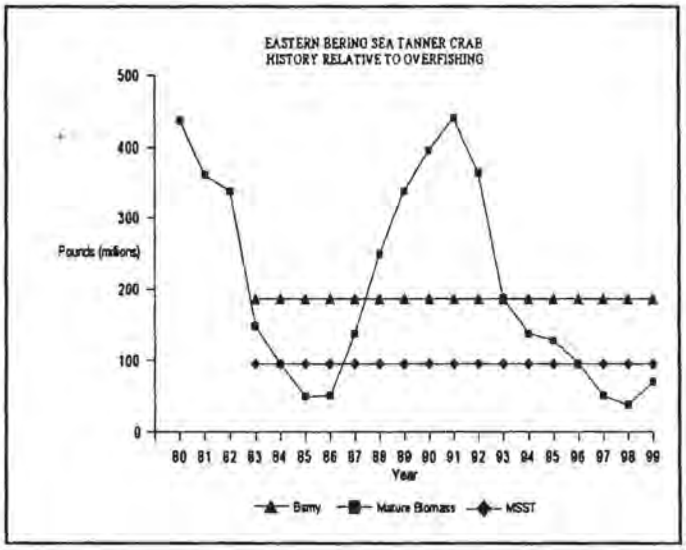
ENVIRONMENTAL ASSESSMENT
for proposed
AMENDMENT 11
to the Fishery Management Plan for the
King and Tanner Crab Fisheries in the Bering Sea/Aleutian Islands

A Rebuilding Plan for the Bering Sea Tanner (C. bairdi) Crab Stock



Lead Agencies: North Pacific Fishery Management Council, Anchorage, Alaska
National Marine Fisheries Service, Alaska Regional Office, Juneau, Alaska
and the
Alaska Department of Fish and Game, Juneau, Alaska

Responsible Official: Clarence Pautzke, North Pacific Fishery Management Council

For Further Information Contact:
David Witherell, North Pacific Fishery Management Council
Gretchen Harrington, National Marine Fisheries Service

Abstract: Amendment 11 is a rebuilding plan for the Bering Sea stock of Tanner crab. The Magnuson-Stevens Fishery Conservation and Management Act requires a rebuilding plan when a stock has been declared overfished. The National Marine Fisheries Service declared the Bering Sea stock of Tanner crab overfished on March 3, 1999.

June 1 2000

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Option 3: (preferred) Request the Board and the Alaska Department of Fish and Game to consider additional measures (such as gear modifications and area closures) to reduce bycatch of Tanner crab in crab fisheries.

C. **Habitat protection**: Adequate habitat is essential for maintaining the productivity of fishery resources. Measures previously implemented that protect Tanner crab habitat from fishing impacts include several areas where trawling and dredging is prohibited. Essential fish habitat (EFH) has been defined and potential threats have been identified. Additional measures could be implemented to further protect habitat.

Option 1: Status quo. Maintain existing habitat protection measures.

Option 2.: (preferred) For agency consultation purposes, highlight the importance of Tanner crab EFH in maintaining stock productivity. To the extent feasible and practicable, this area should be protected from adverse impacts due to non-fishing activities.

Option 3.: Refine existing EFH information to identify discrete areas important to mating, pre-mating/molting adults and juvenile Tanner crab. Conduct thorough analysis of important Tanner crab habitat by using existing observer database and survey information in a comprehensive spatial analysis. This analysis should be completed within one year and be incorporated into the Tanner crab rebuilding plan for habitat protection.

The proposed actions contained in this amendment are timely to rebuild the Bering Sea Tanner crab stock. Although the near-term outlook for this stock is bleak, the 1998 and 1999 surveys encountered a fair number of small crab (30-50 mm CW). These small crabs may represent the cornerstone of stock rebuilding, as protection of these crabs through maturity may pay off in terms of increased spawning and recruitment in future years. Clearly the stock is capable of rebounding in a relatively short time period when conditions are favorable, as was the case in the late 1980's.

Adoption of Alternative 2 (particularly Part A, Option 2) is expected to allow the Bering Sea Tanner crab stock to rebuild, with a 50% probability, to the Bmsy level in 10 years. Adoption of the revised harvest strategy should result in more spawning biomass as more larger male crab would be conserved and fewer juveniles and females would die due to discarding. This higher spawning biomass would be expected to produce good year-classes when environmental conditions are favorable. Protection of habitat and/or reduction of bycatch may reduce mortality on juvenile crabs, thus allowing a higher percentage of each year-class to contribute to spawning (and future landings). Any or all of these actions proposed under Alternative 2 would be expected to improve the status of this stock. No rebuilding benefits are provided by Alternative 1.

Alternative 2B, Option 2, could impact the groundfish trawl fisheries (the flatfish trawl fisheries in particular) depending on the suboption chosen. The crab bycatch limits are apportioned among fisheries pre-season, and reaching one of these limits shuts down a fishery for the remainder of the season. A bycatch limit established at 0.5% of abundance may result in Zone 2 groundfish catch reductions of 24%, equating to about $ 4.75 million exvessel. A bycatch limit established at 0.75% of abundance would have less impacts, depending on how accurately the PSC limits are apportioned among fisheries. The analysis estimates that a PSC mis-apportionment of 10% may cost the flatfish fleet $ 1.9 million exvessel if the catch could not be made up outside Zone 2. Additional costs to the groundfish trawl fisheries would be incurred if additional areas were closed to trawling to protect crab habitat.

Alternative 2C, Option 3, would require a significant amount of additional analysis to identify discrete areas important to mating, pre-mating/molting adults and juvenile Tanner crab. It is not known at this time whether or not current survey and observer data information would be adequate for identification of these areas.

Amendment 11 is exempt from the procedures of E.O. 12866 because this action contains no implementing regulations. None of the alternatives are likely to significantly affect the quality of the human environment, and the preparation of an environmental impact statement for the proposed action is not required by section 102(2)(C) of the National Environmental Policy Act or its implementing regulations. Amendment 11 does not contain implementing regulations so this action is exempt from the procedures of the Regulatory Flexibility Act (RFA), thus a regulatory impact review and initial regulatory flexibility analysis are not required.

1.0 Introduction

The king and Tanner crab fisheries in the Exclusive Economic Zone (EEZ) (3 to 200 miles offshore) of the Bering Sea and Aleutian Islands off Alaska are managed under the Fishery Management Plan for King and Tanner Crab Fisheries in the Bering Sea/Aleutian Islands. This fishery management plan (FMP) was prepared by the North Pacific Fishery Management Council (Council) under the Magnuson-Stevens Fishery Conservation and Management Act (Magnuson-Stevens Act). The BSAI King and Tanner crab FMP was approved by the Secretary of Commerce and became effective in 1989. The FMP defers management of the king and Tanner crab fisheries to the State of Alaska, with Federal oversight by the NMFS and the Council.

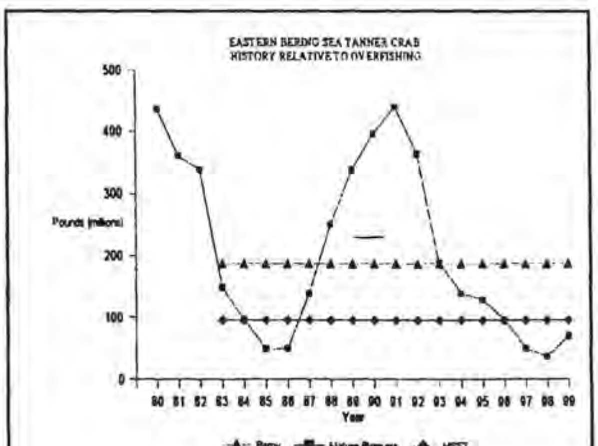
The groundfish fisheries in the EEZ off Alaska are managed under the Fishery Management Plan for Groundfish of the Gulf of Alaska and the Fishery Management Plan for the Groundfish Fisheries of the Bering Sea and Aleutian Islands Area. The Gulf of Alaska Groundfish (GOA) FMP was approved by the Secretary of Commerce and become effective in 1978 and the Bering Sea and Aleutian Islands Area (BSAI) FMP become effective in 1982.

Actions taken to amend the FMPs or implement other regulations governing the BSAI crab and groundfish fisheries must meet the requirements of Federal laws and regulations. In addition to the Magnuson-Stevens Act, the most important of these are the National Environmental Policy Act (NEPA), the Endangered Species Act (ESA), the Marine Mammal Protection Act (MMPA), Executive Order (E.O.) 12866, and the Regulatory Flexibility Act (RFA).

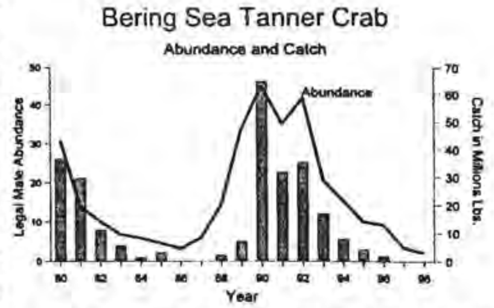
This Environmental Assessment (EA) addresses alternatives for rebuilding Tanner crab stocks in the Eastern Bering Sea as required under the Magnuson-Stevens Act. NEPA requires a description of the purpose and need for the proposed action as well as a description of alternative actions which may address the problem. This information is included in Sections 1 and 2 of this document. Sections 4 through 7 contain information on the biological and environmental impacts of the alternatives as required by NEPA. Impacts on endangered species and marine mammals are addressed in section 6. Section 7 contains information that addresses the economic and socioeconomic impacts of the alternative and options considered by the Council. An EA must include a brief discussion of the need for the proposal, the alternatives considered, the environmental impacts of the proposed action and the alternatives, and a list of document preparers. The sections of the Magnuson-Stevens Act that must be satisfied are: National Standard 1 section 301(a)(1); Required provisions 303(a)(10) and 303(a)(14); Rebuilding overfished fisheries 304(e); and national standard guidelines 50 CFR 600.310. To the fullest extent possible, the rebuilding alternatives adhere to the NMFS Technical Guidance on Rebuilding (Restrepo et al 1998).

1.1 Purpose of and Need for the Action

The Magnuson-Stevens Act, in section 303(a)(10), requires that each FMP specify objective and measurable criteria (status determination criteria) for identifying when stocks or stock complexes covered by the FMP are overfished. To fulfill the intent of the Magnuson-Stevens Act, such status determination criteria are comprised of two components: A maximum fishing mortality threshold and a minimum stock size threshold (see Sec. 600.310(d)(2)).



Amendment 7 to the BSAI King and Tanner Crab FMP redefined overfishing, OY, and MSY, and updated the FMP with new information. The amendment established MSY point estimates, along with minimum stock size thresholds (MSST) for individual crab stocks based on prevailing environmental conditions (1983-1997 period). Overfishing is now defined as a fishing mortality rate in excess of natural mortality (M=0.2 for king crabs, M=0.3 for Tanner crabs) or a biomass that falls below MSST. Because the Tanner crab spawning biomass (64.2 million pounds of biomass in 1997) was below MSST (94.8 million pounds of biomass; see adjacent figure), the stock was deemed "overfished" on March 3, 1999 based on the guidelines, and requires that a rebuilding plan be developed within one year as required under Section 304 of the Magnuson-Stevens Act. The stock continued to decline, with spawning biomass estimated to be only 36.9 million pounds in 1998. The stock has since begun to increase, with the 1999 spawning biomass estimated at 70.1 million pounds.



Abundance and catch of Bering Sea Tanner crab, 1980-1998. The fishery occurred over two seasons in the years 1990 through 1994.

The Bering Sea Tanner crab stock has undergone several large fluctuations. Catches increased from 5 million pounds in 1965 to over 36 million pounds in 1980. The 1980 peak catch was followed by a collapse resulting in low landings (<0.5 million lbs) from 1981-1985, and finally no fishery in 1986 and 1987. The fishery reopened in 1988, and landings increased to over 60 million pounds in 1990. A decline followed, and the Alaska Department of Fish and Game (ADF&G) has closed the fishery since 1997.

This stock is currently at very low abundance. The 1998 estimates of legal males and large females are the lowest in the history of the NMFS bottom trawl survey (**Table 1**). Although the near-term outlook for this stock is bleak, the 1998 survey encountered a fair number of small crab (Stevens et al. 1998). These small (30-50 mm CW) crabs are only 2-3 years from maturity, and may represent the cornerstone of stock rebuilding, because protection of these crabs through maturity may pay off in terms of increased spawning and recruitment in future years. The 1999 survey estimate of mature biomass increased to 70.1 million pounds. The 1999 estimates of sub-legal males increased 20 % and large females increased 147% from the 1998 estimates. Clearly the stock is capable of rebounding in a relatively short time period when conditions are favorable, as was the case in the late 1980's.

1.2 Related NEPA Documents

The projections for fishing year 2000, as well as the status of the stocks and history of the fishery, are contained in the 1999 Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries of the BSAI (NPFMC 1999). Complete discussion and description of the Essential Fish Habitat for Tanner crab are contained in the Environmental Assessment for Amendment 6 to the FMP. Complete discussion and analysis of the overfishing definitions for Tanner crab are contained in the Environmental Assessment for Amendment 7 to the FMP. Descriptions of the affected environment are given in the SEIS for the groundfish fisheries (NMFS 1998) and are incorporated into this document by reference.

2.0 Description of Alternatives and Options

This Environmental Assessment (EA) addresses alternatives for rebuilding the overfished stock of Tanner crab in the Eastern Bering Sea. Two alternatives were developed by the Council at their October, 1998 meeting, and the options finalized in June 1999. Preferred Alternatives and options were chosen at the Council meeting in October 1999. The alternatives examined were the following:

2.1 Alternative 1: Status Quo. No rebuilding plan would be adopted for Bering Sea Tanner crab.

2.2 Alternative 2: (preferred) Establish a rebuilding plan for Bering Sea Tanner crab. The rebuilding plan may have three components: a harvest strategy, bycatch control measures, and habitat protection.

A. **Harvest Strategy**: In previous years when there was a directed fishery, harvest rates for Bering Sea Tanner crab were established at 40% of the mature male abundance. This harvest strategy could be modified to reduce mortality on legal males, females, and juvenile crabs.

Option 1: Status quo. Continue to establish harvest rates for Bering Sea Tanner crab at 40% of the mature male abundance.

Option 2: (preferred) Endorse the new harvest strategy for Bering Sea Tanner crabs as adopted by the Board. ADF&G has recently developed a stairstep harvest strategy for Tanner crabs, which was adopted by the Board in March 1999. The strategy, as detailed in Section 5.1 and Appendix 2, includes lower harvest rates at low biomass levels, and incorporates a threshold female biomass.

B. **Bycatch Controls**: Bycatch control measures have previously been implemented in the crab, scallop, and groundfish fisheries. These measures could be adjusted to reduce mortality on unharvested crabs.

Option 1: Status quo. (preferred) Maintain existing Tanner crab bycatch control measures.

Option 2: Reduce the Zone 2 PSC limit.

Suboption A. The Zone 2 PSC limit would be set equal to 0.75% of the total Tanner crab population as estimated by the NMFS annual bottom trawl surveys, with a maximum PSC limit of 3,000,000 Tanner crabs.

Suboption B. The Zone 2 PSC limit would be set equal to 0.5% of the total Tanner crab population as estimated by the NMFS annual bottom trawl surveys, with a maximum PSC limit of 2,000,000 Tanner crabs.

Option 3: (preferred) Request the Board and ADF&G to consider additional measures (such as gear modifications and area closures) to reduce bycatch of Tanner crab in crab fisheries.

C. **Habitat protection**: Adequate habitat is essential for maintaining the productivity of fishery resources. Measures previously implemented that protect Tanner crab habitat from fishing impacts include several areas where trawling and dredging is prohibited. Essential fish habitat (EFH) has been defined and potential threats have been identified. Additional measures could be implemented to further protect habitat.

Option 1: Status quo. Maintain existing habitat protection measures.

Option 2: (preferred) For agency consultation purposes, highlight the importance of Tanner crab EFH in maintaining stock productivity. To the extent feasible and practicable, this area should be protected from adverse impacts due to non-fishing activities.

Option 3.: Refine existing EFH information to identify discrete areas important to mating, pre-mating/molting adults and juvenile Tanner crab. Conduct thorough analysis of important Tanner crab habitat by using existing observer database and survey information in a comprehensive spatial analysis. This analysis should be completed within one year and be incorporated into the Tanner crab rebuilding plan for habitat protection.

Note that Alternative 2 option 2 (reducing the crab PSC limit for groundfish trawl fisheries) would require, if adopted, a regulatory amendment analysis, thus the preliminary economic and socioeconomic analysis is contained in section 7. Under Amendment 41, the Tanner crab PSC limits are established by regulation based on abundance of Tanner crab as indicated by the NMFS bottom trawl survey (Groundfish FMP Section 14.4.2.2).

3.0 Requirements for Stock Rebuilding

Stock rebuilding is required by the Magnuson Stevens Act, Section 304. The applicable section of the Act is provided below.

(e) **REBUILDING OVERFISHED FISHERIES.--**

(1) The Secretary shall report annually to the Congress and the Councils on the status of fisheries within each Council's geographical area of authority and identify those fisheries that are overfished or are approaching a condition of being overfished. For those fisheries managed under a fishery management plan or international agreement, the status shall be determined using the criteria for overfishing specified in such plan or agreement. A fishery shall be classified as approaching a condition of being overfished if, based on trends in fishing effort, fishery resource size, and other appropriate factors, the Secretary estimates that the fishery will become overfished within two years.

(2) If the Secretary determines at any time that a fishery is overfished, the Secretary shall immediately notify the appropriate Council and request that action be taken to end overfishing in the fishery and to implement conservation and management measures to rebuild affected stocks of fish. The Secretary shall publish each notice under this paragraph in the Federal Register.

(3) Within one year of an identification under paragraph (1) or notification under paragraphs (2) or (7), the appropriate Council (or the Secretary, for fisheries under section 302(a)(3)) shall prepare a fishery management plan, plan amendment, or proposed regulations for the fishery to which the identification or notice applies--

(A) to end overfishing in the fishery and to rebuild affected stocks of fish; or

(B) to prevent overfishing from occurring in the fishery whenever such fishery is identified as approaching an overfished condition.

(4) For a fishery that is overfished, any fishery management plan, amendment, or proposed regulations prepared pursuant to paragraph (3) or paragraph (5) for such fishery shall--

(A) specify a time period for ending overfishing and rebuilding the fishery that shall--

(i) be as short as possible, taking into account the status and biology of any overfished stocks of fish, the needs of fishing communities, recommendations by international organizations in which the United States participates, and the interaction of the overfished stock of fish within the marine ecosystem; and

(ii) not exceed 10 years, except in cases where the biology of the stock of fish, other environmental conditions, or management measures under an international agreement in which the United States participates dictate otherwise;

(B) allocate both overfishing restrictions and recovery benefits fairly and equitably among sectors of the fishery; and

(C) for fisheries managed under an international agreement, reflect traditional participation in the fishery, relative to other nations, by fishermen of the United States.

(5) If, within the one-year period beginning on the date of identification or notification that a fishery is overfished, the Council does not submit to the Secretary a fishery management plan, plan amendment, or proposed regulations required by paragraph (3)(A), the Secretary shall prepare a fishery management plan or plan amendment and any accompanying regulations to stop overfishing and rebuild affected stocks of fish within 9 months under subsection (c).

(6) During the development of a fishery management plan, a plan amendment, or proposed regulations required by this subsection, the Council may request the Secretary to implement interim measures to reduce overfishing under section 305(c) until such measures can be replaced by such plan, amendment, or regulations. Such measures, if otherwise in compliance with the provisions of this Act, may be implemented even though they are not sufficient by themselves to stop overfishing of a fishery.

(7) The Secretary shall review any fishery management plan, plan amendment, or regulations required by this subsection at routine intervals that may not exceed two years. If the Secretary finds as a result of the review that such plan, amendment, or regulations have not resulted in adequate progress toward ending overfishing and rebuilding affected fish stocks, the Secretary shall--

(A) in the case of a fishery to which section 302(a)(3) applies, immediately make revisions necessary to achieve adequate progress; or

(B) for all other fisheries, immediately notify the appropriate Council. Such notification shall recommend further conservation and management measures which the Council should consider under paragraph (3) to achieve adequate progress.

3.1 National Standard Guidelines

The section below is an excerpt from the Final Rule on National Standard Guidelines, published in the Federal Register on May 1, 1998.

Sec. 600.310 National Standard 1--Optimum Yield.

(e) Ending overfishing and rebuilding overfished stocks-- (1) Definition. A threshold, either maximum fishing mortality or minimum stock size, is being ``approached'' whenever it is projected that the threshold will be breached within 2 years, based on trends in fishing effort, fishery resource size, and other appropriate factors.

(2) Notification. The Secretary will immediately notify a Council and request that remedial action be taken whenever the Secretary determines that:

(i) Overfishing is occurring;
(ii) A stock or stock complex is overfished;
(iii) The rate or level of fishing mortality for a stock or stock complex is approaching the maximum fishing mortality threshold;
(iv) A stock or stock complex is approaching its minimum stock size threshold; or
(v) Existing remedial action taken for the purpose of ending previously identified overfishing or rebuilding a previously identified overfished stock or stock complex has not resulted in adequate progress.

(3) Council action. Within 1 year of such time as the Secretary may identify that overfishing is occurring, that a stock or stock complex is overfished, or that a threshold is being approached, or such time as a Council may be notified of the same under paragraph (e)(2) of this section, the Council must take remedial action by preparing an FMP, FMP amendment, or proposed regulations. This remedial action must be designed to accomplish all of the following purposes that apply:

(i) If overfishing is occurring, the purpose of the action is to end overfishing.
(ii) If the stock or stock complex is overfished, the purpose of the action is to rebuild the stock or stock complex to the MSY level within an appropriate time frame.
(iii) If the rate or level of fishing mortality is approaching the maximum fishing mortality threshold (from below), the purpose of the action is to prevent this threshold from being reached.
(iv) If the stock or stock complex is approaching the minimum stock size threshold (from above), the purpose of the action is to prevent this threshold from being reached.

(4) Constraints on Council action.

(i) In cases where overfishing is occurring, Council action must be sufficient to end overfishing.
(ii) In cases where a stock or stock complex is overfished, Council action must specify a time period for rebuilding the stock or stock complex that satisfies the requirements of section 304(e)(4)(A) of the Magnuson-Stevens Act.

(A) A number of factors enter into the specification of the time period for rebuilding:

(1) The status and biology of the stock or stock complex;

(2) Interactions between the stock or stock complex and other components of the marine ecosystem (also referred to as ``other environmental conditions");

(3) The needs of fishing communities;

(4) Recommendations by international organizations in which the United States participates; and

(5) Management measures under an international agreement in which the United States participates.

