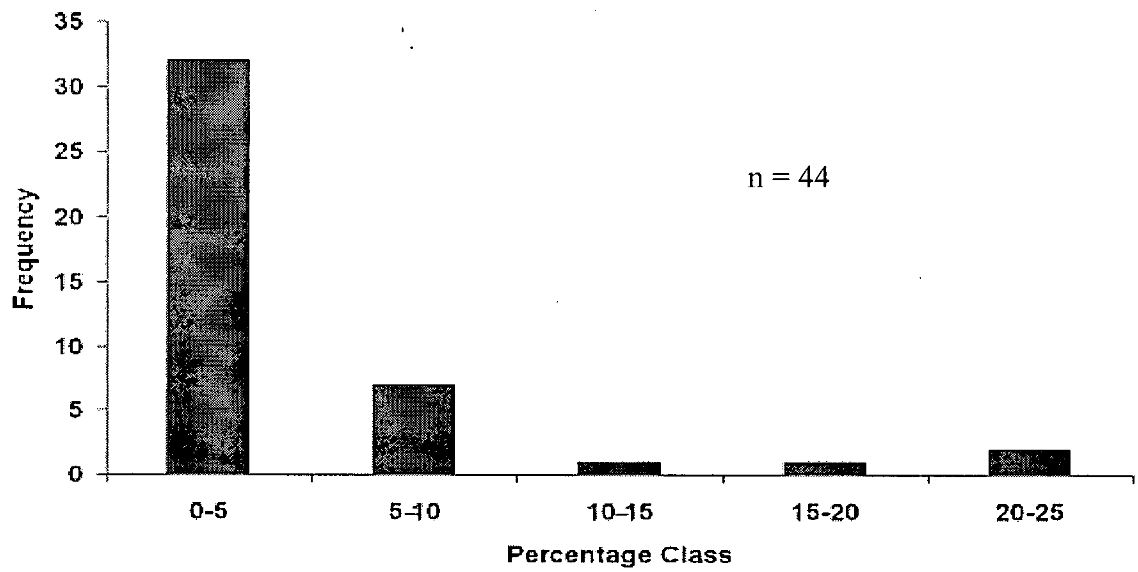

Figure 4.1: Frequency chart of ghost fishing as a percentage reported landings

Table 3 compares estimates of ghost fishing activity from the four taxonomic groups. The lowest incidence of ghost fishing in crabs occurs in Ireland, where low fishing effort leads to a lower amount of traps being lost. The highest incidence occurs in Mississipi, where ghost fishing is high with respect to reported landings. Ghost fishing activity in king crabs is lower in general due to legislation in Alaska requiring the use of 30 thread cotton twine on traps. This is not the case with lobster fisheries, where the lowest occurence of ghost fishing relative to reported landings, in New England, comes about only because the reported landings were very high. As stated above, the high ghost fishing activity, in the 1973 Atlantic lobster fishery, is caused by high effort and trap loss rate. As there was only one case study involving spiny lobsters, the average, lowest and highest ghost fishing activity have the same value; the low estimate is due to a low number of lost traps.

Table 3: Comparison of estimates by taxonomic group

	Average (%)	**Minimum (%)**	**Maximum (%)**
Crabs	4.0	0.01	20
King crabs	0.52	0.002	2.6
Lobsters	6.4	1.2	21.4
Spiny lobsters	0.024	0.024	0.024

Although the relationships used to estimate ghost fishing mortality are linear, two input parameters have a clear impact on ghost fishing mortality: duration of ghost fishing period and total number of gears used in the fishery. Of the 9 case studies in which traps had an effective life of less than 0.417 years (the value used for case studies missing duration of ghost fishing period), 7 had results in which ghost fishing was less than 1% of reported landings. The remaining 2 case studies involved a large amount of fishing gear in use or relatively low reported landings. When a large number of traps is used, a small difference in the rate of gear loss would make a large difference in the total number of traps lost - which in turn affects ghost fishing mortality.

Ghost fishing mortality reduces available biomass for catch or spawning. The case studies above show that ghost fishing can be an issue in many fisheries, even those where biodegradable panels or twines are legislated. In other fisheries where the use of these biodegradable devices are not legislated or enforced, ghost fishing mortality is higher.

Some measures have already been taken to minimise ghost fishing. In some jurisdictions, legislation requires the use of properly marked buoys, escape gaps, and degradable plastics or galvanic timed releases. Federal law in the United States mandates escape vents and a degradable panel that would allow legal sized lobsters and most other prey to escape ghost traps (Carr and Harris 1987). Some fisheries use 'habipots' that lobsters can use as shelter and enter and leave unhindered (Smolowitz 1978). Similarly, decreasing the number of lost traps can reduce the damage that they cause; for example, assigning trap-free lanes in areas of heavy boat traffic prevents buoy lines from being tangled or cut.

Escape vents and biodegradable ports alleviate the high mortality from ghost gear. The most effective way to decrease the effect of fishing effort would be to reduce the number of traps in use. When fishing effort decreases, so does the number of traps used. The fewer the traps that are used, the fewer are lost. Even if the trap loss rate were low, a large number of traps in use would mean that a large number of traps would be lost. Reducing fishing effort, unfortunately, is difficult and expensive to enforce (Breen 1990), and escape ports ameliorate but do not eliminate the problem of ghost fishing (Stevens *et al.* 1993).

Fishers may also resist legislation requiring biodegradable devices on traps, especially if they feel that ghost fishing is not an issue in their particular fishery. It is possible to demonstrate the existence of ghost fishing with sidescan sonar to record the entry and mortality of crustaceans in pots (Stevens *et al.* 2000), but if ghost fishing activity is low, policy-makers may decide not to enact legislation to prevent it. An economic evaluation, comparing the loss of revenue from ghost fishing activity and the cost of using biodegradable devices and enforcing legislation, is one method of justification. In this case, the methodology proposed in this thesis can be adapted to show the economic value of crustaceans lost to ghost fishing. What level of ghost fishing mortality is commercially and politically acceptable becomes a management issue rather than a biological one.