(B) These factors enter into the specification of the time period for rebuilding as follows:

(1) The lower limit of the specified time period for rebuilding is determined by the status and biology of the stock or stock complex and its interactions with other components of the marine ecosystem, and is defined as the amount of time that would be required for rebuilding if fishing mortality were eliminated entirely.

(2) If the lower limit is less than 10 years, then the specified time period for rebuilding may be adjusted upward to the extent warranted by the needs of fishing communities and recommendations by international organizations in which the United States participates, except that no such upward adjustment can result in the specified time period exceeding 10 years, unless management measures under an international agreement in which the United States participates dictate otherwise.

(3) If the lower limit is 10 years or greater, then the specified time period for rebuilding may be adjusted upward to the extent warranted by the needs of fishing communities and recommendations by international organizations in which the United States participates, except that no such upward adjustment can exceed the rebuilding period calculated in the absence of fishing mortality, plus one mean generation time or equivalent period based on the species' life-history characteristics. For example, suppose a stock could be rebuilt within 12 years in the absence of any fishing mortality, and has a mean generation time of 8 years. The rebuilding period, in this case, could be as long as 20 years.

(C) A rebuilding program undertaken after May 1, 1998 commences as soon as the first measures to rebuild the stock or stock complex are implemented.

(D) In the case of rebuilding plans that were already in place as of May 1, 1998, such rebuilding plans must be reviewed to determine whether they are in compliance with all requirements of the Magnuson- Stevens Act, as amended by the Sustainable Fisheries Act.

(5) Interim measures. The Secretary, on his/her own initiative or in response to a Council request, may implement interim measures to reduce overfishing under section 305(c) of the Magnuson-Stevens Act, until such measures can be replaced by an FMP, FMP amendment, or regulations taking remedial action.

(i) These measures may remain in effect for no more than 180 days, but may be extended for an additional 180 days if the public has had an opportunity to comment on the measures and, in the case of Council- recommended measures, the Council is actively preparing an FMP, FMP amendment, or proposed regulations to address overfishing on a permanent basis. Such measures, if otherwise in compliance with the provisions of the Magnuson-Stevens Act, may be implemented even though they are not sufficient by themselves to stop overfishing of a fishery.

(ii) If interim measures are made effective without prior notice and opportunity for comment, they should be reserved for exceptional situations, because they affect fishermen without providing the usual procedural safeguards. A Council recommendation for interim measures without notice-and-comment rulemaking will be considered favorably if the short-term benefits of the measures in reducing overfishing outweigh the value of advance notice, public comment, and deliberative consideration of the impacts on participants in the fishery.

3.2 Technical Guidance on Rebuilding

The section below is an excerpt from the Technical Guidelines on the Use of Precautionary Approaches to Implementing National Standard 1 of the Magnuson-Stevens Fishery Conservation and Management Act (Restrepo et al, 1998).

The National Standard 1 guidelines indicate that once biomass falls below the minimum stock size threshold (MSST), then remedial action is required *"to rebuild the stock or stock complex to the MSY level within an appropriate time frame."* Guidance for determining the adequacy and efficacy of rebuilding plans was prepared by Restrepo et al. (1998) "Technical Guidance on the Use of Precautionary Approaches to Implementing National Standard 1 of the Magnuson-Stevens Fishery Conservation and Management Act". This guidance manual does not have the force of law, but instead provides technical details for stock assessment scientists. What follows in this section (Section 1.3.2) is a short section of text from the Restrepo et al. report, which can be obtained from the NMFS Silver Spring office.

A rebuilding plan is a strategy of selecting fishing mortality rates or equivalent catches that are expected to increase the stock size to the MSY level within a specified period of time. Components for a rebuilding plan typically include: (a) an estimate of B_{MSY}, (b) a rebuilding period, (c) a rebuilding trajectory, and (d) a transition from rebuilding to more "optimal" management (Powers 1996). Specifying a control rule in terms of fishing mortality rate and biomass incorporates these components.

Species life history characteristics will affect rebuilding plans in several ways. Some stocks may possess low productivity and will be incapable of recovering within 10 years[1], even in the absence of fishing mortality. Alternatively, a stock may be highly productive, in which case a rebuilding plan of 10 years will not be precautionary, i.e., the stock has the capability of reaching B_{MSY} well before 10 years.

Often productivity is correlated with the mean generation time of a stock (defined below), which is why the final rule issuing the National Standard Guidelines link the maximum rebuilding time period to generation time when rebuilding cannot be achieved in 10 years. The minimum possible rebuilding period is constrained by a stock's status relative to B_{MSY} and its biological productivity. Linking the rebuilding period with generation time is important because it highlights the time span in the future during which recruitment will begin to depend primarily upon fish that have yet to be born, as opposed to spawners that already exist.

Rebuilding rates will also be affected by the partial recruitment pattern. Generally, greater rebuilding rates are possible by reducing mortality rates on juveniles than by equal mortality rate reductions on adult fish. However, this depends upon the relative growth and natural mortality between the age groups.

For all overfished resources, the overarching principle is that initial actions must provide a very high probability of preventing further stock declines and have a high probability of immediate improvement. Delaying action is not precautionary.

Generation time

Although the National Standard Guidelines do not provide a definition of generation time, various definitions exist in the scientific literature (Caswell 1989). In the context of stock rebuilding time horizons, the definition of generation time used could refer to an unfished state. We recommend that the default definition of generation time, G, be (Goodyear 1995):

$$G = \frac{\sum_{a=1}^{A} a E_a N_a}{\sum_{a=1}^{A} E_a N_a},$$

[1] The MSFCMA requires that the rebuilding time period be as short as possible and not to exceed 10 years with a few exceptions, including cases where the biology of the stock or other environmental conditions dictate otherwise.

where a denotes age, A is the oldest age expected in a pristine (unfished) condition, E_a, is the mean fecundity at age of females, and N_a is the average. number of females per recruit alive at age a in the absence of fishing, i.e.,

$$N_a = N_1 \exp(-\sum_{j=1}^{a-1} M_j),$$

where M is the natural mortality rate. These expressions should be computed on an equilibrium per-recruit basis, i.e., setting $N_1 = 1$. When fecundity data are not available, G can be computed by replacing E_a, with an age-specific vector of maturity ratios times body weight (as commonly used to compute spawning biomass).

The rebuilding plan

In the absence of data and analyses that can be used to justify alternative approaches, we recommend that a default rebuilding plan for stocks below the MSST be based upon the precautionary target control rule of Section 3.3 with the following extensions:

1) The maximum rebuilding period, T_{max}, should be 10 years, unless T_{min}, (the expected time to rebuilding under zero fishing mortality) is greater than 10 years, when T_{max} should be equal to T_{min} plus one mean generation time.

2) The target rebuilding time period, T_{target} should be as short as possible and lower than T_{max} (although it could be adjusted up to T_{max} under the circumstances described in §600.310(e)(4) of the NSGs). We suggest that T_{target} not exceed the midpoint between T_{min} and T_{max}; and,

3) If the stock is well below the MSST (e.g., B≤ ½MSST), it may be necessary to set the fishing mortality rate as close to zero as possible (i.e., to that associated with unavoidable levels of bycatch) for a number of years.

Figure 1.3.2 illustrates what a rebuilding plan might look like for a severely overfished stock. In region **a**, the rebuilding plan's F is set to zero. In region **b**, between ½MSST and B_{MSY}, the rebuilding F is set to 75% of the target F in the control rule of Section 3.3. In region **c**, the stock is rebuilt and the F is set again to the target of Section 3.3. Whether or not a zero F in region **a** and a 75% reduction in region **b** satisfy the requirement for rebuilding within the target time period largely depends on the initial level of stock depletion and the stock's productivity.

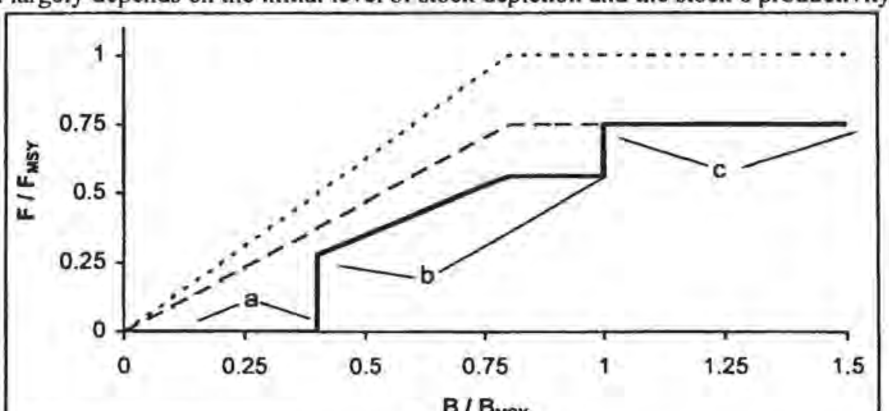


Figure 1.3.2. Example of a rebuilding plan (solid line) for a severely overfished stock. The dotted and dashed lines represent the recommended default limit and target control rules of Sections 2.1.4 and 3.3, respectively. The regions **a**, **b** and **c** represent three phases in the rebuilding plan: part **a** is designed to initiate rebuilding with high probability; part **b** is designed to accelerate rebuilding compared to the rate of rebuilding that is built into the target control rule of Section 3.3; part **c** represents a transition to more "optimal" management.

The role of uncertainty

Accounting for uncertainty in stock dynamics, current stock status and recruitment variability is important in developing rebuilding plans (Rosenberg and Restrepo 1994). As such, we suggest that the rebuilding plan should be designed to possess a 50% — or higher — chance of achieving B_{MSY} within T_{target} years, and a 90% — or higher — chance of achieving B_{MSY} within T_{max} years.

The intent of the MSFCMA is that overfished stocks be rebuilt quickly. For this reason, stock rebuilding should be monitored closely so that adjustments can be made when rebuilding milestones are not being met for whatever reason. For example, if target rebuilding *F*s are exceeded due to quota over-runs, subsequent target *F*s should typically be adjusted downwards to put the stock back on the rebuilding time table.

The magnitude and variability of future recruitment will affect the realized rebuilding trajectory. In cases when one or more very large year classes appear, it may be tempting to utilize them to increase short-term yield at the expense of slower stock rebuilding, hoping that subsequent year classes will be of similar — or at least average — magnitude. Such action would not be precautionary. Furthermore, the resulting change in fishing mortality would depart from the pre-agreed nature of the rebuilding control rule and therefore be inconsistent with the rebuilding plan.

3.3 Definitions from Crab FMP

The definition of optimum yield, MSY, and threshold levels were derived from definitions contained in the Magnuson-Stevens Act or on the guidelines. These definitions were adopted under Amendment 7.

Maximum sustainable yield (MSY) is the largest long-term average catch or yield that can be taken from a stock or stock complex under prevailing ecological and environmental conditions. MSY is estimated from the best information available. Proxy stocks are used for BSAI crab stocks where insufficient scientific data exists to estimate biological reference points and stock dynamics are inadequately understood. MSY for crab species is computed on the basis of the estimated biomass of the mature portion of the male and female population or total mature biomass (MB) of a stock. A fraction of the *MB* is considered sustained yield (*SY*) for a given year and the average of the *SY*s over a suitable period of time is considered the MSY.

Overfishing: The term "overfishing" and "overfished" mean a rate or level of fishing mortality that jeopardizes the capacity of a fishery to produce MSY on a continuing basis. Overfishing is defined for king and Tanner crab stocks in the BSAI management area as any rate of fishing mortality in excess of the maximum fishing mortality threshold, F_{msy}, for a period of 1 year or more. Should the actual size of the stock in a given year fall below the minimum stock size threshold, the stock is considered overfished. If a stock or stock complex is considered overfished or if overfishing is occurring, the Secretary will notify the Council to take action to rebuild the stock or stock complex.

MSY control rule means a harvest strategy which, if implemented, would be expected to result in a long-term average catch approximating MSY. The MSY control rule for king and Tanner crabs is the mature biomass of a stock under prevailing environmental conditions, or proxy thereof, exploited at a fishing mortality rate equal to a conservative estimate of natural mortality.

MSY stock size is the average size of the stock, measured in terms of mature biomass of a stock under prevailing environmental conditions, or a proxy thereof. It is the stock size that would be achieved under the MSY control rule. It is also the minimum standard for a rebuilding target when remedial management action is required. For king and Tanner crab, the MSY stock size is the average mature biomass observed over the past 15 years, from 1983 to 1997.

Maximum fishing mortality threshold (MFMT) is defined by the MSY control rule, and is expressed as the fishing mortality rate. The MSY fishing mortality rate $F_{msy} = M$, is a conservative natural mortality value set equal to 0.20 for all species of king crab, and 0.30 for all *Chionoecetes* species.

Minimum stock size threshold (MSST) is whichever is greater: one half the MSY stock size, or the minimum stock size at which rebuilding to the MSY level would be expected to occur within 10 years if the stock or stock complex were exploited at the maximum fishing mortality threshold. The minimum stock size threshold is expressed in terms of mature biomass of a stock under prevailing environmental conditions, or a proxy thereof.

4.0 Current Crab Management Regime

4.1 Tanner Crab Biology and Fishery Management

Biology: Tanner crab (*Chionoecetes bairdi*) are distributed on the continental shelf of the North Pacific Ocean and Bering Sea from Kamchatka to Oregon. Off Alaska, Tanner crab are concentrated around the Pribilof Islands and immediately north of the Alaska Peninsula, and are found in lower abundance in the Gulf of Alaska. The 1998 survey distribution of Tanner crabs in the Bering Sea is shown in **Figures 1-5.** Size at 50% maturity, as measured by carapace width, is 110 mm for males and 90 mm for females in the Bering Sea. The corresponding age of maturity for male Tanner crab is about 6 years. Growth during the next molt increases the size of males to about 120-140 mm. Mature male Tanner crabs may skip a year of molting as they attain maturity. The 1998 survey length frequency distribution of male Tanner crabs in the Bering Sea is shown in **Figure 6.** Natural mortality of adult Tanner crab is estimated at about 25% per year (M=0.3). Tanner crab females are known to form high-density mating aggregations, or pods, consisting of hundreds of crabs per mound. These mounds may provide protection from predators and also attract males for mating. Mating need not occur every year, as some female Tanner crabs can retain viable sperm in spermathecae up to 2 years or more. Females have clutches of 50,000 to 400,000 eggs. Little information is known about the biology of two other closely related species of Tanner crab found in the Bering Sea and Aleutian Islands area. The grooved Tanner crab (*Chionoecetes tanneri*) and triangle Tanner crab (*Chionoecetes angulatus*) occur in deep water (> 400 fathoms) and have been commercially harvested only in the past few years.

Management measures implemented in the BSAI king and Tanner crab fisheries, as defined by the federal crab FMP, by category.

Category 1 (Fixed in FMP)	Category 2 (Frameworked in FMP)	Category 3 (Discretion of State)
• Legal Gear	• Minimum Size Limits	• Reporting Requirements
• Permit Requirements	• Guideline Harvest Levels	• Gear Placement and Removal
• Federal Observer Requirements	• Inseason Adjustments	• Gear Storage
• Limited Access	• Districts, Subdistricts and Sections	• Gear Modifications
• Norton Sound Superexclusive Registration Area	• Fishing Seasons	• Vessel Tank Inspections
	• Sex Restrictions	• State Observer Requirements
	• Closed Waters	• Bycatch Limits (in crab fisheries)
	• Pot Limits	• Other
	• Registration Areas	

Management: Tanner crab stocks in the Bering Sea are managed by the State of Alaska through a federal BSAI king and Tanner crab fishery management plan (FMP). Under the FMP, management measures fall into three categories: (1) those that are fixed in the FMP under Council control, (2) those that are frameworked so that the State can change following criteria outlined in the FMP, and (3) those measures under complete discretion of the State. In previous years, the State set pre-season guideline harvest levels for Tanner crab based on a mature male harvest rate of 40%. Minimum legal size for Bering Sea Tanner crab, *C. bairdi*, is 5.5 inches carapace width. Minimum legal sizes for other Tanner species are: *C. tanneri* 5.0 inches; *C. angulatus* 4.5 inches.

In addition to minimum size and sex restrictions, the State has instituted numerous other regulations for the Eastern Bering Sea crab fisheries. The State requires vessels to register with the state by obtaining licenses and permits, and register for each fishery and each area. Observers are required on all vessels processing king and Tanner crab in the BSAI. Season opening dates are set to maximize meat yield and minimize handling of softshell crabs. The season opening date for the Bering Sea Tanner crab fishery is November 1. Pot limits have been established for the Tanner crab fishery based on vessel size; the current pot limits are 250 for vessels > 125 feet, and 200 for vessels < 125 feet. In the Bering Sea, a 3" maximum tunnel height opening for Tanner crab pots is required to inhibit the bycatch of red king crab. Escape rings were adopted by the Board in 1996 to reduce capture and handling mortality of non-target crab; a minimum of four

5.0" rings, or 1/3 of the web on one panel of 7 1/4" stretched mesh, is required on pots used in Tanner crab fisheries. Other gear restrictions include a requirement that crab pots be fitted with a degradable escape mechanism consisting of #30 cotton thread (max. diameter) or a 30-day galvanic timed release mechanism. In years when no GHL is established for the Bristol Bay red king crab stock, the Tanner crab fishery is restricted to the area west of 163° W longitude. There are no recreational fisheries for Bering Sea Tanner crab.

Overfishing for Bering Sea Tanner crabs adopted under Amendment 7 is defined as a fishing mortality rate in excess of F_{MSY} estimated as F = M = 0.3 based on longevity of Tanner crab. Amendment 7 definition of overfishing is more conservative than was previously in place under Amendment 1. Under Amendment 7 a minimum stock size threshold (MSST) was specified for Bering Sea Tanner crabs to equal ½ the estimated MSY stock size. Estimated spawning biomass of Tanner crabs from the 1997 survey was 64.2 million pounds below the MSST of 94.8 million pounds. Hence, the Bering Sea Tanner crab stock was designated overfished when Amendment 7 was approved by the Secretary of Commerce.

Stock Structure: Tanner crab (*C. bairdi*) are managed into 2 separate stocks: eastern Bering Sea and Aleutian Islands. The grooved Tanner crab (*C. tanneri*) fishery is likewise regulated by these management areas.

Aleutian Islands Stock: The Tanner crab stock of the Aleutian Islands is very small, and populations are found in only a few large bays and inlets. As such, the fishery is managed in a precautionary manner. Annual harvests in the Aleutian Islands area were 200,000 to 800,000 pounds through 1985. Thereafter, stocks declined, and landings were reduced. No landings were made in either area in 1995. No fishery has been allowed in the Eastern Aleutians since 1996.

Fisheries for deepwater species of Tanner crab have been developing in recent years. A directed fishery for grooved Tanner crab began in 1993, and about 200,000 pounds were landed in 1995. These crab weighed an average of 1.9 pounds, and sold for $1.50 per pound exvessel. Less than 3 vessels reported landings of *C. angulatus* in 1995 and 1996, and consequently, catches are confidential. There were no landings of *C. angulatus* in 1997 or 1998.

Eastern Bering Sea Stock: The Bering Sea Tanner stock has undergone two large fluctuations. Catches increased from 5 million pounds in 1965 to over 78 million pounds in 1977. After that, the stock declined to the point where no fishery occurred in 1986 and 1987. The fishery reopened in 1988, and landings increased to over 40 million pounds in 1990. Another decline ensued, and the 1995 Tanner crab season produced only 4.2 million pounds. The 1995 fishery was prosecuted by 196 vessels and lasted 15 days. Average weight of crab landed was 2.3 pounds valued at $2.80 per pound

Abundance of legal males (millions of crab ≥5.5" from NMFS trawl survey), pre-season guideline harvest levels (millions of pounds), and total catches (millions of pounds, including deadloss) of Bering Sea Tanner crab (*C. bairdi*), 1980-1998.

Year	Abundance (mil. crabs)	GHL (mil. lbs.)	Catch (mil. lbs.)	Catch (mil crabs)
1980	31.0	28 - 36	36.6	14.7
1981	14.0	28 - 36	29.6	11.8
1982	10.1	12 - 16	11.0	4.8
1983	6.7	5.6	5.3	2.3
1984	5.8	7.1	1.2	0.5
1985	4.4	3.0	3.1	1.3
1986	3.1	0	0	0
1987	5.9	0	0	0
1988	14.3	5.6	2.2	0.9
1989	33.6	13.5	7.0	2.9
1990	45.1	72.3	64.6	27.3
1991	35.1	32.8	31.8	12.9
1992	41.8	39.2	35.1	15.3
1993	20.6	19.8	16.9	7.2
1994	15.4	7.5	— 7.8	3.4
1995	10.0	5.5	4.2	1.9
1996	9.2	6.2	1.8	0.7
1997	3.4	0	0	0
1998	2.2	0	0	0
1999	2.0	0	0	0

Note: abundance through 1988 included Pribilof area Tanner crab.

exvessel. Total value of the 1995 fishery was $11.7 million. In 1994 and 1995, fishing was prohibited east of 163°W to reduce bycatch of red king crab. In 1996, 196 vessels harvested 1.8 million pounds of Tanner crab in the directed fishery (12 days) and incidental to a red king crab fishery (4 days). Average weight was 2.5 pounds valued at $2.50 per pound.

The total population abundance of Bering Sea Tanner crabs has declined steadily since 1989 when the strong cohort of crabs (apparently 1988-1992) recruited to the fishery then began decline due to natural mortality and fishery removals. As this cohort aged, the proportion of oldshell and very oldshell crabs increased and that of newshell crabs decreased. Old shell crab are thought to stop molting again in their life span which further contributes to lack of new recruits to the legal portion of the population. The abundance index of large male, pre-recruit male and large female crabs decreased over 60% from 1996 to 1997. This is the second lowest estimate of large male crabs and the lowest estimate of large female crabs in the history of the fishery. Low abundance of recruit size crabs suggests that the population will remain low in the near term, but the good news is that recent surveys have indicated an average year class may recruit in the next few years.

In 1996, the GHL for Bering Sea Tanner crabs was set at 6.2 million pounds based on a 40% exploitation of legal male crabs. A total of 1.8 million pounds of Tanner crab were harvested before the fishery was closed due to low catch per pot. This poor fishery performance coupled to depressed stock abundance was instrumental in the management decision to forego the 1997 fishery that had an estimated guideline harvest level of 3.4 million pounds. Stock conservation concerns particularly for potential overfishing were paramount in this decision. The fishery remained closed in 1998 as survey information indicated continued decline of this stock. The fishery was closed in 1999 as well.

Catch, effort, and economic data from the Bering Sea Tanner crab fishery, 1989-1998. Catch includes deadloss.

Year	Catch	# of vessels	# of days	# of pots	price per lb	total value
1989	7.0	109	110	43,600	2.90	20,300,000
1990	64.6	179	89	46,400	1.50	90,000,000
1991	31.8	255	126	75,400	1.50	47,300,000
1992	35.1	294	137	85,400	1.69	58,800,000
1993	16.9	296	42	53,700	1.90	31,600,000
1994	7.8	183	20	38,600	3.75	28,500,000
1995	4.2	196	15	40,800	2.80	11,700,000
1996	1.8	135	12	30,000	2.50	4,500,000
1997	0			No Commercial Fishery		
1998	0			No Commercial Fishery		
1999	0			No Commercial Fishery		

4.2 Overview of Tanner Crab Bycatch

4.2.1 Crab Fisheries

Bycatch of crab in directed crab fisheries is another source of mortality to be considered in a rebuilding plan. Crab bycatch includes females of target species, sublegal males of target species, and non-target crab. Numbers of Tanner crab taken as bycatch in recent major Bering Sea crab fisheries are listed in the adjacent table. Due to the difference in legal size versus market size for snow crab, a portion of the legal crabs are not retained as harvest, and are thus considered bycatch.

Some crabs taken as bycatch die due to handling mortality. Several laboratory and field studies have been conducted to determine mortality caused by handling juvenile and female crab taken in crab fisheries. There are a variety of effects caused by handling, ranging from sublegal (reduced growth rates, molting probabilities, decreased visual acuity from bright lights, and vigor) to lethal effects. Studies have shown a range of mortality due to handling based on gear type, species, molting stage, number of times handled, table. Due to the difference in legal size versus market size for snow crab, a portion of the legal crabs are not retained as harvest, and are thus considered bycatch.

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Byersdorfer and Watson (1992, 1993) examined red king crab and Tanner crab taken as bycatch during the 1991 and 1992 red king crab test fisheries. Instantaneous handling mortality of red king crab was <1% in 1991, and 11.2% in 1992. Stevens and MacIntosh (1993) found average overall mortality of 5.2% for red king crabs and 11% for Tanner crabs on one commercial crab vessel. Authors recommend these results be viewed with caution, noting that experimental conditions were conservative. Mortality for red king crab held 48 hours was 8% (Stevens and MacIntosh 1993, as cited in Queirolo et al. 1995). A laboratory study that examined the effects of multiple handling indicated that mortality of discarded red king crabs was negligible (2%), although body damage increased with handling (Zhou and Shirley 1995).

Delayed mortality due to handling does not appear to be influenced by method of release. In an experiment done during a test fishery, red king crab thrown off the deck while the vessel was moving versus those gently placed back into the ocean showed no differences in tag return rates (Watson and Pengilly 1994). Handling methods on mortality have been shown to be non-significant in laboratory experiments with red king crab (Zhou and Shirley 1995, 1996) and Tanner crab (MacIntosh et al. 1995). Although handling did not cause mortality, injury rates were directly related to the number of times handled.

Mortality of crabs is also related to time out of water and air temperature. A study of red king crabs and Tanner crabs found that crabs exposed to air exhibited reduced vigor and righting times, feeding rates (Tanner crabs), and growth (red king crabs) (Carls and Clair 1989). For surviving females, there was no impact on survival of eggs or larvae. Cold air resulted in leg loss or immediate mortality for Tanner crabs, whereas red king crabs exhibited delayed mortality that occurred during molting. A relationship was developed to predict mortality as the product of temperature and duration of exposure (measured as degree hours). Median lethal exposure was -8°C for red king crab and -4.3°C for Tanner crab. For example, if crabs were held on deck for 10 minutes and it was -23°C or 10 degrees below zero (Fahrenheit) outside, about 15% of the king crab and 50% of the Tanner crab would die of exposure. Because BSAI crab fisheries occur from November through March, cold exposure could cause significant handling mortality to crabs not immediately returned to the ocean. Zhou and Shirley (1995) observed that average time on deck was generally 2 to 3 minutes, and they concluded that handling mortality was not a significant source of mortality.

Further research has indicated that wind chill may be an important mortality factor. In 1997, a laboratory study examined the effects of cold windchill temperature on mortality, limb loss, and activity (righting response) for sublegal sized male Tanner crabs (Zhou and Kruse, 1998, Shirley 1998). The study found significant inverse relationships between windchill and crab mortality, limb loss, and activity. Crabs were exposed to combinations of temperatures and wind speeds for a duration of 5 minutes, then placed in seawater tanks and held for 7 days. Zhou and Kruse (1998) found that virtually all crabs died when exposed to windspeeds greater than 7.7 m/s (15 nautical miles per hour) and air temperatures less than -10.4°C (13.3°F). Stronger winds, even at warmer temperatures (but still below freezing), can have the same effect. Shirley (1998) estimated that 50% of the crabs would die in windchill temperatures of -11°C (this windchill temperature can result from air temperatures of 21°F and wind speeds of 30 nautical miles per hour). He concluded that "The effects of windchill on sublegal Tanner crabs is dramatic, and undoubtedly results in decreased recruitment to adult stocks. Management steps should be taken to restrict exposure of discarded crabs to debilitating windchill by regulating aerial exposure (sorting within water tables) or by regulating fishing effort during periods of extreme windchill".

On the other hand, there is evidence from the fishery itself that wind chill during the snow crab fishery may not be as important a mortality factor as would be expected from the laboratory study (Shirley 1998) and prevailing weather conditions. The primary evidence in this regard is the low rate of deadloss that occurs during the snowcrab fishery. The snow crabs that are delivered to processors are subjected to the same wind chill exposures before being sorted on deck and deposited into the holding tank as are non-legal snow crabs and Tanner crabs before they are sorted and discarded. Data collected by onboard observers during the 1999 snow crab fishery indicate that bycatch crabs generally are not exposed to the air any longer than the retained catch (D. Tracy, ADF&G, pers. comm). The effects of windchill on snow crabs have not been directly studied. It would, however, be expected for retained legal snow crabs (males, generally > 101 mm CW) to show similar effects due to windchill as bycatch Tanner crabs due to the morphological similarity of snow and Tanner crabs and because bycatch Tanner crabs also tend to be males > 101 mm CW (D. Tracy, ADF&G, pers. comm). Because snow crabs are typically kept in holding tanks for one to three weeks prior to offloading at processors (R. Morrison, ADF&G, pers. comm.), high rates of deadloss would be expected in the deliveries if on-deck wind chill exposure resulted in mortality rates comparable to those experienced by Tanner crabs in the laboratory study. Commercial catch statistics from the 1990 through 1998 snow crab seasons (Morrison 1999), however, indicate that the annual deadloss averaged only 1.3% of the total delivered snow crabs and ranged from 0.7% to 2.0%. Such low rates of deadloss, despite the low temperatures and high winds that can occur in the Bering Sea during the snow crab fishery, may be reflective of features of fishing vessels and fishing practices that serve to protect captured and sorted crabs from windchill exposure. Shelter decks, storm walls, use of totes, and leeward alignment of vessels during gear retrieval, for example, would all tend to protect crabs from windchill exposure during sorting. Additionally, observer data collected during the 1998 and 1999 snow crab seasons indicate that sorted bycatch typically is returned to the sea in less time than the 5 minutes that crabs were exposed to windchill during the laboratory study (D. Tracy, ADF&G, pers. comm). Data on limb autotomies collected from bycatch Tanner crabs by onboard observers during the 1999 snow crab season also indicate that the effects of windchill in practice is less than that predicted from laboratory studies and prevailing weather. Examination of 1,718 bycatch bairdi prior to discarding during the 1999 season indicates a limb autotomy rate of only 0.3% -- well below the limb autotomy rates seen in the laboratory study for wind chills associated with high mortality rates. In summary, although it has been conclusively shown that windchill can effect high rates of mortality in Tanner crabs, there is also evidence that exposure of captured crabs to such windchill may not be common during actual fishing.

Catching mortality is ascribed to those crabs that enter a pot and are eaten by other pot inhabitants before the pot is retrieved. Catching mortality likely occurs during the molting period, when crabs are more susceptible to cannibalism. Most crab fisheries are set to occur outside of the molting season, and catching mortality in these fisheries may be limited to octopus or large fish entering a pot. Because no evidence of crab is left in the pot, these mortalities remain unassessed.

Mortality is also caused by ghost fishing of lost crab pots and groundfish pots. Ghost fishing is the term used to describe continued fishing by lost or derelict gear. The impact of ghost fishing on crab stocks remains unknown. It has been estimated that 10-20% of crab pots are lost each year (Meyer 1971, Kruse and Kimker

1993). Based on skipper interviews, about 10,000 pots were estimated lost in the 1992 Bristol Bay red king, and Bering Sea Tanner and snow crab fisheries (Tracy 1994). Fewer pots are expected to be lost under pot limit regulations and shorter seasons. Bob Schofield, a major crab pot manufacturer, testified at the January 1996 Council meeting that he was making fewer pots since inception of the pot limit. He estimated that 6,461 pots were replaced in 1995. It is not known how long lost pots may persist and continue to fish, or just litter the bottom.

A sonar survey of inner Chiniak Bay (Kodiak, Alaska) found a high density of lost crab pots (190 pots) in an area of about 4.5 km^2 (Vining et al 1997). Underwater observations indicated that crabs and fish were common residents of crab pots, whether or not the pot mesh was intact. Intact pots recovered from the Chiniak Bay study area often contained crabs (primarily Tanner crabs) and octopus. High (1985) and High and Worlund (1979) observed that 20% of legal sized male red king crab and 8% of the sublegals captured by lost pots failed to escape.

Crabs captured in lost pots may die of starvation or by predation. Captured crab are subject to cannibalism (Paul et al. 1993), and predation by octopus, halibut and Pacific cod (High 1976). Crabs also have limited abilities to withstand starvation. In a simulated field study, 39% mortality of Tanner crabs was observed after 119 days of starvation (Kimker 1992). In a laboratory study, 10% of the Tanner crabs tested died of starvation in 90 days. Of the 90% that had survived 90 days, all later died even though they were freely fed (Paul et al. 1993). To reduce starvation mortality in lost pots, crab pots have been required be fitted with degradable escape mechanisms. Regulations required #120 cotton thread from 1977-1993. Beginning in 1993, regulations required #30 cotton thread or 30-day galvanic timed release mechanisms. A #30 cotton thread section is also required in groundfish pots. The average time for #30 cotton twine to degrade is 89 days, and the galvanic timed release about 30 days to degrade. Pots fitted with an escape mechanism of #72 cotton twine had a fishable life of 3-8 years and documented retention of up to 100 crabs per lost pot (Meyer 1971). High and Wolund (1979) estimated an effective fishing life of 15 years for king crab pots. Pots without escape mechanisms could continue to catch and kill crabs for many years, however testimony from crabbers and pot manufacturers indicate that all pots currently fished in Bering Sea crab fisheries contain escape mechanisms.

Mortality of crab caused by ghost fishing is difficult to estimate with precision given existing information. Mortality caused by continuous fishing of lost pots has not been estimated, but unbaited crab pots continue to catch crabs (Breen 1987, Meyer 1971), and pots are subject to rebaiting due to capture of Pacific cod, halibut, sablefish, and flatfish. In addition to mortality of trapped crab by ghost pots, and predation by octopus and fish, pot mesh itself can kill crabs. Lost pots retrieved by NMFS trawl surveys occasionally contain dead crabs trapped in loose webbing (Brad Stevens, NMFS, pers. comm). Pot limits and escape mechanisms may have greatly minimized ghost fishing due to pot loss in recent years.

Another very minor source of human induced crab mortality is direct gear impacts. Direct gear impacts result from a pot landing on the ocean floor when it is being set, presumably damaging any crab on which it lands. With reasonable assumptions, direct gear impacts is only a very minor source of mortality, however. An estimate of this impact can be derived by multiplying the number of pot lifts, the area they occupy, and relative crab density within areas fished in the Bering Sea. Assuming that pots land on different areas after each lift, and crab pots are set non-randomly over areas with relatively high density of crabs in directed fisheries, the total number of crab impacted can be roughly estimated. For 1993 the red king crab fishery, assuming a density of 5,000 red king crab of all sizes per square mile (density data from Stevens et al. 1994), a maximum of about two thousand red king crab were impacted (NPFMC 1996). Similarly, a maximum of 9,000 Tanner crabs (assuming 10,000 crab/$mile^2$) and 110 thousand snow crabs (assuming 75,000 crab/$mile^2$) were impacted by direct gear impacts in respective crab fisheries in 1993. It is not known what proportion of these crab die when a crab pot lands on them.

Tanner crab bycatch in the 1998 Bering Sea CDQ Crab Fisheries

1998 was the inaugural year of the Bering Sea king and Tanner crab Community Development Quota (CDQ) Program fisheries. Four CDQ fisheries (Bering Sea snow crab, Pribilof red and blue king crab, St. Matthew blue king crab, and Bristol Bay red king crab) were prosecuted during 1998 (Gish 1999). Each 1998 CDQ crab fishery was prosecuted after closure of the corresponding open-access fishery. Mandatory shellfish observers were stationed on each vessel participating in the 1998 CDQ fisheries and collected data on bycatch of Tanner crabs. Observer data indicates that bycatch of Tanner crabs during the CDQ Bering Sea king crab fisheries was non-existent to negligible, whereas an estimated 113,000 Tanner crab were captured and returned to the sea during the CDQ Bering Sea snow crab fishery (see adjacent Table).

Estimates of Bering Sea Tanner crab (*C. bairdi*) in the 1998 Bering Sea CDQ fisheries. ADF&G Observer Program data. Note that there was no CDQ fishery for Bering Sea Tanner crab in 1998.

Fishery	Legal	Sublegal	Females	Total
C. opilio	0	94,000	19,000	113,000
St. Matthew blue	0	0	0	0
Pribilof king crab	37	294	0	331
BB red king	0	1,224	52	1,276
Total	**37**	**96,000**	**19,000**	**115,000**

Estimated catch per pot lift (CPUE) of Tanner crabs during the 1998 CDQ snow crab fishery was slightly lower than that estimated from observers on C/Ps during the 1998 open-access snow crab fishery (2.6 Tanner crab per pot in the CDQ fishery versus 4.6 for the C/Ps during the 1998 open-access fishery; L. Byrne, ADF&G, *pers. comm.*). Soak time of pots sampled during the CDQ fishery tended to be greater than those sampled during the open-access fishery; the median soak time for pots sampled during the CDQ fishery was 50 hours whereas the median for sampled pots during the open-access fishery was 36 hours. The longer soak time in the CDQ fishery does not alone adequately explain the lower Tanner crab CPUE in the CDQ fishery, however, because the CPUE of female and sublegal snow crab was actually higher in the CDQ fishery than in the open-access fishery. Although other factors may be responsible, the differences in Tanner crab bycatch may reflect differences in the areas fished. Random pot sample data indicates that the CDQ fishery tended to concentrate effort to the northeast of the open-access effort (Moore et al. *in prep*). The area southeast of the Pribilof Islands that showed relatively high CPUE of Tanner crabs during the 1998 open-access fishery (Figures 61, 62, 63) received little effort during the subsequent CDQ season (Moore et al *in prep*).

4.2.2 Trawl Fisheries

Crab bycatch is estimated by the National Marine Fisheries Service through the groundfish Observer Program (Queirolo et al. 1995). Observer coverage depends on vessel length; 100% observers on vessels > 125 feet, 30% coverage on vessels 60-125 feet, and 0% coverage on vessels <60 feet. Shoreside processors have 100% coverage. 100% coverage means that an observer is always onboard; it does not mean that every haul or landing is observed.

Bycatch of crabs in Bering Sea groundfish trawl fisheries, 1993-1998 . Reported by NMFS Blend estimates.

Year	bairdi	opilio	red king
1993	3,413,642	14,631,617	248,121
1994	2,496,761	12,351,899	280,096
1995	2,212,181	5,165,555	44,934
1996	1,836,031	3,643,612	30,967
1997	1,917,736	5,276,208	50,711
1998	1,477,816	4,122,648	42,003

Bycatch on Tanner crab in recent trawl fisheries is shown in the adjacent table; more detailed information is found in Tables 2-4. A total of 1.5 million Tanner crab were taken as bycatch in the 1998 BSAI groundfish fisheries. Bycatch of Tanner crab has been reduced in recent years, down significantly from 4.3 million in 1992. Most Tanner crab bycatch is taken in the trawl fisheries (about 98%) and to a lesser extent in the longline (1.5%) and groundfish pot fisheries (0.5%). Although Tanner crabs are bycaught in nearly every trawl fishery, the yellowfin sole fishery takes the largest share, followed by the rock sole/other flatfish fisheries. Bycatch has been highest in NMFS statistical areas 509 and 513; and large numbers of Tanner crab area have also been consistently taken in areas 517 and 521.

Tanner crab bycatch has been significantly reduced in recent years. A combination of factors is likely responsible for this reduction. First, abundance of Tanner crab has declined, so fewer have been available to be incidentally taken. Second, bycatch limits have been reduced, and has limited fisheries in Zone 1 in particular. Third, the trawl industry has implemented a voluntary bycatch avoidance program in the Bering Sea, allowing vessels to avoid fishing in crab hotspot areas (Gauvin et al. 1995).

The effect of crab bycatch on crab stocks is somewhat tempered by survival of discarded crabs. There have been numerous studies conducted on crab bycatch mortality, with each study having different objectives, methodology, and results. A summary of these studies is provided below, but many questions remain unanswered. Stevens (1990) found that 21% of the king crabs and 22% of the Tanner crabs captured incidentally in BSAI trawl fisheries survived at least 2 days following capture. Blackburn and Schmidt (1988) made observations on instantaneous mortality of crab taken by domestic trawl fisheries in the Kodiak area. They found acute mortality for softshell red king crab averaged 21%, hard shelled red king crab 1.2%, and 12.6% for Tanner crab. Another trawl study indicated that trawl induced mortalities aboard ship were 12% for Tanner crab and 19% for red king crab (Owen 1988). Fukuhara and Worlund (1973) observed an overall Tanner crab mortality of 60-70% in the foreign Bering Sea trawl fisheries. They also noted that mortality was higher in the summer (95%) than in the spring (50%). Hayes (1973) found that mortality of Tanner crab captured by trawl gear was due to time out of water, with 50% mortality after 12 hours. Natural Resource Consultants (1988) reported that overall survival of red king crab and Tanner crab bycaught and held in circulation tanks for 24-48 hours was <22%. In other analyses, the estimated mortality rate of trawl bycaught red king crab and Tanner crab was 80% (NPFMC 1993, 1995).

Not all crab in the path of a trawl are captured. Some crab pass under the gear, or pass through the trawl meshes. Non-retained crab may be subject to mortality from contact with trawl doors, bridles, footrope, or trawl mesh, as well as exposure to silt clouds produced by trawl and dredge gear. Only a few studies have been conducted to estimate catchability of crabs by trawl gear, and these studies are summarized below.

In one experiment to mèasure non-observable mortality, 169 red king crab were tethered in the path of an Aleutian combination trawl (Donaldson 1990). The trawl was equipped with a footrope constructed of 14 inch bobbins spaced every 3 feet, separated by 6.5 inch discs. Thirty-six crabs (21.3%) were recovered onboard the vessel in the trawl. Divers recovered 46.2% of the crabs not captured by the trawl. Another 32.5% were not recovered but assumed to have interacted with the trawl. Of the 78 crab not retained in the trawl, but captured by divers, only 2.6% were injured. If all injured crabs die, the non-observable mortality rate for trawl gear on red king crab is estimated at 2.6% (Donaldson 1990). It should be noted that hard shelled crabs were used in this experiment; higher impacts would be expected if softshelled crabs were tested. Additionally, some areas have had higher intensity of bottom trawling than other areas, thus potentially exposing some crab to multiple interactions with trawl gear.

In 1995, NMFS used underwater video cameras to observe the interaction of trawl gear with king and Tanner crabs (Craig Rose, NMFS, unpublished data). The experiment was conducted in Bristol Bay in an area with large red king crabs and Tanner crabs. Three types of trawl footropes were examined and they are as follows: a footrope with 3-4 foot lengths of 6" discs separated by 10" discs (called disc gear), a footrope with 24" rollers (tire gear), and an experimental float/chain footrope with the groundgear suspended about 8" off the seafloor. For disc gear, preliminary analysis indicated that all red king crab encountered entered the trawl and about 76% of the Tanner crab were caught. Tire gear captured fewer king crab (42%) and Tanner crab (1%). The float/chain gear did not catch any of the crabs encountered. At the December 1995 Council meeting, excerpts of the NMFS video were shown to the Council and public. Trawl industry representatives testified that groundgear used to harvest finfish in this area depended on target species and bottom type, with tire gear type footropes used in hard bottom areas, and disc type gear used on smooth bottom areas. Testimony also indicated that there was also variability in groundgear used among vessels, but that on average, most gear used in Bristol Bay trawl fisheries would be comprised of groundgear with discs or rollers larger than the disc gear tested and smaller than the tire gear tested.

The NMFS underwater video observations were further analyzed to determine the proportion of red king crab that were injured by passage under bottom trawl footropes (Rose, 1999 unpublished manuscript). Injury rates of 5% to 10% were estimated for crabs that encountered, but were not captured, in the center section of the trawl.

4.2.3 Other Groundfish Fisheries

Some crabs are caught incidentally by non-trawl gear in pursuit of groundfish, and a portion of these crabs die. No field or laboratory studies have been made to estimate mortality of crab discarded in these fisheries. However, based on condition factor information from the trawl survey, mortality of crab bycatch has been estimated and used in previous analyses (NPFMC 1993). Discard mortality rates for red king crab were estimated at 37% in longline fisheries and 37% in pot fisheries. Estimated bycatch mortality rates for Tanner crab were 45% in longline fisheries and 30% in pot fisheries. No observations had been made for snow crab, but mortality rates are likely similar to Tanner crab. In the analysis made for Amendment 37, a 37% mortality rate was assumed for red king crab taken in longline fisheries and an 8% rate for pot fisheries. Observer data on condition factors collected for crab during the 1991 domestic fisheries suggested lower mortality of red king crab taken in groundfish pot fisheries. Bycatch mortality rates used in the analysis of Amendment 37 (NPFMC 1996) for Tanner crab were 45% in longline fisheries and 30% in pot fisheries, based on previous analyses.

Bycatch of crabs in Bering Sea fixed gear groundfish fisheries, 1993-1998. Reported by NMFS Blend estimates.

Year	bairdi	opilio	red king
1993	9,484	129,104	428
1994	48,221	130,228	928
1995	87,674	230,233	3,257
1996	279,560	267,395	75,676
1997	50,218	554,103	25,613
1998	46,552	549,139	7,012

4.2.4 Scallop Fishery

Bycatch of Tanner crab in the scallop fishery is relatively small, and has been much reduced in recent years. Although the scallop fishing grounds have remained in the same location, the fishery now encounters more opilio than bairdi, which was previously the dominant bycatch species. In 1993, the average size was 100 mm carapace width for Tanner crab with a 50:50 sex ratio. The 1996 scallop fishery also took relatively large female (75-100 mm CW) and male (100-140 mm CW) bairdi (Barnhart and Saglkin 1998).