Ghost fishing is one type of illegal, unregulated and unreported (IUU) fishing that has only recently been explicitly studied in much depth by fisheries scientists. Even within the realms of IUU fishing, relatively little attention has been given to lost gear. By introducing a simple yet effective methodology, this thesis allows existing information to be consolidated and examined for trends and patterns despite the dearth of studies on ghost fishing activity. A study of this scope is a starting point towards a better understanding of the impact of ghost fishing, and hopefully the precursor of others to come.

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Appendix 1: Visual Basic Code for Monte Carlo Simulations

Parameter (Par) list:

Par(1): Total gear
Par(2): Annual trap loss rate
Par(3): Gear lost per year
Par(4): Percentage of lost traps ghost fishing
Par(5): Number of traps ghost fishing
Par(6): Length of ghost fishing period
Par(7): Number of traps ghost fishing per year
Par(8): Mortality rate per trap
Par(9): Annual ghost fishing mortality
Par(10): Average weight of species
Par(11):Weight of annual ghost fishing mortality
Par(12): Reported landings
PerGhostCalc: Ghost fishing as a percentage of reported landings

ParL() is the lower limit in the range of the parameter
ParU() is the upper limit in the range of the parameter
ParM() is the mean in the range of the parameter

--- Begin Code ---

```
Sub CaseStudyAnalysis()
Dim i As Integer, j As Integer, CS As Integer, trials As Integer
Dim PerGhost() As Double
Dim ParL(12) As Single, ParU(12) As Single, ParM(12) As Single
Dim ColCount As Integer, pcount As Integer
Dim PerGhostCalc As Double
Dim xx As Single, Ntrials As Integer, NCases
  Worksheets("Case Studies tri values").Activate
  Ntrials = 10000: NCases = 60
  ReDim PerGhost(NCases, Ntrials)
  For CS = 1 To NCases
    ColCount = 8
    pcount = 0
    Do
      pcount = pcount + 1
      ParM(pcount) = Cells(CS + 2, ColCount)
      ParL(pcount) = Cells(CS + 2, ColCount + 1)
```

```
      ParU(pcount) = Cells(CS + 2, ColCount + 2)
      ColCount = ColCount + 3
    Loop Until pcount = 12

    For trial = 1 To Ntrials
          xx = 0
      If ParM(1) > 0 Then
        If ParU(1) = 0 Then
          If ParM(2) = 0 Then
            xx = ParM(3)
          Else
            xx = ParM(1)
          End If
        Else
          xx = ((rantriangle((ParL(1) * ParM(1)), (ParU(1) * ParM(1)))) + ParM(1))
        End If

        If ParU(2) = 0 Then
          xx = xx * ParM(2)
        Else
          xx = xx * ((rantriangle((ParL(2) * ParM(2)), (ParU(2) * ParM(2)))) +
ParM(2))
        End If
      Else
        xx = ParM(3)
      End If

      If ParL(3) > 0 And ParU(3) = 0 Then xx = ParM(3)
      If ParL(3) > 0 And ParU(3) > 0 Then xx = ((rantriangle((ParL(3) * ParM(3)),
(ParU(3) * ParM(3)))) + ParM(3))
      If ParU(4) = 0 Then
        xx = xx * ParM(4)
      Else
        xx = xx * ((rantriangle((ParL(4) * ParM(4)), (ParU(4) * ParM(4)))) + ParM(4))
      End If

      If ParU(6) = 0 Then
        xx = xx * ParM(6)
      Else
        xx = xx * ((rantriangle((ParL(6) * ParM(6)), (ParU(6) * ParM(6)))) + ParM(6))
      End If
```

```
        If ParU(8) = 0 Then
            xx = xx * ParM(8)
        Else
            xx = xx * ((rantriangle((ParL(8) * ParM(8)), (ParU(8) * ParM(8)))) + ParM(8))
        End If


        If ParU(10) = 0 Then
            xx = xx * ParM(10)
        Else
            xx = xx * ((rantriangle((ParL(10) * ParM(10)), (ParU(10) * ParM(10)))) +
ParM(10))
        End If


        If ParU(12) = 0 Then
            PerGhostCalc = xx / ParM(12)
        Else
            PerGhostCalc = xx / ((rantriangle((ParL(12) * ParM(12)), (ParU(12) *
ParM(12)))) + ParM(12))
        End If
        PerGhost(CS, trial) = PerGhostCalc
    Next trial
  Next CS

  Worksheets("Temp").Activate

  For CS = 1 To NCases
    For i = 1 To Ntrials
      Cells(i, CS) = PerGhost(CS, i)
    Next i
  Next CS
End Sub

Function rantriangle(ErrLow As Variant, ErrHi As Variant) As Single

Dim U1 As Single
Dim U2 As Single
Dim U3 As Single
```

```
Dim U4 As Single
Dim T1 As Single
Dim T2 As Single
Dim F As Single
Dim P As Single

ErrLow = Abs(ErrLow)
ErrHi = Abs(ErrHi)
U1 = ErrLow * Rnd
U2 = ErrLow * Rnd
T1 = -Abs(U1 - U2)
U3 = ErrHi * Rnd
U4 = ErrHi * Rnd
T2 = Abs(U3 - U4)
F = Rnd
P = ErrLow / (ErrLow + ErrHi)
If F < P Then
  rantriangle = T1
Else
  rantriangle = T2
End If

End Function
```