Bycatch of crabs in Bering Sea weathervane scallop fisheries, 1993-1998 (preliminary). ADF&G Observer Program data. Note that the Bering Sea scallop fishery was closed in 1995.

Year	bairdi	opilio	red king
1993	276,000	15,000	6
1994	245,000	incl. w/bairdi	20
1995	0	0	0
1996	17,000	107,000	0
1997	28,000	187,000	0
1998	36,000	121,000	146

Observations from scallop fisheries across the state suggest that mortality of crab bycatch is low relative to trawl gear due to shorter tow times, shorter exposure times, and lower catch weight and volume. For crab taken as bycatch in the Gulf of Alaska weathervane scallop fishery, Hennick (1973) estimated that about 30% of Tanner crabs and 42% of the red king crabs bycaught in scallop dredges were killed or injured. Hammerstrom and Merrit (1985) estimated mortality of Tanner crab at 8% in Cook Inlet. Kaiser (1986) estimated mortality rates of 19% for Tanner crab and 48% for red king crab bycaught off Kodiak Island. Urban el al. (1994) reported that in 1992, 13-35% of the Tanner crab bycaught were dead or moribund before being discarded, with the highest mortality rate occurring on small (<40 mm cw) and large (>120 mm cw) crabs. Delayed mortality resulting from injury or stress was not estimated. Mortality in the Bering Sea appears to be lower than in the Gulf of Alaska, in part due to different sizes of crab taken. Observations from the 1993 Bering Sea scallop fishery indicated lower bycatch mortality of red king crab (10%), Tanner crab (11%) and snow crab (19%). As with observations from the Gulf of Alaska, mortality appeared to be related to size, with larger and smaller crabs having higher mortality rates on average than mid-sized crabs (D. Pengilly, ADF&G, unpublished data). Immediate mortality of Tanner crabs from the 1996 Bering Sea scallop fishery was 12.6% (Barnhart and Sagalkin 1998). Delayed mortality was not estimated. In the analysis made for Amendment 41, a 40% discard mortality rate (immediate and delayed mortality combined) was assumed for all crab species.

4.2.5 Total Bycatch Mortality Estimates (all fisheries)

Number of crab bycaught

Based on data discussed in previous sections, it is possible to estimate the impacts of bycatch on the Bering Sea bairdi crab stock. In recent years, bycatch has declined from a high of 21.8 million bairdi crab in 1994 to a low of 5.8 million in 1998. Relative to the total number of larger juvenile and adult bairdi in the Bering Sea (population estimate from survey data), bycatch accounted for 11% of the larger crab population in 1994, but this had been reduced to about 4% by 1997.

Bycatch of *C. bairdi* crabs (numbers of crab) in Bering Sea fisheries, 1994-1998.

Year	directed crab pot	groundfish trawl	groundfish fixed gear	scallop dredge	Total
1994	19,003,200	2,496,761	48,221	245,000	21,793,182
1995	15,897,300	2,212,181	87,674	0	18,197,155
1996	4,588,000	1,836,031	279,560	17,000	6,930,591
1997	4,865,900	1,917,736	50,218	28,000	6,861,854
1998	4,293,800	1,477,816	46,552	36,000	5,854,168

Mortality of crab bycaught

These bycatch estimates can be converted into mortality estimates by applying bycatch mortality rates estimated from scientific observations, as summarized in previous sections. Discard mortality rates for bairdi used in previous analysis (NPFMC 1995) were: crab pot - 8%, trawl - 80%, longline- 45%, groundfish pot - 30%, scallop dredge - 40%. Because about 2/3 of crab bycatch from fixed gear fisheries is taken by pot gear, an estimate of 35% was applied to bairdi bycatch in fixed gear fisheries. The mortality rate of Tanner crabs bycaught in the snow and Tanner crab fisheries was increased to 25% and 20%, respectively, to provide reasonable assurance that the bycatch mortality in the two fisheries that have accounted for most of the Tanner crab bycatch during crab fisheries is not underestimated. These increased bycatch mortality rate estimates reflect the need to consider new information on the potential for mortality due to windchill. The bycatch mortality rate of 20% for the Tanner crab fishery used here is identical to that used by Zheng and Kruse (1999) in modeling alternative harvest strategies for Tanner crab. The 20% bycatch mortality in the bairdi fishery was used in the harvest strategy analysis (Zheng and Kruse 1999), and a slightly higher number was applied to the opilio fishery to account for increased windchill effects. These mortality rates for crab and trawl fisheries may not be the perfect number for all conditions, but represent our best estimates at this time. Applying these rates to bycatch data provides total discard mortality (in number of crabs) estimates that are useful in evaluating potential rebuilding scenarios.

Estimated bycatch mortality of *C. bairdi* crabs (numbers of animals) in Bering Sea fisheries, 1994-1998.

Year	directed crab pot	groundfish trawl	groundfish fixed gear	scallop dredge	Total
1994	4,236,099	1,997,409	16,877	98,000	6,348,385
1995	3,387,584	1,769,745	30,686	0	5,188,015
1996	1,045,556	1,468,825	97,846	6,800	2,619,027
1997	1,157,672	1,534,189	17,576	11,200	2,720,637
1998	1,039,144	1,182,253	14,858	14,400	2,250,655

To examine how sensitive these crab mortality estimates were to the mortality rates used, mortality was also estimated using different mortality rates, as suggested by the Council in June 1999. The adjacent table shows the difference in estimated bycatch mortality of Tanner crabs under different mortality rate scenarios.

Sensitivity analysis of bycatch mortality of *C. bairdi* crabs (numbers of animals) in Bering Sea fisheries, 1994-1998, using different mortality rates.

Table A. Bycatch mortality of C. bairdi crabs (numbers of crab) in Bering Sea fisheries, 1994-1998.
Baseline analysis with mortality rates: 80% trawl, 45% longline, 30% groundfish pot, 40% scallop dredge, 20% Tanner crab pot, 25% opilio crab pot, 8% other crab pot fisheries.

Year	snow crab fishery	tanner crab fishery	other crab fisheries	groundfish trawl	groundfish pot	groundfish longline	scallop dredge	Total
1994	2,302,875	1,916,480	16,744	1,997,409	7,103	11,046	98,000	6,349,656
1995	1,282,000	2,073,400	32,184	1,769,745	18,911	11,086	0	5,187,326
1996	801,000	223,060	21,496	1,468,825	78,605	7,894	6,800	2,607,680
1997	1,130,000	0	27,672	1,534,189	11,633	5,149	11,200	2,719,842
1998	1,023,000	0	16,144	1,182,253	12,183	2,674	14,400	2,250,654

Table B. Bycatch mortality of C. bairdi crabs (numbers of crab) in Bering Sea fisheries, 1994-1998.

Sensitivity analysis with mortality rates: **50% trawl**, 45% longline, **50% groundfish pot**, 40% scallop dredge, **50% Tanner crab pot, 75% opilio crab pot**, 8% other crab pot fisheries.

Year	snow crab fishery	tanner crab fishery	other crab fisheries	groundfish trawl	groundfish pot	groundfish longline	scallop dredge	Total
1994	6,908,625	4,791,200	16,744	1,248,381	11,838	11,046	98,000	13,085,833
1995	3,846,000	5,183,500	32,184	1,106,091	31,519	11,086	0	10,210,380
1996	2,403,000	557,650	21,496	918,016	131,008	7,894	6,800	4,045,864
1997	3,390,000	0	27,672	958,868	19,388	5,149	11,200	4,412,276
1998	3,069,000	0	16,144	738,908	20,305	2,674	14,400	3,861,431

Table C. Bycatch mortality of C. bairdi crabs (numbers of crab) in Bering Sea fisheries, 1994-1998.

Sensitivity analysis with mortality rates: **50% trawl**, 45% longline, **50% groundfish pot**, 40% scallop dredge, **35% Tanner crab pot, 50% opilio crab pot**, 8% other crab pot fisheries.

Year	snow crab fishery	tanner crab fishery	other crab fisheries	groundfish trawl	groundfish pot	groundfish longline	scallop dredge	Total
1994	4,605,750	3,353,840	16,744	1,248,381	11,838	11,046	98,000	9,345,598
1995	2,564,000	3,628,450	32,184	1,106,091	31,519	11,086	0	7,373,330
1996	1,602,000	390,355	21,496	918,016	131,008	7,894	6,800	3,077,569
1997	2,260,000	0	27,672	958,868	19,388	5,149	11,200	3,282,276
1998	2,046,000	0	16,144	738,908	20,305	2,674	14,400	2,838,431

By incorporating the size (age) of crabs taken as bycatch, one can estimate the impacts of bycatch on a future adult population. The is allows for direct comparison of adult equivalents among the various sources of mortality and so provides better estimates of impacts across fisheries. Based on information summarized in Section 4 and in the analysis of Amendment 37 to the BSAI Groundfish FMP, a simple accounting formula was used to estimate mortality in adult equivalents for males and females. Adult equivalents were calculated based on the following equation:

$$Q = (N*n*D)*(A)^t$$

where:

Q = adult equivalents, measured in number of crab of the sex and species examined
N = Number of crab bycaught of that species
n = proportion of bycatch observed to be male (of female depending on application)
D = discard mortality rate; the proportion of crab bycaught that die due to capture and handling (trawl, 0.80; longline, 0.45; groundfish pot, 0.30; scallop dredge 0.40; crab pot 0.08, 0.20, and 0.25 depending on fishery)
A =conditional annual survival rate set at 0.75, based on (e^{-M}) where M=0.30
t = years to recruitment in fishery (males) or spawning stock (females); based on average age of bycatch versus average age of crab in directed fishery (males) or average age to maturity (females).
(N*n*D) = number of crab of killed for the sex and species examined
$(A)^n$ = adjustment factor to account for age

Results of this exercise indicate that the effects of trawling and other human activities on crab mortality depend on species, sex, and year examined. Results are shown separately for 1994-1998 for male and female Bering Sea Tanner crab (**Tables 5-10**). [Note that the impacts calculated for 1998 do not include data from all crab fisheries, which were not available at the time of document preparation. Hence, the analysis underestimates the impact of bycatch in crab fisheries for 1998.] Although the estimates generated by this analysis may not be precise due to numerous assumptions that have been made regarding bycatch mortality, the results should provide some indication of the effects of bycatch on crab populations.

Estimated adult equivalent crab removals by groundfish, scallop, and crab fisheries, 1994-1997.

	1994		1995		1996		1997	
Fishery	male	female	male	female	male	female	male	female
Groundfish	849,564	377,917	757,272	337,452	647,660	291,623	653,089	290,807
Scallop	20,672	36,750	0	0	1,434	2,550	2,363	4,200
Crab	4,995,663	1,313,389	3,001,060	1,389,794	1,169,924	271,106	553,691	173,332
Total	5,865,899	1,728,056	3,758,332	1,727,246	1,819,018	565,279	1,209,143	468,339

This exercise of determining adult equivalents provided insights into the impact of crab bycatch. First, a comparison of adult equivalent mortality across fisheries is instructive for developing a crab rebuilding policy. In most years when a GHL is established, the single largest source of human induced crab mortality is removals of legal males by directed crab fisheries and associated bycatch. Crab fisheries accounted for about a majority of the male Tanner crab mortality. The crab fishery has a somewhat smaller impact on females, but still the largest source of fishing mortality for female Tanner crabs when there is a bairdi crab fishery. Most of the remaining removals are due to the trawl and other groundfish fisheries. In all years examined, the scallop fishery had relatively little impact on crab stocks as measured by observed bycatch. These data indicate that reductions in crab quotas for crab fisheries may have relatively more impact on rebuilding than reductions in crab bycatch in trawl or dredge fisheries.

Estimated adult equivalent mortality of *C. bairdi* crabs (numbers of animals) in Bering Sea fisheries, 1994-1998.

Year	directed crab pot	groundfish trawl+fixed	scallop dredge	Total
1994	6,309,052	1,227,481	57,422	7,593,955
1995	4,390,854	1,094,724	0	5,485,578
1996	1,441,030	939,485	3,984	2,384,297
1997	727,023	943,896	6,563	1,677,482
1998	646,483	728,204	8,438	1,383,125

This analysis also indicates that reducing the PSC limits for groundfish fisheries may not drastically improve or rebuild crab stocks if only this option is chosen. Because bycatch mortality caused by trawl fisheries is small relative to other sources of removals due to natural and fishing mortality, reductions in bycatch limits may not result in measurable improvements to crab stock abundance. However, any reduction in mortality would slow the decline of the Bering Sea Tanner crab stock and improve survival of juvenile crab. Adult equivalent removals of female spawners likely has more impact on the Tanner crab stock when abundance is low than when the stock is at higher levels.

Concern has been raised about the unknown mortality of crabs caused by trawling, and reducing PSC limits may exacerbate these unobservable impacts. In an attempt to catch less crabs (via reduced bycatch limits, VIP regulations, AFA pooling, or proposed measures such as VBAs, etc.), trawl fishermen may modify their gear. Modifications to footrope design, roller size, and mesh size can result in fewer crabs being retained and counted by observers (NRC 1988). For trawl fisheries historically limited by bycatch limits, reduced bycatch rates of PSC species may result in increased effort (at least until limited by TAC of targets). In turn, increased trawl effort could result in increased unobservable impacts on crab resources, simply because more crab are encountered by trawl gear. This possibility was also raised during the Council's 1993 deliberations over trawl codend mesh size, but the benefits of reduced bycatch were felt to outweigh the possible costs of unobserved mortality due to non-retention.

4.3 Temporal and Spatial Aspects of Tanner Crab Bycatch

4.3.1 Groundfish Fisheries

Observer data from year-round or seasonal fisheries were examined to provide additionaLinsight into Tanner crab distribution throughout the year and across years. Bering Sea NMFS observer data provided by the Observer Program from 1994 – 1997 was used in this analysis. The observed bycatch of Tanner crab and snow crab (*C. opilio*) crabs and the total observed groundfish catch by gear-types were summarized by month, gear group (fixed or trawl), and 1/2° latitude by 1° longitude blocks. Bycatch rates of Tanner crab were calculated as total observed Tanner crab divided by total groundfish catch. Maps were prepared for each of the four years by month providing the general distributions of Tanner crab and snow crab bycatch numbers, number of hauls, and bycatch rates of Tanner crab. In addition, groundfish observer data from bottom trawl gear were used to summarize catch rates (catch in kilograms per hour trawled) in 5 km by 5 km grids by year from 1990 to 1997 in the Bering sea. Each observed bottom trawl haul in the Bering Sea was assigned to a 5 km by 5 km grid. The catch of tanner crab by haul was summed for all hauls in a grid and divided by the sum of the hours towed.

It should be noted that observations falling on block borders (e.g. zero in the decimal place) are assigned to blocks according to processes internal in ArcView, and that no specific criteria were adopted to account for these cases. The assignment by cell is not problematic when overall numbers are being displayed, but for calculated cells, such as bycatch rates, there can be more noticeable results. For instance, high bycatch rates appear to have occurred within one cell of the Red King Crab Savings Area, which is closed to all trawling. The data revealed that all of the (7) tows assigned to this cell were recorded at the border.

The total estimated bycatches of Tanner crab by trawl gear and fishery group in the Bering Sea are provided below as acquired from the NMFS web page. These estimates are expanded from observed hauls to the entire fleet. Fixed gear restrictions on Tanner crab bycatch are not in place, and the estimates are not provided by NMFS. Accounting of snow crab was begun in 1998. The percentages in the table below indicate the percent of the cap that was taken by each target group.

The pollock fishery takes the dominant tonnage of groundfish in the Bering Sea, but bycatch of crab is not as great as in the flatfish fisheries (and bottom trawling for pollock has been banned for 1999 and future years). In 1994, 8.2% of the total Tanner crab bycatch in Zone 1 was taken by the pollock group (from the table above). Approximately 81.2% of the Tanner crab were bycaught in the rocksole/other flatfish and yellowfin sole groups in Zone 1, and 72.0% were taken by these groups in Zone 2. In 1995, the pollock group took 11.8% of the Zone 1 bycatch of Tanner crab, and the rocksole/other flatfish and yellowfin sole groups took approximately 66.5% of the Zone 1 Tanner crab bycatch and 92.8% of the Zone 2 bycatch. Similarly in 1996, the pollock group bycaught 9.4% of the Zone 1 Tanner crab bycatch, and the rocksole/other flatfish and yellowfin sole groups took approximately 75.3% of the Zone 1 Tanner crab bycatch and approx. 94.6% of the Zone 2 bycatch. In 1997, the pollock group bycatch of Tanner crab dropped to 1.3% of the Zone 1 bycatch and the rocksole/other flatfish and yellowfin sole groups took approximately 75.6% of the Zone 1 bycatch and 90% of the Zone 2 bycatch. The bycatch of Tanner crab caused the following annual or period closures:

1994: Zone 2 on May 7-December 31 to RSOL/OFLAT; Zone 1 on May 16-December 31 to YSOL.
1995: Zone 1 on March 20-December 31 to PCOD; Zone 1 on April 4-December 31 to YSOL.
1996: Zone 1 on March 20-April 1 to YSOL.
1997: Zone 1 on March 4-December 31 to RSOL/FSOL/OFLAT.
1998: no closures

As discussed above, the table contains total bycatch estimates expanded from observed hauls to represent bycatch by the entire fleet. Data from observed (unexpanded) hauls was examined to look for trends in bycatch by year, month, and gear type. The monthly bycatch of Tanner crab from observed hauls is provided in **Figure 7** with observed bycatch being highest during the periods February – April and August – September. The sustained bycatch levels into April are in contrast to the decline in total observed groundfish catch which is apparent between February and April (**Figure 8**). The primary catch in February and March is pollock and pollock is the dominant Bering Sea catch. As noted above the bycatch of Tanner crab in the pollock fisheries constitutes 10% or less of the total observed Tanner crab bycatch, so the total catch in **Figure 8** may not reflect the portion of the effort that results in the high Tanner crab bycatch. Observed snow crab bycatch is highest during the months of August through November (**Figure 9**). The probable cause for this could be movement of effort to the north and west to an area of higher snow crab concentrations (e.g. Zone 2) as the season progresses.

Figure 10 is provided as a reference to the series of maps that follow. Federal statistical areas, the Red King Crab Savings Area (shaded) and the 1/2° latitude by 1° longitude grid are indicated with latitude and longitude markers. Due to the small size of the individual maps that follow, the latitude and longitude coordinates were not added. Note that the scales in all of the figures with maps are particular to each figure and consistent among maps within a figure. The scales were chosen so that there is an equal interval between classes, with the upper class often stretched to include a more extreme value. The scale in each figure is based on the map with the largest values.

The annual observed bycatch of Tanner crab by trawl gear during the years 1994 – 1997 are provided in **Figure 11**. The scale and associated patterns are indicated in the upper center of the figure, and in this case, increments of 50,000 crabs from 0 to 200,000 crabs and a category for 200,000 to 500,000 crabs are shown. It is apparent from the figure that the majority of Tanner crab are bycaught within the two blocks between 165° and 166° longitude and 56.5° and 57.5° latitude. However, blocks coded in the higher ranges of bycatch occur in the general area between the two blocks with highest bycatch and the Alaska Peninsula near Unimak Island. The higher bycatch rates do not generally occur in the same pattern as high bycatch (**Figure 12**). The two blocks with the high bycatch numbers (**Figure 11**) occasionally fall into the 5-10 crab per ton range, but are generally in the 1-5 crab per ton range.

Tanner crab catch rates (kg per hour) for 5km by 5km blocks are displayed using four shades of gray (**Figures 17 to 24**). The grids with zero catch per hour are shown as the lightest gray in the figures. The grids with greater than zero catch per hour were divided into three groups of equal number. The darkest gray in the figures represents the grids in the upper third of the distribution of average catch per hour. The absolute catch per hour cutoff will differ in each year depending on the distribution of catch rates in that year.

The areas where bottom trawling occurred has changed over time. Effort was more dispersed in the early 1990's with fishing occurring farther west and north than in the late 1990's. In 1997 most of the fishing occurred between about 55 N and 163 W to 58 N and 167 W except for the area between about 58 N and 163 W and 60N and 165 W where the tanner crab catch rate was zero with very few grids of low catch rate. The area north of Unimak Island shows up each year as a high catch rate area. However, when fishing effort occurred from near Unimak Island more or less continuously to the north and west, high catch rates occurred throughout the area of fishing. The distribution of high catch rates show in general the same distribution as bycatch rates.

In the fixed-gear fisheries, the higher bycatch blocks for Tanner crab are either in the vicinity of the Alaska Peninsula, or are to the east of the Pribilof Islands, however, there does not appear to be a consistent spatial pattern in bycatch locations (**Figure 13**). Bycatch rates for fixed gear (**Figure 14**) are even more dispersed than the patterns seen for bycatch numbers. The bycatch of snow crab is much more broadly distributed than was Tanner crab bycatch in both the trawl and fixed gear fisheries (**Figures 15 and 16**). In the trawl fisheries, the two blocks with high Tanner crab bycatch (between 165° and 166° longitude and 56.5° and 57.5° latitude) were also generally the highest blocks for snow crab.

Trawl effort data was considered by examining the observed number of hauls made ~~by~~ trawl vessels by month (maps not included in this analysis). The highest number of hauls in any given cell was 2,000 hauls. Trawling generally occurs in the southeast Bering Sea, north of the Alaska Peninsula during January and February, especially in the vicinity of Unimak Island. Effort also extends along the 200 meter contour (the border of Area 521) in March and April, and the centers of effort have moved more northerly to 56.5° or 57° latitude. In May and June the overall number of hauls is much reduced, and trawl effort, especially in 1996 and 1997, is concentrated to the south of Nelson and Nunivak Islands and between 165° and 166° longitude and 56.5° and 57.5° latitude. In July the relatively small amount of effort is to the east of the Pribilof Islands.

August, September and October generally see an increase in the number of hauls in a much more widely distributed pattern. Centers of trawl concentration are in the vicinity of between 165° and 166° longitude and 56.5° and 57.5° latitude.

Observed bycatch rates of Tanner crab (number of crab divided by total observed catch) by month in the trawl fisheries were also examined (maps not included in this analysis). Bycatch rates were very dispersed, and it was difficult to identify any specific spatial patterns, either across years within a month or across months. However, it was also evident that in the somewhat larger area encompassed by 165° and 166° longitude and 56° and 57.5° latitude, some of the higher bycatch rates were found in at least some of the cells within this area between May and October in 1996 and 1997. That is, areas of high catch and bycatch were in the same vicinity as blocks with high bycatch rates.

TRAWL BAIRDI TANNER CRAB

	Zone 1			Zone 2		
1994 Fishery Group	Crabs (#'s)	Cap (#'s)	%	Crabs (#'s)	Cap (#'s)	%
Pacific cod	79,398	175,000	45%	168,262	200,000	84%
Rocksole/ Other	362,107	475,000	76%	353,268	260,000	136%
Yellowfin sole	245,977	175,000	141%	878,372	1,275,000	69%
PLCK/AMCK/OTHER	61,366	175,000	35%	309,657	1,250,000	25%
Rockfish	0	0	0%	105	10,000	1%
GTRB/ARTH/SABL	0	0	0%	60	5,000	1%
Total	**748,848**	**1,000,000**	**75%**	**1,709,724**	**3,000,000**	**57%**
1995						
Pacific cod	195,849	225,000	87%	44,485	260,000	17%
Rocksole/ Other	338,347	475,000	71%	80,122	510,000	16%
Yellowfin sole	260,019	225,000	116%	1,116,051	1,525,000	73%
PLCK/AMCK/OTHER	105,821	75,000	141%	48,171	690,000	7%
Rockfish	0	0	0%	0	10,000	0%
GTRB/ARTH/SABL	0	0	0%	66	5,000	1%
Total	**900,036**	**1,000,000**	**90%**	**1,288,895**	**3,000,000**	**43%**
1996						
Rocksole/ Other	341,178	345,000	99%	128,695	510,000	25%
Pacific cod	128,364	250,000	51%	38,435	260,000	15%
Yellowfin sole	292,023	330,000	88%	788,173	1,530,000	52%
PLCK/AMCK/OTHER	78,824	75,000	105%	11,901	690,000	2%
Rockfish	0	0	0%	430	10,000	4%
GTRB/ARTH/SABL	0	0	0%	1,470	0	0%
Total	**840,389**	**1,000,000**	**84%**	**969,103**	**3,000,000**	**32%**
1997						
Rocksole/ Other	341,768	296,052	115%	131,779	357,000	37%
Pacific cod	189,577	133,224	142%	86,758	195,000	44%
Yellowfin sole	278,973	276,316	101%	830,980	1,071,000	78%
PLCK/AMCK/OTHER	10,854	44,408	24%	12,749	470,000	3%
Rockfish	0	0	0%	352	7,000	5%
GTRB/ARTH/SABL	0	0	0%	0	0	0%
Total	**821,173**	**750,000**	**109%**	**1,062,618**	**2,100,000**	**51%**
1998						
Rocksole/ Other	247,463	273,848	90%	204,540	330,225	62%
Pacific cod	65,285	123,232	53%	38,858	180,375	22%
Yellowfin sole	233,729	255,592	91%	617,034	990,675	62%
Pollock/At Other	17,843	41,077	43%	37,449	434,750	9%
Rockfish	0	0	0%	699	6,475	11%
GTRB/ARTH/SABL	0	0	0%	2,553	0	0%
	------	------	----	------	--------	---
Total	**564,320**	**693,749**	**81%**	**901,134**	**1,942,500**	**46%**

4.3.2 Crab Fisheries

Onboard observers stationed on fishing vessels participating in Bering Sea crab fisheries have collected data on the bycatch of Tanner crab that occurs during those fisheries. Crab fisheries in which bycatch of Tanner crab can occur are: the directed Bering Sea Tanner crab fishery, the Bering Sea snow crab fishery, the Pribilofs blue and red king crab fishery, the Bristol Bay red king crab fishery, and the Bering Sea Korean hair crab fishery. For the 1994-1998 period reviewed here observers in the Tanner and snow crab fisheries and in the Pribilofs king crab fishery have been limited to mandatory observer coverage on all participating catcher-processor vessels (C/Ps). Observers are also mandatory for C/Ps in the Bristol Bay red king crab fishery, but in the 1997 and 1998 seasons ADF&G staff biologists also served as observers on 11 and 10 catcher-only vessels, respectively. Observers are required on all vessels fishing in the Korean hair crab. Due to the low number of CPs that have participated in the Pribilofs king crab fishery, bycatch data from that fishery is either non-existent or confidential.

Bycatch of female and undersized male Tanner crabs has been highest in the directed Tanner crab fishery itself, with bycatch estimates exceeding 9 million animals for the 1994 and 1995 Tanner crab seasons. Estimated bycatch of females and undersized males in the directed Tanner crab fishery dropped dramatically in 1996, in terms of total animals captured, (down to 1.1 million animals), in terms of catch-per-pot, and in terms of catch per retained crab. That drop in bycatch may be due to new escape-mechanism requirements (four 5-inch rings or 7.25-inch stretched mesh escape panels) established in 1996. On the other hand, that drop in bycatch may have been due to the depressed nature of the stock itself. Catch-per-pot of non-retained Tanner crabs during the Tanner crab fishery as estimated from observer data has consistently been higher than that for legal crabs (Boyle et al. 1997). With the closure of the Tanner crab fishery that began in 1997, bycatch during the directed Tanner crab fishery has not been an issue.

Bycatch of legal male, undersized male, and female Tanner crab during the snow crab fishery has been high throughout the 1994-1998 period, with estimates ranging from 3.2 million animals in 1997 to 9.2 million animals in 1995. Sublegal males generally account for two-thirds or more of the Tanner crab bycatch that occurs in the snow crab fishery. Legal males, on the other hand, usually account for less than 10% the Tanner crab bycatch during that fishery. Although the estimated catch of Tanner crabs has been high, the catch rates of Tanner crabs during the snow crab fishery are far lower than occurs in the directed Tanner crab fishery. Observer data indicates that, whereas, catch-per-pot of retained legal snow crab has been well in excess of 100 crabs-per-pot during this period, the catch-per-pot of Tanner crabs has been in the range of 5-10 crabs-per-pot. It is the high number of pot lifts (>800,000 in recent snow crab fisheries) that accounts for the high overall bycatch of Tanner crab.

Figures 35 through 52 plot the catch-per-pot of Tanner crab by size-sex class in the 1994 through 1996 snow crab and Tanner crab seasons. For the 1994 and 1995 data (**Figures 35 through 46**), pot-sample locations from west of the Pribilof Islands mainly represent the snow crab fishery, pot samples from the Pribilofs area represent a mix of the snow and Tanner crab fisheries, and pot-sample locations from Bristol Bay represent the Tanner crab fishery. For the 1996 season (**Figures 47 through 52**), pot-sample locations from the Pribilof Islands and west still mainly represent the snow crab fishery, but the samples from northeast of Unimak Island are from a mix of snow crab and Tanner crab effort. **Figures 53 through 63** show the catch-per-pot of Tanner crab by size-sex class in the 1997 and 1998 snow crab fisheries (the Tanner crab fishery was closed for the 1997 and 1998 seasons). Generally, sampled effort in the snow crab fishery has been from between the 100-m and 200-m depth contours whereas that for the Tanner crab fishery has been from depths shallower than 100 m. Comparison of the 1994 and 1995 snow crab pot-sample locations with that from the 1997 and 1998 seasons illustrates the eastward shift in effort that occurred in the snow crab fishery following an eastward expansion in concentrations of snow crab.

Over the period examined, there is no area within the distribution of the snow crab fishery effort that clearly and consistently shows "hot spots" of Tanner crab bycatch. Bycatch of Tanner crabs during the snow crab fishery appears to occur at low rates throughout the distribution of effort. With the expansion of effort southeast from the Pribilof Islands that has occurred in the 1997 and 1998 snow crab seasons, there has been a corresponding expansion in the area over which Tanner crab bycatch in the snow crab fishery has occurred.

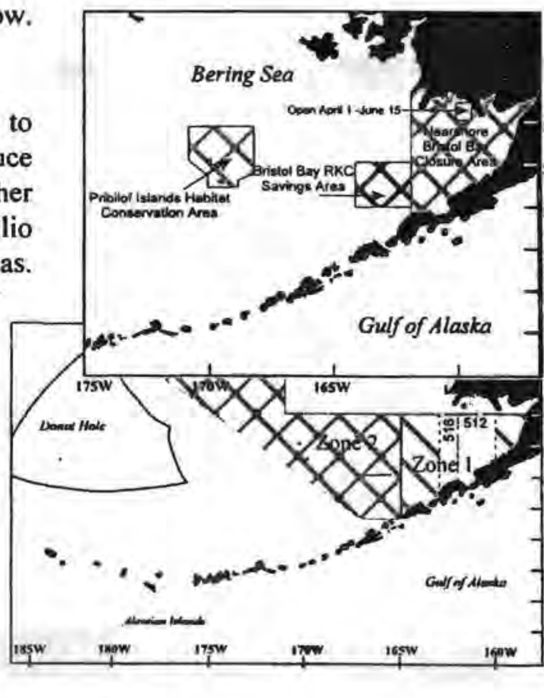
Combined bycatch of Tanner crab in the remaining two fisheries for which observer data exists – the Bering Sea Korean hair crab fishery and the Bristol Bay red king crab fishery -- has totaled less than 500,000 crabs in each of the 1994 through 1998 seasons. Bycatch of Tanner crab during the hair crab fishery is dominated by sublegal males and females and is concentrated in the vicinity of Pribilof Islands – the area in which the effort in that fishery is concentrated. Catch-per-pot of Tanner crabs during the Korean hair crab fishery is very low (<1 crab-per-pot), but number of pot lifts executed during the fishery can be high (> 200,000).

Over the 1994 through 1998, the bycatch of Tanner crabs during the Bristol Bay red king crab fishery has been relatively low due to three factors: closure of the fishery during the 1994 and 1995 seasons; the legal retention of legal-sized male Tanner crabs towards the Tanner crab guideline during the red king crab season; and for the 1996-1998 seasons, low bycatch rates relative to the number of pot lifts performed. Effort in the Bristol Bay red king crab fishery occurs generally at depths between 50-m and 100-m east of 165° W. longitude in Bristol Bay.

No estimates are available for the bycatch within the Pribilof Islands king crab fisheries. What little data that does exist indicates that catch-per-pot of Tanner crabs has been low during 1994-1998 (< 1 crab-per-pot). Effort in the Pribilof king crab fishery has also been low (20,000-40,000 pot lifts pre season).

4.4 Measures to Control Crab Bycatch in Scallop and Groundfish Fisheries

The Council and the Alaska Board of Fisheries (Board) have adopted numerous regulations designed to protect habitat and minimize bycatch and bycatch mortality of crab taken incidentally in Bering Sea groundfish and scallop fisheries (Witherell and Pautzke 1997). An overview of these measures is provided below.



Location of the crab bycatch limitation zones.

<u>Closure Areas</u>

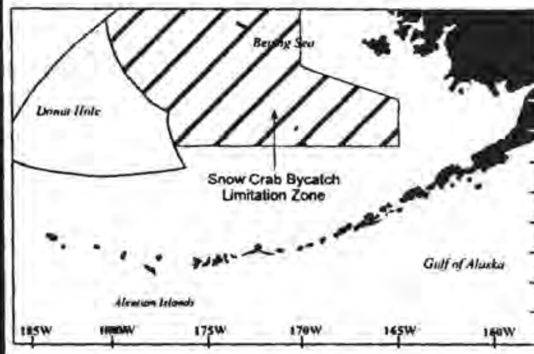
Several areas of the Bering Sea have been closed to groundfish trawling and scallop dredging to reduce potential adverse impacts on the habitat for crab and other resources. Survey data have shown that Tanner crab, opilio crab, and red king crab are all found in these areas. Beginning in 1995, the Pribilof Islands Conservation Area was closed to all trawling and dredging year-round to protect blue king crab habitat (NPFMC 1994). Also beginning in 1995, the Red King Crab Savings Area was established as a year-round bottom trawl and dredge closure area (NPFMC 1995). This area was known to have high densities of adult red king crab, and closure of the area greatly reduced bycatch of this species. To protect juvenile red king crab and critical rearing habitat (stalked ascidians and other living substrate), another year-round closure to all trawling was implemented for the nearshore waters of Bristol Bay. Specifically, the area east of 162° W (i.e., all of Bristol Bay) is closed to trawling and dredging, with the exception of an area bounded by 159° to 160° W and 58° to 58°43' N that remains open to trawling during the period April 1 to June 15 each year. Because NMFS trawl surveys have shown Tanner crab are abundant in these areas, the existing trawl closures provide some degree of habitat protection for the Tanner crab stock.

Bycatch Limits

The Council has adopted numerous limits on the incidental capture of crabs taken in groundfish and scallop fisheries. Prescribed bottom trawl fisheries in specific areas are closed when prohibited species catch (PSC) limits of Tanner crab, snow crab *(C. opilio)*, and red king crab are taken. Bycatch limitation zones for Tanner and red king crab PSC are shown in the figure below. Crab PSC limits for groundfish trawl fisheries are based on crab abundance as shown in the adjacent table. Note that in 1998, the Council adopted a provision to reduce Tanner crab bycatch by an additional 50,000 crab and red king crab bycatch by 3,000 crab as part of the regulation prohibiting the use of bottom trawl gear for pollock fisheries.

PSC limits for red king crab and C. bairdi Tanner crab.

Species	Zone	Crab Abundance	PSC Limit
Red King Crab	Zone 1	Below threshold or 14.5 million lbs of effective spawning biomass (EBS)	35,000
		Above threshold, but below 55 million lbs of EBS	100,000
		Above 55 million lbs of EBS	200,000
Tanner Crab	Zone 1	0-150 million crabs	0.5% of abundance
		150-270 million crabs	750,000
		270-400 million crabs	850,000
		over 400 million crabs	1,000,000
Tanner Crab	Zone 2	0-175 million crabs	1.2% of abundance
		175-290 million crabs	2,100,000
		290-400 million crabs	2,550,000
		over 400 million crabs	3,000,000



Location of the C. opilio bycatch limitation zone (COBLZ).

Under Amendment 40 of the BSAI Groundfish FMP, PSC limits for snow crab (*C. opilio*) taken in groundfish fisheries are based on total abundance of *C. opilio* crab as indicated by the NMFS standard trawl survey (NPFMC 1996). The snow crab PSC cap is set at 0.1133% of the Bering Sea snow crab abundance index, with a minimum PSC of 4.5 million snow crab and a maximum of 13 million snow crab. Snow crab taken within the "C. Opilio Bycatch Limitation Zone" (COBLZ) accrue towards the PSC limits established for individual trawl fisheries. Upon attainment of a snow crab PSC limit apportioned to a particular trawl target fishery, that fishery are prohibited from fishing within the snow crab zone. Note that in 1998, the Council adopted a provision to reduce snow crab bycatch by an additional 150,000 crab as part of the regulation prohibiting the use of bottom trawl gear for pollock fisheries.

Crab bycatch limits have also been established by ADF&G for the Alaska scallop fisheries. Annual crab bycatch limits (CBLs) are specified for red king crab and Tanner crab species in each registration area or district thereof. CBLs are based on the biological condition of each crab species, historical bycatch rates in the scallop fishery, and other socioeconomic considerations that are consistent with the goals and objectives of the FMP.

Weathervane scallop registration areas, seasons, GHL's (pounds, shucked), and crab bycatch limits established for the 1999 scallop fishery, by area. Note: snow crab includes hybrids.

			Crab Bycatch Limits		
Area	GHL (pounds)	Fishing Season	king crab	Tanner crab	Snow crab
D - District 16	0 - 35,000	July 1 - Feb 15	n/a	n/a	n/a
D - Yakutat	0 - 250,000	July 1 - Feb 15	n/a	n/a	n/a
E - PWS	0 - 20,000	July 1 - Feb 15	n/a	500	n/a
H - Cook Inlet (Kamishak)	0 - 20,000	Aug 15 - Oct 31	60	24,992	n/a
Cook Inlet (Outer area)	combined	Jan 1 - Dec 31	98	2,170	n/a
K - Kodiak (Shelikof)	0 - 180,000	July 1 - Feb 15	250	42,500	n/a
Kodiak (Northeast)	0 - 75,000	July 1 - Feb 15	150	66,500	n/a
M - AK Peninsula	0 - 200,000	July 1 - Feb 15	300	75,500	n/a
O - Dutch Harbor	0 - 110,000	July 1 - Feb 15	10	10,700	n/a
Q - Bering Sea	0 - 400,000	July 1 - Feb 15	500	65,000	300,000
R - Adak	0 - 75,000	July 1 - Feb 15	50	10,000	n/a

4.5 Measures to Control Bycatch in the Crab Fisheries

The directed Tanner crab fishery has accounted for most of the bycatch of Tanner crabs that has occurred in the commercial crab fisheries (see 4.2.1). Regulations adopted by the Board have addressed this source of bycatch. Coincident with the adoption of these measures, the estimated adult equivalent mortality of Tanner crab due to bycatch during crab fisheries has dropped by an order of magnitude over the five year period examined here (from 6.3 million in 1994 to 0.6 million in 1998) while that for the groundfish fisheries has shown a less dramatic decline (from 1.2 million in 1994 to 0.7 million in 1998; see 1.5.2.5).

The Tanner crab harvest strategy that was adopted by the Board addresses the effects of bycatch of females and undersized males in the commercial Tanner crab fishery by implicitly accounting for and correcting for effects of handling mortality to bycatch females and undersized males. The simulations that were used to determine the threshold and harvest rate parameters of the harvest strategy assumed bycatch of females and undersized males comparable to the early 1990's Tanner crab fisheries and handling mortality rates of 20% (Appendix 2). Thus, any effects on the health of the population due to handling mortality of discarded Tanner crabs during the commercial Tanner crab fishery are corrected for by the harvest rates employed at a given stock size. Most notably, at low stock levels (<21 million pounds of mature-sized females), the commercial Tanner crab fishery is closed. So, at low stock levels there is absolutely no mortality to female, undersized males, or legal-sized males Tanner crabs due to the commercial Tanner crab fishery.

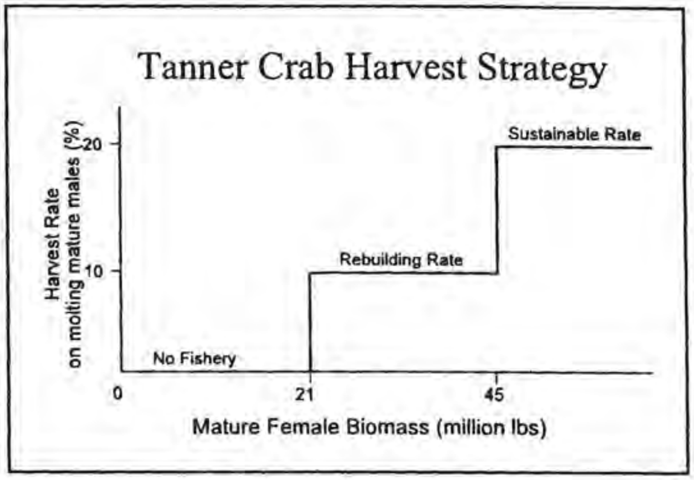
When the Tanner crab fishery is opened, the 1996 regulations requiring escape rings or mesh in pots used to commercially fish for Tanner crabs also serve to reduce the bycatch due to crab fisheries relative to that seen in the early 1990's. Although only one fishery season (1996) has been prosecuted with the current escape-mechanism regulations, a dramatic drop in estimates for bycatch of female and undersized male Tanner crabs was observed during that fishery (from over 9 million animals in the 1994 and 1995 seasons to 1 million in the 1996 season; see 4.3.2).

5.0 Evaluation of Alternatives and Options

5.1 Harvest Strategy

At their March 1999 meeting the Alaska Board of Fisheries (Board) approved a new harvest strategy for Tanner crabs in the Eastern Subdistrict of the eastern Bering Sea. The elements of this plan are based on analyses and recommendations by ADF&G as summarized in Zheng and Kruse (1999) in **Appendix 2**. The technical details of the approach are articulated in four scientific papers that describe a length-based analysis (Zheng et al. 1998), analysis of a terminal molt hypothesis (Zheng and Kruse MSb), stock-recruit analysis (Zheng and Kruse MSa), and analysis of alternative harvest strategies (Zheng and Kruse MSc).

The new harvest strategy specifies a threshold of 21.0 million pounds of mature female biomass which, for management purposes, are taken to be females ≥ 80 mm CW. No directed crab fishery is prosecuted when female biomass is below threshold. When the stock is above threshold, a 10%/20% stair-step harvest rate is applied to "molting mature males" depending on mature female biomass. Molting mature males represent those mature males that are likely to continue to grow and are defined as 100% of newshell and 15% of oldshell males > 112 mm CW. When the biomass of females ≥ 80 mm CW is ≥ 21.0 million pounds and < 45.0 million pounds, then a 10% harvest rate is applied to molting mature males. When the biomass of females ≥ 80 mm CW is ≥ 45.0 million pounds, then a 20% harvest rate is applied. Separate GHLs are calculated for the areas east of 168° W (Bristol Bay) and west of 168° W (Pribilof Islands). If the GHL in either area is too low to manage effectively, the fishery can be closed for that area. This measure is to prevent localized depletion.



Several circumstances lead to modification of this stair-step harvest strategy. First, largely to avoid high harvest rates on legal males (≥ 138 mm CW) when the stock is rebuilding, a cap is established so that no more than 50% of "exploitable legal males" may be taken in any one year. Exploitable legal males are those legal males that are targeted by the fleet and are defined as 100% of newshell and 32% of oldshell legal males. Second, as a precautionary approach, the prescribed guideline harvest level (GHL) is reduced 50% in the first year after a rebuilding stock exceeds the threshold. Finally, no fishery will be prosecuted in years when the GHL < 4.0 million pounds, because such small harvests are unmanageable under current harvesting capacity.

Relative to the status quo, the new harvest strategy is much more conservative, particularly at low stock sizes, and would be expected to help maintain long term stock productivity, as well as increase the probability of stock rebuilding.

5.2 Bycatch Controls

Mortality associated with crab bycatch in the groundfish and directed crab fisheries may adversely effect the recovery of the Tanner crab stock. For the rebuilding plan, this EA analyses the effectiveness of existing measures that limit crab bycatch and whether or not new measures to reduce bycatch are required to rebuild the Tanner crab stock. Based on 1994-97 data from Section 4.0, an estimated 2.2 million to 6.3 million Tanner crabs were killed incidentally in Bering Sea crab and groundfish fisheries. This equates to about 1.4% to 3.3% of the total abundance of Tanner crab as measured by the NMFS trawl surveys.

Groundfish Fisheries

Bycatch mortality due to groundfish fisheries has ranged between 1.2 million and 2.0 million Tanner crabs during the 1994-98 period. This equates to 0.77% to 1.0% of the total stock. From a mortality standpoint, this is similar to mortality associated with other groundfish fishery PSC species such as herring (1%), halibut (1.3% trawl and longline combined) and chum salmon (<1%), but is more than red king crab (0.1%) and C. opilio crab (0.1%), yet less than chinook salmon (2%-4%) (Witherell et al., 2000).

The current Tanner crab bycatch limits were negotiated by an industry committee in 1996 and adopted as Groundfish Plan Amendment 41. As part of the industry agreement (**Appendix 1**), PSC limits were to be reviewed in 3 years (in 1999), so a review in this amendment package is timely.

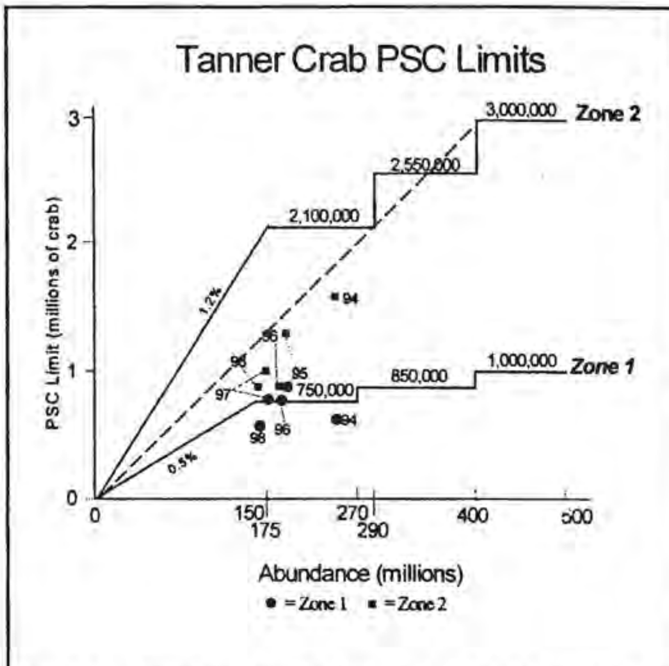


Figure 5.2. Tanner crab bycatch limits in Zone 1 and Zone 2 relative to observed levels, 1994-1998. Data points show abundance when specifications were set and the number of crabs taken in the following year. The option to reduce the PSC limit in Zone 2 to 0.75% of abundance is shown by the dashed line.

Close examination of Tanner crab bycatch limits suggests that the Zone 2 PSC limit could be reduced somewhat as preventative control measure, without unduly impacting trawl fisheries. For example, the total bycatch of Tanner crab in Zone 2 has never come close to the allowable limit. In fact, the only time Zone 2 has been closed in recent years was once in 1994, when the rock sole/other flatfish fishery reached its allocated PSC limit. In hindsight, this was due to a gross mis-allocation of too much PSC to the pollock fishery (see table in Section 4.3.1).

A Zone 2 PSC limit set at 0.75% of abundance may not be constraining if PSC was properly allocated, based on past history. The largest number of Tanner crab ever taken in Zone 2 was 2.7 million in 1992, when the stock was abundant (equated to about 0.35% of the stock). By 1993, the Zone 2 bycatch dropped to 2.3 million crabs, concurrent with declining stock abundance.

PSC limits for Zone 2 bairdi under proposed bycatch limit set at 0.5% of abundance, compared with observed bycatch.

Year	Observed	Proposed	Difference	% Diff
1994	1,709,724	960,000	-749,724	43.9%
1995	1,288,895	945,000	-343,895	26.7%
1996	969,103	878,000	-91,103	9.4%
1997	1,062,618	795,000	-267,618	25.2%
1998	901,134	782,500	-118,634	13.2%
AVERAGE				**23.7%**

A Zone 2 PSC limit set at 0.50% of abundance with a 2 million limit would be expected to constrain groundfish fisheries, even if PSC was properly allocated, based on past history. Had this limit been in place in recent years, fisheries would have been shut down early, as the total observed bycatch has been higher than proposed under this option. As shown in the adjacent table, PSC limits proposed under this 0.5% option would be about 24% lower than was actually estimated to have been taken as bycatch. This method also provides an estimate of groundfish catch reduction that would be expected under this option.

The options to reduce the Zone 2 PSC limit would maintain tighter control on the allowable bycatch of Tanner crabs, particularly when the stock is at low levels. However, because bycatch mortality caused by trawl fisheries is small (≤1% of abundance) relative to other sources of mortality, reductions in bycatch limits may not result in measurable improvements to crab stock abundance. Witherell and Harrington (1996) evaluated alternative measures to reduce the impacts of trawling and dredging on BSAI crab stocks, and concluded that a reduction in bycatch limits would conserve some crab, but would have little overall impact on crab stocks. Further, reducing the PSC limit may have unintended consequences on some sectors of the groundfish fleet due to mis-allocation of PSC. The economic and socioeconomic impacts of reducing the PSC on the groundfish fleet are discussed in section 7.0.

Crab Fisheries

Bycatch mortality associated with directed crab fisheries may have been substantial, particularly if consideration is given to the effects of windchill on discarded crabs. As discussed in Section 4.0, large numbers of female and undersized male Tanner crab have been caught in the crab fisheries, principally in the C. opilio and – especially – the directed Tanner crab fishery itself. For example, the 1994 Tanner crab fishery season resulted in 9.6 million crabs discarded and 3.4 million kept. In other words, for every legal Tanner crab retained during the 1994 Tanner crab season, about 3 female or undersized male Tanner crabs were thrown back. The 1995 Tanner crab fishery season had even higher rates, with 10.4 million crabs discarded and only 1.9 million kept. Bycatch of female and undersized male Tanner crabs dropped dramatically in the 1996 season, however, coincident with escape-mechanism regulations passed by the Board in 1996. The fishery threshold in the Tanner crab harvest strategy, under which the fishery season is closed when stocks are low, has further served to reduce bycatch due to the Tanner crab fishery. As a result, estimated adult-equivalent mortality of Tanner crab due to bycatch in the crab fisheries has dropped steadily over 1994-1998, from 6.3 million in 1994 to 0.6 million in 1998. Bycatch of Tanner crab has also been high in the *C. opilio* fishery, with estimated numbers of Tanner crabs captured and discarded during the *C. opilio* fishery ranging from 3.2 million to 9.2 million during the 1994-1998 fishery seasons. Hence, examination of future means to further reduce bycatch of Tanner crab in the crab fisheries should focus on measures to reduce bycatch mortality in both the directed Tanner crab fishery and other crab fisheries, such as the *C. opilio* fishery.

Several options may be available to reduce bycatch and handling mortality of Tanner crabs caught during crab fisheries. Options may include gear modifications, area closures, change in fishing seasons, and prosecution of concurrent fisheries. Owing to different body sizes and shapes of different crab species, it may be possible to modify pot gear configurations to promote the capture and retention of one crab species over another. Modifications may include *escape rings, mesh size, and tunnel configurations*. ADF&G is researching pot gear modification that will reduce bycatch of females and sublegal males in the Tanner crab and C. opilio crab fisheries. Also, if areas of high Tanner crab bycatch occur in crab fisheries, then it may be possible to design *area closures* that allow attainment of crab GHLs while reducing overall Tanner crab bycatch. *Fishing seasons* may also be adjusted to increase the survival of crabs returned to the sea. Recent laboratory studies show that crabs experience high mortality rates when aerially exposed for 5 minutes to subfreezing temperatures under windy conditions typical of Bering Sea crab fisheries in winter. On the other hand, Tanner crabs molt in spring and meat fill and product quality improves through fall. It should be possible to optimize fishing seasons for low handling mortality while maintaining high product quality.

Concurrent fisheries for more than one crab species reduces crab handling mortality below levels expected if there were separate directed fisheries in which non-target species were discarded. In years when a GHL is established for Tanner crabs, legal males caught during the Bristol Bay red king crab fishery, (which will open in future years on October 15th, based on changes adopted by the Board in March 1999), may be retained toward the Tanner crab guideline harvest level (GHL). If the Tanner crab GHL is not attained before the red king crab fishery closes, then a separate directed fishery for Tanner crabs is prosecuted 10 days after the closure of the red king crab fishery. However, substantial numbers of Tanner crabs are bycaught during the snow crab fishery that opens on January 15th and all these Tanner crabs must be returned to the sea.

At their March 1999 meeting, the Board considered an industry proposal to alter Tanner crab fishing seasons to address this issue. Under the proposal, Tanner crabs could still be retained during the Bristol Bay red king crab fishery. However, rather than prosecuting a separate directed fishery for Tanner crabs, any remaining GHL would be harvested concurrent with the snow crab fishery. Thus, Tanner crab bycatch in the snow crab fishery would be reduced by an amount equivalent to the number of legal Tanner crabs that would have been taken in the directed fishery. This proposal had broad support among industry. To facilitate rebuilding and avoid localized depletion, a new Tanner crab harvest strategy provides for separate GHLs for Tanner crabs in the Bristol Bay and Pribilof Islands areas. However, the Eastern Subdistrict of the snow crab fishery has no eastern boundary, so retainable Tanner crab bycatch could result in disproportionate Tanner crab harvests among the two areas. ADF&G staff, in conjunction with the crab plan team and industry, will work out the details for concurrent Tanner and snow crab fisheries for consideration by the Board. Ongoing analyses may lead to other bycatch reduction proposals that may be brought to the Board as part of a Tanner crab rebuilding plan.

This analysis considered an additional option considered to reduce Tanner crab bycatch by allowing retention of Tanner crabs captured during the Bering Sea snow crab fishery. The current distribution of snow crabs overlaps both the Pribilof and Bristol Bay portions of the Eastern Bering Sea Tanner crab stock. Under the new harvest strategy, each portion of the Tanner crab stock would have it's own separate Guideline Harvest Level (GHL). Attempting to manage both Tanner crab GHLs simultaneously within a larger area open to the harvest of snow crabs would likely result in sub-area closures for both Tanner and snow crabs once the GHL for one Tanner crab fishing area was reached. This has the potential to leave a large portion of the snow crab GHL unharvested. If and when snow crab stock distribution shifts and no longer overlaps both portions of the Eastern Bering Sea Tanner crab stock, then bycatch retention of Tanner crabs, during the snow crab fishery could be considered in the area of overlap. Other problems that would need to be addressed include the differences in escape-mechanism requirements that exist between the C. opilio and Tanner crab fisheries and the choice of the season-opening date (e.g., if there were no C. opilio season due to low abundance in that stock, would the opening of a Tanner crab season still be delayed until January 15th?). Additionally, it should be noted that observer data indicates that the legal male Tanner crabs typically have constituted less than 10% of the Tanner crab bycatch during the 1994-1998 snow crab fishery seasons. Nonetheless, given that the Tanner crab and C. opilio fisheries have been responsible for the majority of the Tanner crab bycatch in crab fisheries, solutions to the problems of merging the post-Bristol Bay Tanner crab season with the C. opilio fishery season should continue to be explored.

5.3 Habitat Protection

Analysis of crab distributions based on survey data, and observer data from groundfish and crab fisheries suggests that Tanner crab are widely distributed over the Bering Sea. Current distribution is more contracted in the area north and west of Unimak Island. Yet the areas of high abundance seem to vary from year to year. Additionally, the NMFS summer trawl survey shows a much different distribution of Tanner crabs than a distribution based on fishery observer data (primarily winter data), suggesting that the crabs move seasonally.

This information suggests that it is not possible at this time to identify a discrete place in the Bering Sea where one could protect Tanner crabs on a long-term basis with any certainty. For example, if an area closure was established in the early 1990's based on hotspot distribution information, the areas protected may not encompass any significant numbers of Tanner crab. The bottom line is that unlike Bristol Bay red king crab, Tanner crab do not appear to have any discrete habitat areas that are required for maintenance of this stock.

Additional analysis may allow for identification of discrete areas important to mating, pre-mating/molting adults and juvenile Tanner crab. It is not known at this time whether or not current survey and observer data information would be adequate for identification of these areas. A significant amount of additional analysis would be required. The Council directed the crab plan team to examine existing habitat information to identify discrete areas important to mating, pre-mating/molting adults, and juvenile C. opilio snow crab. Methodology developed for this spatial analysis may serve as a template for analysis of other crab species in the future. This methodology will also be used to reevaluate the habitat protection measures under the Tanner crab rebuilding plan, including incorporating new habitat information and evaluate existing information.

Some portion of the Tanner crab stock is protected from trawling impacts by existing closure areas. The average distribution over the past three surveys is shown in the adjacent table. Analysis indicates that 18.4% of the total stock is distributed within the trawl closure areas (11.7 % in 1996 to 24.9 % in 1998). Analysis showed that closure areas protect more large males than other group.

Table 5.3 Percentage distribution of eastern Bering Sea Tanner crab within year-round bottom trawl closure areas; average 1996 - 1998 NMFS surveys. Males > 109 mm and females > 84 mm in carapace width are used to represent mature crab.

Zone/area	Males > 109 mm	Male Total	Females > 84 mm	Female Total	Species Total
B.B Nearshore	5.4	1.3	2.2	0.5	0.9
RKC Savings	10.7	7.2	7.8	6.1	6.7
Unclosed area	29.1	25.2	33.0	24.6	25.0
Total Zone 1	*45.2*	*33.7*	*43.0*	*31.2*	*32.6*
Pribilof closure	10.8	11.4	6.3	10.1	10.7
Unclosed Area	41.4	51.9	47.5	57.6	54.5
Total Zone 2	*52.2*	*63.2*	*53.8*	*67.7*	*65.3*
Outside Zone	*2.6*	*3.1*	*3.1*	*1.2*	*2.2*
Total w/in closures	**26.9**	**19.8**	**16.4**	**16.7**	**18.4**

The 1998 NMFS survey data clearly show that the Red King Crab Savings Area is utilized by all size classes of Tanner crab. Therefore, it seems reasonable to rename the area to "The Crab Savings Area", to more accurately reflect its function. In a similar vein, the Nearshore Bristol Bay Trawl Closure Area was adopted to protect vulnerable habitat for juvenile red king crab, so "The Bristol Bay Habitat Conservation Area" may be more appropriate. The Red King Crab Savings Area, the Nearshore Bristol Bay closure area, and the Pribilof Islands Conservation area are all used by Tanner crabs.

At present, there are no indications that human activities in the BS/AI area have had any measurable effect on the existing habitats of Tanner crab. The present primary human use of the offshore area is commercial fishing. While the establishment of other activities could potentially generate user conflicts, pollution, and habitat deterioration, most scientists consider that the status of the habitat in this management area is generally unaffected by other human activities at this time. Activities that could adversely affect habitat in this area, as discussed in the crab FMP include: offshore petroleum production, coastal development and filling, marine mining, ocean discharge and dumping, litter, benthic habitat damage, and discharge of wastes.

Given the current status of Tanner crab, it seems reasonable that the importance of Tanner crab EFH in maintaining stock productivity should be a priority message contained in consultations on any proposed activities. To the extent feasible and practicable, this area should be protected from adverse impacts. The interim final rule for EFH states the following in the case of an overfished stock: *"If a species is overfished, and habitat loss or degradation may be contributing to the species being identified as overfished, all habitats currently used by the species should be considered essential in addition to certain historic habitats that are necessary to support rebuilding the fishery and for which restoration is technologically and economically feasible. Once the fishery is no longer considered overfished, the EFH identification should be reviewed, and the FMP amended, if appropriate."* Therefore, EFH for BSAI Tanner crab should be considered as all habitats used by this stock, at least until such a time as the stock is above MSST.

5.4 Specification of the Rebuilding Time Period

In cases where a stock is overfished, Section 304(e)(4)(A) of the Magnuson-Stevens Act requires that Council action must specify a time period for stock rebuilding. Factors affecting the length of the rebuilding period include stock status and biology, interactions with other components of the ecosystem, and needs of fishing communities. The lower time limit for rebuilding is determined by the status and biology of the stock and its interactions with the marine ecosystem. It is defined as the amount of time that would be required for rebuilding if fishing mortality was eliminated entirely. If the lower limit is less than 10 years, it may be adjusted upward to 10 years if warranted to accommodate the needs of fishing communities. If the lower limit is 10 years or longer, the specified time period may be adjusted upward to accommodate needs of fishing communities within other constraints. The time period for rebuilding must be no longer than the expected rebuilding time in the absence of fishing plus the number of years corresponding to one mean generation time.

The expected rebuilding time in the absence of fishing depends on the prospects for strong year classes that are very difficult to predict. A size-based model (Zheng et al. 1998) and stock-recruitment relationships (Zheng and Kruse 1998) for Tanner crabs in Bristol Bay were combined in a computer simulation model to estimate rebuilding probability. With cyclic nature of recruitment, it is difficult for the Tanner crab stock to remain at or above the biomass level that produces MSY (B_{msy}) "on a continuing basis". Based on the recruitment dynamics of this stock, we called the stock "rebuilt" when the stock reaches B_{msy} in two consecutive years. This "rebuilt" definition reduces chances of rebuilding caused by survey measurement error or a single strong year class. The common features of the simulations for all scenarios and options are as follows:

- The model was initialized with data on population status for 1998.
- Measurement errors were assumed as lognormally distributed with a standard deviation of 0.2 and mean of zero. To prevent extremely large errors in abundance estimation, both ends of the measurement-error distribution were truncated to fall within its 95% confidence limits. The measurement errors were applied to the 1998 initial abundance and the biomasses and abundances used to set catch quota.
- For each option, we simulated the population and fishery for 35 years with 2000 replicates. The rebuilding probabilities (the proportion of replicates being rebuilt) and frequency distributions of total mature biomass from the simulations were compared for three management options. The B_{msy}

is defined for Tanner crabs in the entire eastern Bering Sea, whereas our population model addresses just Bristol Bay. Based on the survey data from 1983 to 1997, we approximated the equivalent B_{msy} for Bristol Bay Tanner crabs as 53,200 metric ton of total mature male and female biomass.

- Recruitment was modeled by an autocorrelated Ricker stock-recruitment model: $R_t = S_{t-k}\ e^{\alpha - \beta\ S_{t-k} + \upsilon_t}$, where S_{t-k} is effective spawning biomass in year t-k, k is recruitment age, α and β are constants, and $\upsilon_t = \delta_t + \varphi\ \upsilon_{t-1}$ is environmental noise. $\{\delta_t\}$ was assumed as a $N(0, \sigma)$. The parameter values were estimated as: $\alpha = 2.0402$, $\beta = 0.0563$, $\varphi = 0.73$, $\sigma = 0.86$ (Zheng and Kruse 1998). The component of normally distributed noises ($N(0, \sigma)$) was truncated by its 2.5% and 97.5% limits to prevent unreasonably large or small recruitment.

- The handling mortality rate of captured but discarded females and sublegal males was assumed to be 20% for the crab fishery, a middle rate between low rates from a study that attempted to emulate the fishing process (MacIntosh et al. 1996) and high rates from a laboratory study (Carls and O'Clair 1995) that considered extremely cold air temperatures during winter fisheries.

Three management options during rebuilding periods were compared in the simulations:

1. No mortality occurs during any fisheries, and annual natural mortality rate, uncontaminated by any fishery related effects, is 26% (M=0.3) for males and 27% (M=0.32) for females. This option is equivalent to a complete closure of the directed Tanner crab fishery and a maximum constraint of other fisheries. The current MSY and minimum stock size threshold (MSST) were estimated with M=0.3.

2. Annual natural mortality rate was set at 33% (M=0.4) for males and 35% (M=0.43) for females. The directed Tanner crab fishery was closed, and bycatch mortality from all non-pot fisheries was simulated separately from natural mortality. Bycatch from groundfish and scallop fisheries was set according to current prohibited species cap regulations, and handling mortality rate was assumed as 80% for the groundfish fisheries and 40% for the scallop fishery. Annual "natural mortality" may include some fishery-related sources of mortality that haven't been explicitly separated. This option approximately represents no directed fishing mortality other than unavoidable mortality.

3. The same as option (2) except with the new harvest strategy on the directed Tanner crab fishery. This option allowed the directed Tanner crab fishery to occur under the new harvest strategy and all other non-Tanner-crab fisheries to occur under the current regulations.

After the population was rebuilt, options (1) and (2) would be replaced by option (3) during the remainder of the simulation duration. That is, the same management option was used during non-rebuilding periods.

Estimated rebuilding probabilities from the computer simulations are shown in Figure 5.4.1. Generally for all three options, zero probability was estimated during the first two years. Rebuilding times for ≥50% probability and ≥90% probability were 7 and 20 years, respectively, for option (1), 8 and 26 years for option (2), and 10 and 30 years for option (3). Distributions of total mature biomass were very skewed, and the long tail for large biomasses caused the mean biomass to be much larger than the median value (Figure 5.4.2).

Female (male) Tanner crabs mature at approximately 6-7 years (7-8 years) from egg fertilization and may live to reproduce up to 5 years. An estimate of mean generation time is 8 years. Because some bycatch mortality is unavoidable, we used option (2) to establish the lower limit of rebuilding time. Based on a 50%

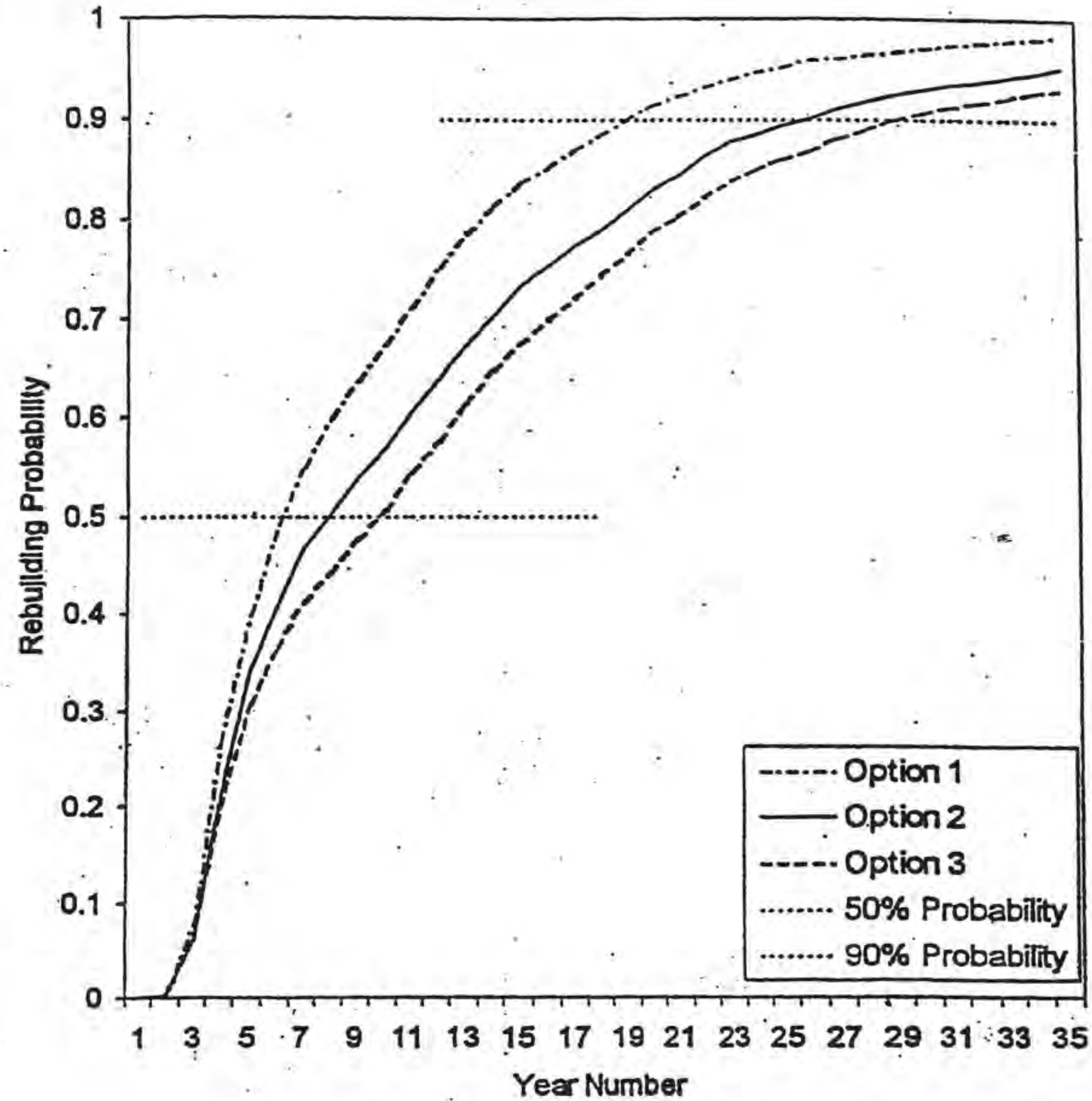
rebuilding probability, the lower limit of rebuilding time is 8 years, and the upper limit should be 10 years. Because the lower limit of rebuilding time is less than 10 years, generation time is not applied here. If a 90% rebuilding probability is used, the lower limit of rebuilding time is 26 years, and the upper limit equals the lower limit plus mean generation time, or 34 years. The rebuilding time for option (3) fell between the lower and upper limits.

Both autocorrelated and cyclic Ricker stock-recruitment curves fit the data equally well, and current data do not allow us to conclude as to the merits of the cyclic or autocorrelated recruitment curves with any degree of confidence. Zheng and Kruse (1999, Appendix 2) used the cyclic curve to evaluate harvest strategies. The current cycle length of Tanner crab recruitment is one of the most important factors on rebuilding probability, and there is a great deal of uncertainty of the current cycle length. While periodic bursts of recruitment appear to be regular for eastern Bering Sea Tanner crabs over the short history of observations, future patterns of recruitment are uncertain. Some stocks of Tanner and red king crabs in the Gulf of Alaska have been depressed for more than a decade, and previous patterns of periodic recruitment have disappeared, or the cycle lengths have greatly increased. We cannot rule out the possibility of depensation in the stock-recruitment curve at extremely low stock sizes under some environmental conditions. If the cyclic curve were used to estimate rebuilding probability, we would have to make assumptions about current cycle length and amplitude. Use of the autocorrelated curve randomly generates the cycle length and amplitude, thus avoiding these assumptions.

Sensitivities of rebuilding probability and rebuilding time period to recruitment dynamics and handling mortality were examined through computer simulations. The cyclic stock-recruitment model has the same values of α and β as the autocorrelated model but has an error term as $\upsilon_t = A\,sin(2\pi t/P) + \delta_t$, where $\{\delta_t\}$ was also assumed as a $N(0, \sigma)$. The parameter values were estimated as: A = 1.268, P = 13.0 years, and σ = 0.46 (Zheng and Kruse 1998). For sensitivity studies, estimated autocorrelated and cyclic models were called base models, and only one parameter value was changed for each scenario. Eleven scenarios were compared: (1) 6 for the autocorrelated model: base model, depensatory model, φ = 0.4 and 0.95, and 0.0 and 0.5 handling mortality rates; and (2) 5 for the cyclic model: base model, A = 0.75 and 1.75, and P = 8.0 and 21.0 years. These values cover likely ranges of parameters. An empirical constant for each scenario was multiplied to recruitment such that expected mean recruitment levels over a long time period for all scenarios are approximately the same. The depensatory model is the same as the autocorrelated model except that the deterministic component of recruitment was computed as $R_t = \kappa S^{\theta}_{t-k}$ when S_{t-k} was 6,395 t or less, where κ = 0.203 and θ = 2.803 (Zheng and Kruse 1998).

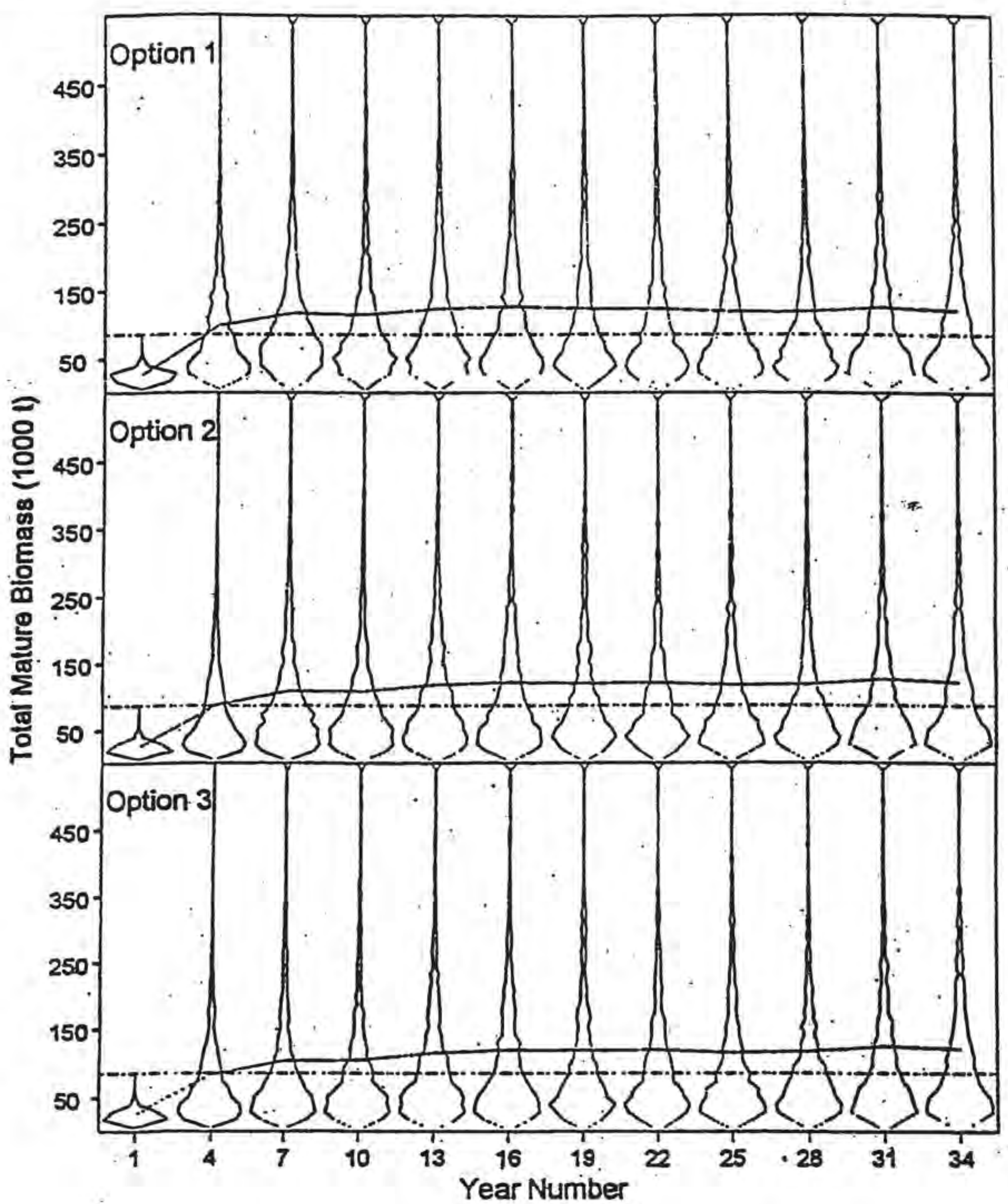
There are some differences between the results under the cyclic model and autocorrelated model. If the amplitude is high enough, the stock will rebuild with certainty for all replicates within a cycle length with the cyclic recruitment function, whereas achievement of 100% rebuilding probability is problematic with the autocorrelated recruitment function. Also, simulated population abundances and rebuilding probabilities are generally more spread out over time with the autocorrelated curve than with the cyclic curve (Table 5.4.1). For base models, years required to achieve ≥50% and 90% rebuilding probabilities were always shorter for the cyclic model than for the autocorrelated model whereas the opposite was true for years to achieve a ≥10% rebuilding probability (Table 5.4.1).
Figure 5.4.1

Figure 5.4.1



Estimated rebuilding probabilities for three management options for eastern Bering Sea Tanner crabs. Year number 1 corresponds to 1999.

Figure 5.4.2



Frequency distributions of total mature biomass of eastern Bering Sea Tanner crabs. Year number 1 corresponds to 1999, bell shapes are distributions, solid lines are mean mature biomass, and dashed lines are biomass at the MSY level.

Table 5.4.1. Comparisons of years required to achieve ≥10%, 50% and 90% rebuilding probabilities (RP) and mean proportions of years with fishery closure and mean annual yields within 5, 10 and 20 years for three management options under different assumptions of recruitment dynamics and handling mortality. AC: autocorrelated stock-recruitment model; CY: cyclic stock-recruitment model.

Scenarios	Years at RP ≥			Fishery Closure			Mean Annual Yield (t)		
	10%	50%	90%	5yr	10yr	20yr	5yr	10yr	20yr
Management Option 1 During Rebuilding Period									
AC: Base model	4	7	20	0.85	0.67	0.53	1886.3	3676.3	4981.0
Dipensatory	4	7	25	0.85	0.70	0.57	1886.3	3166.1	4499.2
Low AC (0.4)	3	5	9	0.74	0.47	0.30	3096.5	4675.6	5703.5
High AC (0.95)	9	35	35	0.99	0.96	0.91	62.8	612.4	2037.3
0.0 handling m.	4	7	20	0.85	0.67	0.53	1958.5	3923.6	5339.4
0.5 handling m.	4	7	20	0.85	0.68	0.54	1776.1	3308.6	4437.4
CY: Base model	5	6	7	0.96	0.49	0.46	243.6	5623.3	4446.6
8 yr. cycle	4	4	5	0.70	0.46	0.28	3387.3	4585.1	4644.0
21 yr. cycle	7	9	10	1.00	0.76	0.48	0.0	2240.3	5533.3
0.75 amplitude	5	5	6	0.89	0.45	0.30	667.0	5185.1	4645.7
1.75 amplitude	6	6	7	0.99	0.51	0.55	55.6	5856.0	4361.4
Management Option 2 During Rebuilding Period									
AC: Base model	4	8	26	0.88	0.72	0.59	1543.8	3246.0	4554.5
Dipensatory	4	10	35	0.88	0.75	0.63	1543.8	2762.0	3974.9
Low AC (0.4)	3	5	12	0.78	0.54	0.35	2527.3	4116.0	5409.1
High AC (0.95)	11	35	35	1.00	0.97	0.93	45.6	523.6	1809.4
0.0 handling m.	4	8	26	0.88	0.72	0.58	1605.9	3468.9	4884.9
0.5 handling m.	4	8	26	0.88	0.73	0.59	1450.6	2914.0	4053.5
CY: Base model	6	6	7	0.98	0.52	0.47	95.0	5089.3	4176.3
8 yr. cycle	4	5	5	0.74	0.50	0.30	2827.9	4091.3	4565.6
21 yr. cycle	8	9	11	1.00	0.84	0.51	0.0	1489.1	4912.0
0.75 amplitude	5	6	7	0.95	0.50	0.31	321.0	4653.8	4397.1
1.75 amplitude	6	6	7	1.00	0.54	0.56	18.9	5320.9	4081.9
Management Option 3 During Rebuilding Period									
AC: Base model	4	10	30	0.64	0.51	0.44	2177.2	3741.7	4894.5
Dipensatory	4	12	35	0.64	0.56	0.50	2177.2	3222.1	4276.9
Low AC (0.4)	3	5	14	0.46	0.30	0.21	3384.0	4643.8	5694.2
High AC (0.95)	13	35	35	0.97	0.92	0.88	134.0	646.0	1924.8
0.0 handling m.	4	10	28	0.63	0.51	0.43	2320.7	4056.6	5290.9
0.5 handling m.	4	11	32	0.64	0.52	0.45	1964.5	3283.1	4299.1
CY: Base model	6	6	7	0.66	0.33	0.38	895.4	5363.2	4311.8
8 yr. cycle	4	5	5	0.51	0.38	0.24	3246.4	4227.1	4647.0
21 yr. cycle	9	10	11	0.89	0.48	0.33	217.1	2369.4	5255.2
0.75 amplitude	5	6	7	0.52	0.26	0.19	1379.9	5030.8	4583.9
1.75 amplitude	6	6	7	0.77	0.39	0.49	566.1	5532.9	4186.8

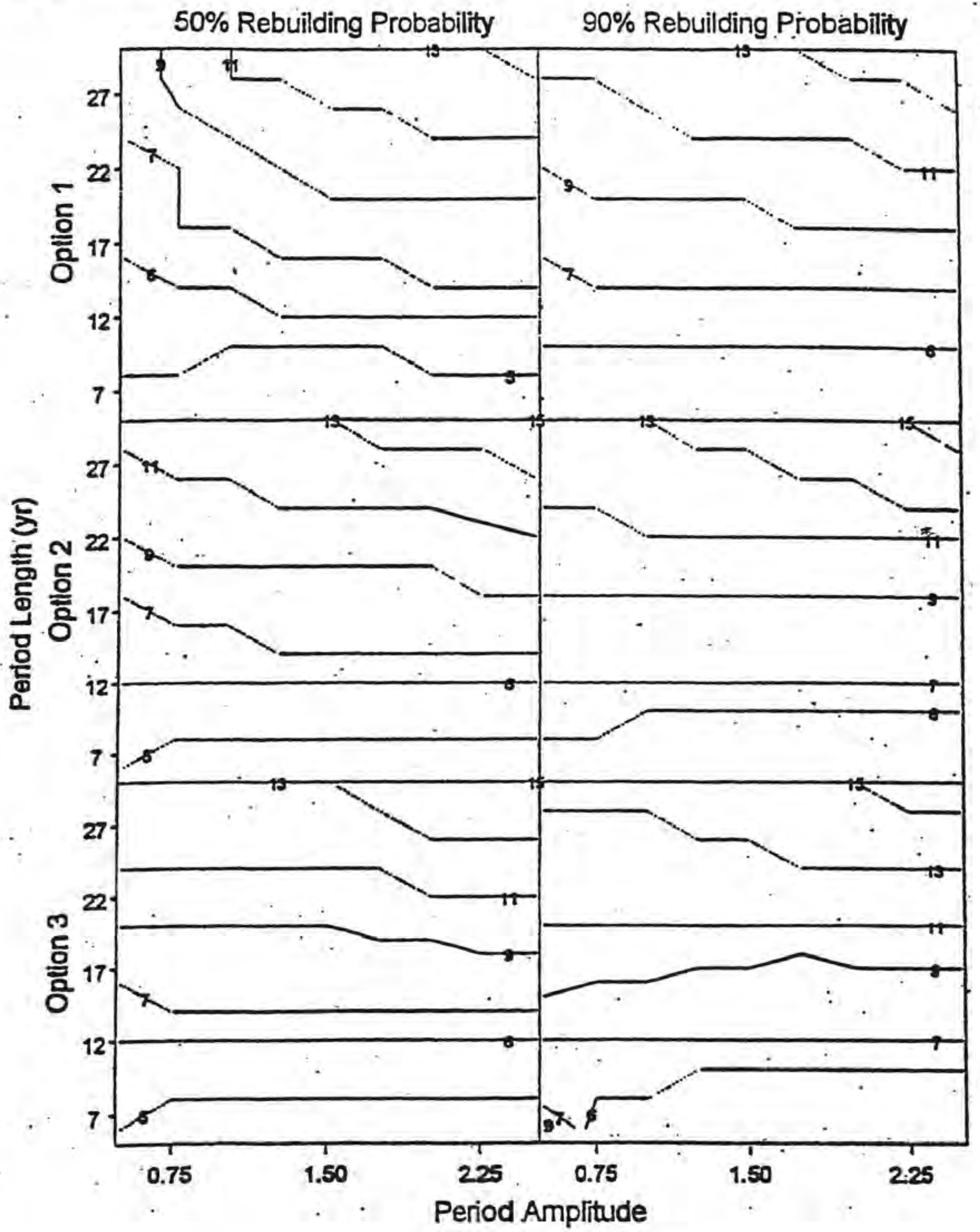
Rebuilding time periods, proportions of years with fishery closure, and mean annual yields were generally sensitive to the recruitment dynamic (Table 5.4.1). Depensation on the stock-recruitment curve generally prolonged the rebuilding time and resulted in a higher proportion of years with fishery closure and a lower mean yield with a planning horizon of 10 years or longer. A lower autocorrelation coefficient reduced rebuilding time and proportion of years with fishery closure and increased mean yield. The large impact of handling mortality was on mean yield with higher handling mortality rates resulting in lower yields. As expected, a longer recruitment cycle increased rebuilding time (Figure 5.4.3) and proportion of years with fishery closure and decreased mean yield. The rebuilding times were similar between low and high recruitment cycle amplitude (Figure 5.4.3), but the high amplitude reduced the fishing opportunities considerably. Generally speaking, under the same condition, management option (1) had the shortest rebuilding times, option (2) had the highest proportions of years with fishery closure and the lowest mean yield, and option (3) had the longest rebuilding times and the lowest proportions of years with fishery closure. However, for many scenarios, all three management options resulted in the same rebuilding times.

Survey data in recent years provide some hints on occurrence of a strong year class and whether the observed recruitment cycle will repeat. Figure 5.4.4 shows carapace width (CW) frequency distributions for Tanner crabs caught during the NMFS stock assessment surveys of the Eastern District of the eastern Bering Sea during 1995-1999. Typically, survey catches of juvenile Tanner crabs <70 mm CW are unreliable indices of year-class strength. Apparently, survey catchability fluctuates with crab size from year to year, so size frequency data on juveniles must be interpreted with much caution. Modes of juvenile Tanner crabs occurred at approximately 37.5 mm CW in 1996, 32.5 mm and 42.5 mm in 1997, 42.5 mm in 1998, and 32.5 mm in 1999. The mode of about 82.5 mm and 87.5 mm CW in 1999 was caused by crabs primarily from a single survey station. The lack of consistent modal progression over these 4 years is inconsistent with expected growth rates associated with a strong year class. However, although abundance estimates remain an order of magnitude smaller than prevalent during in 1976-1992, relative abundance of 25-100 mm CW newshell crabs has been increasing since 1995. The high survey abundance of small newshell crabs in 1999 gives us some hope that the observed recruitment cycle may repeat itself. Although it is too early to tell whether the high survey abundance in 1999 is an indicator that strong year classes are coming, if it does, the rebuilding time will be shorter than estimates here. On the other hand, if the high survey abundance in 1999 was caused by survey measurement errors, the current recruitment cycle will be longer than the observed one, so the rebuilding time may be longer than our estimates.

Recent research (Rosenkranz 1998, Rosenkranz et al. 1998) on environmental factors affecting year-class strength of eastern Bering Sea Tanner crabs found statistical support for the following three hypotheses: (1) cold bottom water temperature adversely affects the spawning population by interrupting or delaying egg development and disrupting the timing of mating and/or hatching; (2) winds blowing from the northeast along the north side of the Alaska Peninsula promote advection of larvae to preferred offshore habitats for settlement composed of fine mud and sand; and (3) warm surface water temperatures promote growth of copepod populations, the preferred prey of larval Tanner crabs.

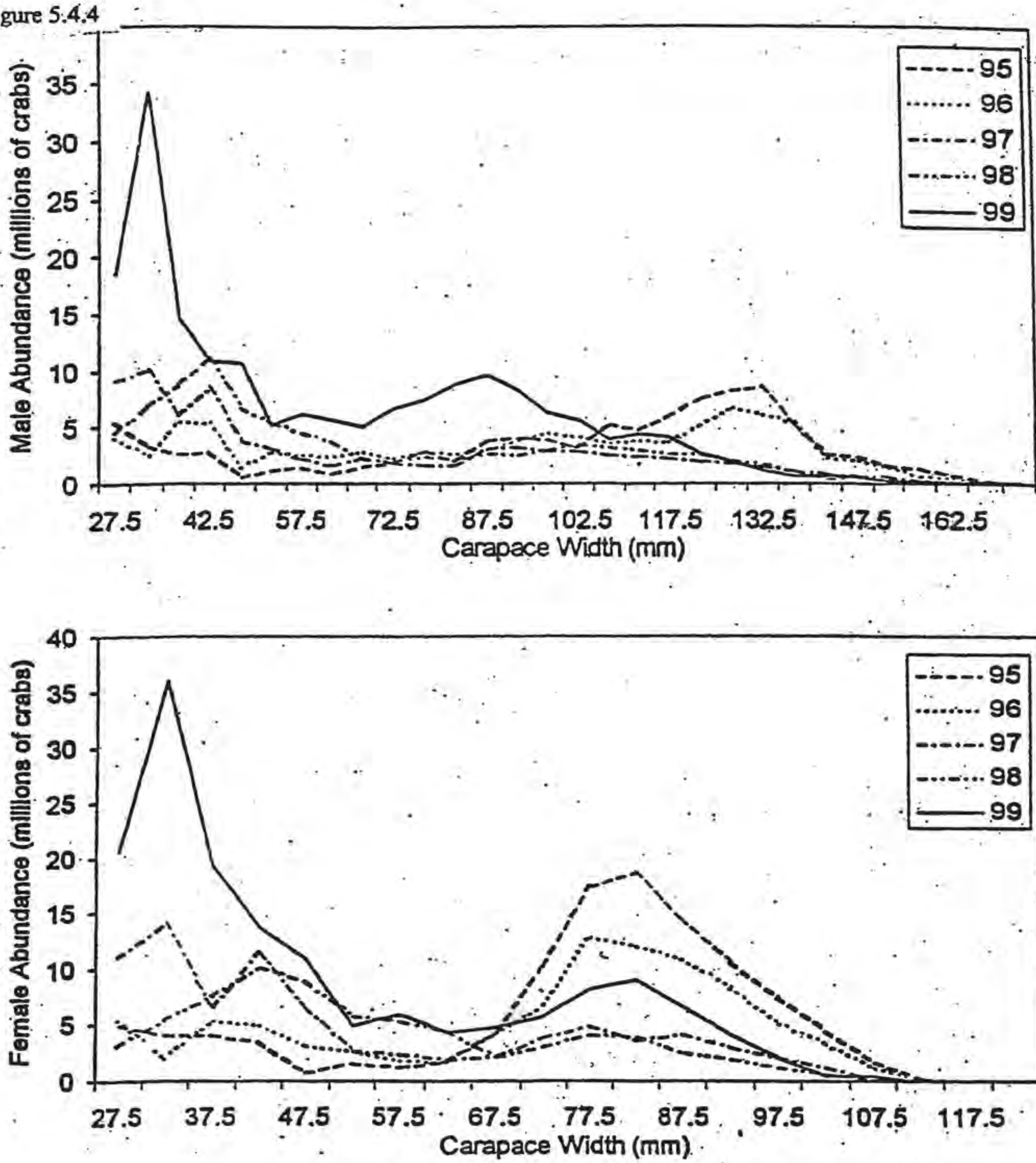
Statistical modeling with bottom temperature, surface temperature, and wind data suggests that recruitment to the surveyed stock should increase from 1997 through 2000, corresponding to brood years in the late 1980s and early 1990s (Rosenkranz 1998). However, the survey data so far do not indicate such a strong recruitment in 1997 and 1998. If the recruitment starting in 2000 is strong enough, this could be somewhat consistent with an optimistic interpretation of the survey data on juvenile Tanner crabs in which attainment of the B_{msy} could be possible early to middle part of the next decade, similar to our optimistic scenarios.

Figure 5.4.3



Contour plots of years required to achieve ≥50% and ≥90% rebuilding probabilities by period amplitude and period length of the recruitment dynamics for Bristol Bay Tanner crabs. The plots are classified by three management options and two rebuilding probabilities.

Figure 5.4.4



Size frequency distributions of male (top panel) and female (bottom panel) Tanner crabs in the Eastern District of the eastern Bering Sea from NMFS trawl surveys during 1995-1999. Abundance estimates are based on area-swept methods.

There are many caveats to such forecasts. During 1965 to 1985 there was a positive relationship between bottom temperature, sea surface temperature, and northeast winds when these factors appeared to contribute synergistically to recruitment from those brood years. However, during 1986 to 1995 bottom temperature was negatively related to these other two surface factors, and it is not yet possible at this time to sort out their competing positive and negative roles on Tanner crab year-class strength. Declining bottom temperatures during this period are expected to have a negative effect on reproduction, whereas increasing strength of northeast winds would be expected to have a positive influence on larval advection to nursery areas. Increasing sea surface temperatures during 1986-1993 would favor availability of copepod prey to Tanner crab larvae, but sea surface temperature declined in 1994 and 1995 contrary to the northeast wind. As in the case of the analysis of stock recruitment, a longer time series of environmental and recruitment data are necessary to predict cycles in Tanner crab year-class strength with any degree of confidence.

In summary, the prospects for Tanner crab stock rebuilding depend largely on future recruitment levels that are difficult to predict. Given empirical survey data and computer simulation studies, a rebuilding period to B_{msy} is projected to be 10 years under option (3) (with a 50% probability of rebuilding within this time period). This rebuilding projection is only two additional years more than the maximum rebuilding rate possible under no directed crab fishing (8 years) and falls within the rebuilding period allowed under the guidelines (maximum rate of 10 years). To achieve a 90% rebuilding probability, the rebuilding time would have to increase to 30 years under option (3), four additional years more than the maximum rebuilding rate possible under no directed crab fishing (26 years).

The harvest strategy provides a balance between a complete fishery closure until stocks are rebuilt and the opportunity for commercial fishery openings during the rebuilding period. That balance is achieved through the fishery-threshold component of the harvest strategy; when the biomass of mature-sized females falls below the 21-million-pound threshold, the fishery is closed. The commercial Tanner crab fishery was, in fact, closed under the harvest strategy for the 1999 season and simulation results indicate that the harvest strategy would close the fishery roughly half of the years during the projected 10-year rebuilding period. In summary, the harvest strategy minimizes the risk of jeopardizing stock rebuilding and results in only a minor protraction of the rebuilding process while allowing for the occasional fishery openings that meet community needs.

5.5 Mechanisms for Monitoring Effectiveness of the Rebuilding Plan

Mechanisms are in place for monitoring the effectiveness of the rebuilding plan. NMFS eastern Bering Sea bottom-trawl survey provides an annual assessment of the status of the eastern Bering Sea Tanner crab stock. ADF&G will use the results of that survey to determine openings and harvest levels according to the eastern Bering Sea Tanner crab harvest strategy. The annual survey will allow the BSAI Crab Plan Team to include an assessment of the Tanner crab stock status relative to the overfished level and its progress towards the rebuilt level in the Stock Assessment and Fishery Evaluation (SAFE) Report for the king and Tanner crab fisheries of the BSAI.

Programs exist within ADF&G and NMFS to contain levels of catch and bycatch at those prescribed in the rebuilding plan. Any catch or bycatch level that departs from that prescribed by the rebuilding plan can be assessed and will be reported in the SAFE. ADF&G will monitor catch and bycatch from the directed Tanner crab fishery and NMFS and ADF&G will monitor bycatch of Tanner crabs in other fisheries. There currently exist programs for reporting catch to ADF&G fishery managers during the directed Tanner crab fishery so that the harvest can be capped at the level prescribed by the harvest strategy. ADF&G currently has a dockside sampling program for monitoring landings during the commercial fishery to shoreside processors and an observer program for monitoring landings by floater-processor vessels and catcher-processor vessels. ADF&G reports the total harvest from the commercial fishery and that report will be included annually in the SAFE. The NMFS observer program provides the means by which bycatch of Tanner crabs can be monitored inseason and kept below the prescribed bycatch caps during the BSAI trawl groundfish fisheries.

The Board passed regulations in 1999 that allow for expansion of the state observer program for crab fisheries into the catcher-only vessel component effective July 2000. Coupled with the existing state program that provides for observer coverage on catcher-processor vessels, the expanded crab-fishery observer program will provide improved estimates of the bycatch of Tanner crabs that occurs during the crab fisheries. Estimates of bycatch in the groundfish pot and longline fisheries will be provided by the existing NMFS observer program and estimates of bycatch in the scallop fishery will be provided by the existing ADF&G program. Estimates of Tanner crab bycatch from all commercial fisheries will be reported annually in the SAFE and the BSAI Crab Plan Team will assess that bycatch relative to the expectations and assumptions of the rebuilding plan.

6.0 Environmental Consequences

The crab fisheries occur in the Bering Sea in the U.S. EEZ from 50° N to 65°N. Descriptions of the affected environment are given in the FSEIS for the groundfish fisheries (NMFS 1998). Substrate is described at section 3.1.1, water column at 3.1.3, temperature and nutrient regimes at 3.1.4, currents at 3.1.5, marine mammals at 3.4, seabirds at 3.5, benthic infauna and epifauna at 3.6, prohibited species at 3.7, and the socioeconomic environment at 3.10. The projections for fishing year 1999, as well as the status of the stocks and history of the fishery, are contained in the 1999 BSAI crab SAFE report (NPFMC 1999).

An environmental assessment (EA) is required by the National Environmental Policy Act of 1969 (NEPA) to determine whether the action considered will result in significant impact on the human environment. If the action is determined not to be significant based on an analysis of relevant considerations, the EA and resulting finding of no significant impact (FONSI) would be the final environmental documents required by NEPA. An environmental impact statement (EIS) must be prepared for major Federal actions significantly affecting the human environment. This section contains the discussion of the environmental impacts of the alternatives including impacts on threatened and endangered species and marine mammals.

The environmental impacts generally associated with crab fishery management actions are effects resulting from (1) harvest of crab stocks which may result in changes in food availability to predators and scavengers, changes in the population structure of target stocks, and changes in the marine ecosystem community structure; (2) changes in the physical and biological structure of the marine environment as a result of fishing practices, e.g., effects of pot gear use; and (3) entanglement/entrapment of non-target organisms in active or inactive fishing gear.

Amendment 11, the Tanner crab rebuilding plan, contains no fishery management measures. The rebuilding plan will reduce the environmental consequences of the Tanner crab fishery by 1) prohibiting fishing some years, and 2) allowing fishing at a reduced harvest rate during other years. For the rebuilding plan, the Council adopted the harvest strategy for Tanner crab developed by ADF&G and adopted by the Alaska Board of Fisheries. The harvest strategy is intended to improve management of the Tanner crab fishery and improve long term stock productivity, as well as increase the probability of stock rebuilding. The harvest strategy will be implemented by ADF&G. The harvest strategy will close the Tanner crab fishery when abundance is low, allow a fishery at a reduced harvest level when abundance has increased, and a establish sustainable harvest rate, which is less that the status quo, when the stock is rebuild. The harvest strategy is detailed in Appendix 2.

6.1 Trophic Interactions

The marine food-web of North Pacific marine fishes are complex (Livingston and Goiney 1983). Numerous species of plankton, phytoplankton, invertebrates, mollusks, crustaceans, forage fish, demersal, mid-water, and pelagic fish, marine mammals, seabirds, and humans combine to comprise the food-web present in the BSAI and GOA. Environmental changes as well as human exploitation patterns can effect changes to trophic interactions. Fishing causes direct changes in the structure of benthic communities by reducing the abundance of target or by-catch species, then these reductions may lead to responses in non-target species through changes in competitive interactions and predator prey relationships. Indirect effects of fishing on trophic interactions in marine ecosystems may also occur. Current debates on these topics include comparing relative roles of "top down" (predator) or "bottom up" (environmental and prey) control in ecosystems and the relative significance of "donor controlled" dynamics (in which victim populations influence enemy dynamics but enemies have no significant effect on victim populations) in the food webs (Jennings and Kaiser 1998.)

Pacific cod is the main predator on Tanner crabs in terms of biomass. Predators consume primarily age 0 and 1 juvenile Tanner crab less than 7 cm carapace width. Flathead sole, rock sole, and yellowfin sole are important predators in terms of numbers of small crab. Larval predators include salmon, herring, and jellyfish. There is a high rate of cannibalism among juvenile crabs.

6.2 Impacts on Habitat

Inclusively all the marine waters and benthic substrates in the management areas comprise the habitat of all marine species. Additionally the adjacent marine waters outside the EEZ, adjacent State waters inside the EEZ, shoreline, freshwater inflows, and atmosphere above the waters, constitutes habitat for prey species, other life stages, and species that move in and out of, or interact with, the fisheries' target species, marine mammals, seabirds, and the ESA listed species.

This section contains analyses of potential fishing gear impacts on benthic substrate attributable to the Tanner crab fishery. The habitat impacts of the Tanner crab fishery will not increase due to this proposed action because the proposed action does not increase the amount of crab harvested or change the location of the fishery. In fact, under the rebuilding plan harvest strategy, the fishery will have no habitat impacts in the years that the fishery is closed and will have a decreased habitat impacts when the harvest level is reduced. Further, once the stock is rebuilt, the new harvest strategy will ensure that the harvest rate remains below the status quo harvest rate. Summaries and assessments of habitat information for BSAI king and Tanner crab are provided in the "Essential Fish Habitat Assessment Report for the Bering Sea and Aleutian Islands King and Tanner Crabs" dated March 31, 1998 (available from the NPFMC).

6.2.1 Direct Impacts of Fishing Gear on Habitat

The Tanner crab fishery uses pot gear. This gear type likely affects habitat during setting and retrieval of pots; however, no research quantifying the impacts has been conducted to date. Whatever the direct effects of setting and pulling pot gear on the benthic environment, they appear to be small in comparison to the potentially large-scale effects of "ghost-fishing" by derelict pots. Lost by the fishery, these pots may continue to entrap animals until their netting or escape panels disintegrate. Inasmuch as they are unbated, the primary attraction of derelict pots is their physical structure, which adds complexity and vertical relief to a generally featureless environment. No additional pot loss is expected under the proposed action. Under the rebuilding plan, no pot loss will occur in years when the fishery is closed.

Like other fisheries, pot fisheries incur some bycatch of incidental fish and crab. Bycatch in crab pot fisheries includes crabs, octopus, Pacific cod, halibut, and other flatfish (Tracy 1994). Crab bycatch in the Tanner crab fishery includes females of target species, sublegal males of target species, and non-target crabs, primarily *C. opilio* crab. Section 3.1.2.3 of the groundfish FSEIS (NMFS 1998) provides a detailed description of the impacts of pot gear on the seas floor. Section 4.2 of this document provides a detailed description of bycatch in the Tanner crab fishery and bycatch of Tanner crab in other fisheries.

6.2.2 Impacts on Essential Fish Habitat

Section 303(a)(7) of the Magnuson-Stevens Act requires all FMPs to describe and identify EFH , which it defines as "those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity." In addition, FMPs must minimize effects on EFH caused by fishing and identify other actions to conserve and enhance EFH. Groundfish and Tanner crab fisheries occur within essential fish habitat (EFH) for a number of fish and invertebrate species. In the Bering Sea, EFH includes those identified for pollock, Pacific cod, many flatfish species, other groundfish species, red king crab, Tanner crab, and snow crab. Additional information on EFH can be found in the EA for Amendments 55/55/8/5/5 (NPFMC 1999 -

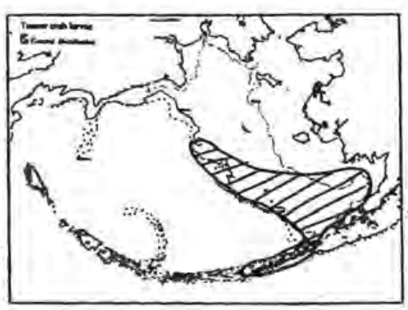
copies of this document can be obtained from the Council office upon request). Actions taken to protect Tanner crab habitat could potentially benefit groundfish and other crab stocks in the area. None of the proposed alternatives would affect areas identified as habitat areas of particular concern.

Given the current status of Tanner crab, it seems reasonable that the importance of Tanner crab EFH in maintaining stock productivity should be a priority message contained in consultations on any proposed activities. To the extent feasible and practicable, this area should be protected from adverse impacts. The interim final rule for EFH states the following in the case of an overfished stock: *"If a species is overfished, and habitat loss or degradation may be contributing to the species being identified as overfished, all habitats currently used by the species should be considered essential in addition to certain historic habitats that are necessary to support rebuilding the fishery and for which restoration is technologically and economically feasible. Once the fishery is no longer considered overfished, the EFH identification should be reviewed, and the FMP amended, if appropriate."* Therefore, EFH for BSAI Tanner crab should be considered as all habitats used by this stock, at least until such a time as the stock is above MSST. Additional and updated information on Tanner crab habitat was provided in this analysis.

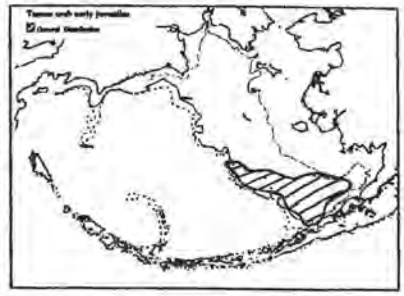
The Tanner crab fishery occurs in the Bering Sea, concentrating in the south east region, east of the Pribilof Islands. According to the EA for Amendment 8 to Crab FMP, it is reasonable to assume that the Tanner fisheries may impact the EFH of the following species: yellowfin sole, Greenland turbot, arrowtooth flounder, rock sole, Alaska Place, flathead sole, sablefish, northern rockfish, dusky rockfish, skates, sculpins, golden king crab, scarlet king crab, *C. opilio* crab, and Triangle Tanner crab. Insufficient data exists to determine the extent of the impacts on EFH, beyond the fact that the Tanner crab fishery occurs in the species general distribution. No evidence suggests that the Tanner crab fishery impacts the EFH of salmon, marine mammals, or seabirds. The Tanner crab fishery does not occur on any areas designated as Habitat Areas of Particular Concern (HAPC). This proposed action will not change the location of the Tanner crab fishery.
The rebuilding plan reduces the harvest rate from status quo and provides for decreased harvest if the stock is below the minimum stock size threshold and provides for no fishing when the stock is at very low levels of abundance. The action proposed by this regulatory amendment will not increase the amount of harvest, the intensity of harvest, or the location of harvest, therefore, this action is presumed not to increase the impacts of the fishery to EFH. Based on the above, this action, in the context of the fishery as a whole, will not adversely affect EFH for species managed under the five North Pacific FMPs. As a result of this determination, an EFH consultation is not required.

On January 20, 1999, the Council's five FMPs (BSAI and GOA groundfish, salmon, crab, and scallops) were amended to incorporate EFH provisions. These provisions included identification and description of EFH including habitat areas of particular concern, identification of research and information needs, and identification of potential adverse effects on EFH due to fishing and non-fishing activities. Additional information on EFH can be found in the EA for Amendments 55/55/8/5/5 (NPFMC 1999 - copies of this document can be obtained from the Council office upon request). Habitat requirements for Tanner crab are listed in Table 6.2.2. The EFH definitions adopted for Tanner crab life stages are listed below.

Egg - Level 0_b, Level 1 and Level 2: See mature. Essential habitat for eggs is known for the stocks of *C. bairdi* Tanner crabs in Bristol Bay and the Pribilof Islands based on general distribution (level 1) and density (level 2) of egg bearing female crabs. Essential habitat for eggs of the Eastern Aleutian *C. bairdi* Tanner crab stock is based on general distribution (level 1) of the egg bearing females. Essential habitat for eggs of the Western Aleutian *C. bairdi* Tanner crab stock is inferred from the general distribution of mature females.

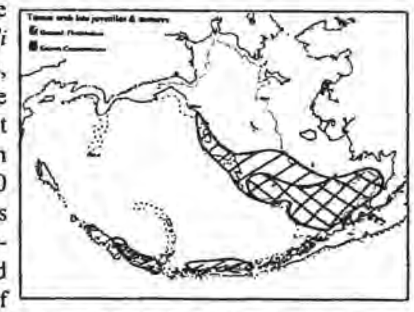


Larvae - Level 0_c and Level 1: Larvae of *C. bairdi* Tanner crabs are typically found in Bering Sea Aleutian Island water column from 0 – 100 m in early summer. They are strong swimmers and perform diel migrations in the water column (down at night). They usually stay near the depth of the chlorophyll maximum during the day. The last larval stage settles onto the bottom mud. Essential habitat of *C. bairdi* Tanner crab larvae is based on general distribution (level 1) for the Bristol Bay and Pribilof Islands stocks. Information is not available to define essential habitat for larval *C. bairdi* Tanner crab in the Eastern Aleutian and Western Aleutian stocks.



Early Juvenile - Level 0_c, Level 1 and Level 2. Early juvenile *C. bairdi* Tanner crabs occur at depths of 10 - 20 m in mud habitat in summer and are known to burrow or associate with many types of cover. Early juvenile *C. bairdi* Tanner crabs are not easily found in winter. Essential habitat of early juvenile *C. bairdi* Tanner crabs is identified by the general distribution (level 1) of this life stage for the Bristol Bay, Pribilof Islands, and Eastern Aleutian stocks. Information to identify essential habitat of early juvenile *C. bairdi* Tanner crabs in not available for the Western Aleutian stock.

Late Juvenile - Level 0_c, Level 1 and Level 2: The preferred habitat for late juvenile *C. bairdi* Tanner crabs is mud. Late juvenile Tanner crab migrate offshore of their early juvenile nursery habitat. Essential habitat of late juvenile *C. bairdi* Tanner crabs is based on the general distribution (level 1) and density (level 2) of this life stage for the Bristol Bay, Pribilof Islands, and Eastern Aleutian stocks. Information to identify essential habitat of late juvenile *C. bairdi* Tanner crabs in not available for the Western Aleutian stock.



Mature - Level 1 and Level 2: Mature *C. bairdi* Tanner crabs migrate inshore and mating is known to occur February through June. Mature female *C. bairdi* Tanner crabs have been observed in high density mating aggregations, or pods, consisting of hundreds of crabs per mound. These mounds may provide protection from predators and also attract males for mating. Mating need not occur every year, as female *C. bairdi* Tanner crabs can retain viable sperm in spermathecae up to 2 years or more. Females carry clutches of 50,000 to 400,000 eggs and nurture the embryos for one year after fertilization. Primiparous females may carry the fertilized eggs for as long as 1.5 years. Brooding occurs in 100-150 m depths. Essential habitat is based on the general distribution (level 1) and density (level 2) of mature *C. bairdi* Tanner crabs of the Bristol Bay, Pribilof Islands, and Eastern Aleutian stocks. Essential habitat of mature *C. bairdi* Tanner crabs is identified as the general distribution (level 1) for the Western Aleutian stock.

Table 6.2.2 Habitat associations for Bering Sea Tanner Crab (*C. bairdi*).

		Feeding Types						Movements							Behavior								Periods				
Species	Life Stage Activity	Duration of Life Stage (years)	Lecithotrophic	Planktotrophic	Omnivore	Detritivore	Unknown	Drift with Ocean Conditions	Reside in Nursery Areas	Inshore Molting/Mating Migration	Offshore Migration	Diel Migration	Nocturnally Active	Unknown	Solitary	Burroughing	Mating Aggregation	Molting Aggregation	Defensive/Podding Aggregation	Special Aggregation	Other Aggregation	Unknown	Months Mating	Unknown	Months Mating	Unknown	Life Stage/Activity
Tanner Crab	M	7-15+				x				x	x				x	x	x			x			Jan-Jun		Feb-Jun		M
	LJ	4				x					x				x	x							Jan-Dec				LJ
	EJ	2				x			x						x	x							Jan-Dec				EJ
	L	0,2		x				x				x								x			Jun-Jul				L
	E	1	x																								EJ

		Pelagic Domain										Benthic Domain											
												Shelf					Slope			Canyon			
Species	Life Stage Activity	Estuarine	Inshore Water (0-3 miles)	Offshore Water (3+ miles)	Surface Water	Midwater	Near Bottom	Vertical Depth (m)	Epipelagic (<200 m)	Mesopelagic (200-1000 m)	Bathypelagic (<1000 m)	Bottom Depth Range (m)	Intertidal	Subtidal (<30 m)	Middle (30-100 m)	Outer (100-200 m)	Upper (Break-500 m)	Intermediate (500-1000 m)	Lower (>500 m)	Head (<100 m)	Upper and Middle (100-500 m)	Lower (>500 m)	Life Stage Activity
Tanner Crab	M											3-700		x	x	x	x	x	x	x	x	x	M
	LJ											3-200		x	x	x				x	x		LJ
	EJ											3-200		x	x	x				x	x		EJ
	L	x	x	x	x	x	x	0-100	x														L
	E											3-700		x	x	x	x	x	x	x	x	x	E

		Structure										Substrate								Community											Ocean		
Species	Life Stage Activity	Bars	Banks	Sinks	Slumps/Rocksls/Debris Field	Channels	Ledges	Pinnacles	Reefs	Vertical Walls	Man-Made	Organic Debris	Mud/Clay/Silt	Sand/Granule	Gravel	Pebble	Cobble	Boulder	Bedrock	Algal Cover	Anenomes	Enchnoderms	Corals (soft)	Mollusca	Drift Algae/Kelp	Kelp Forest	Polychaetes	Sea Grasses	Sea Onions	Tuncates	Temperature (Celsius)	Salinity (ppt)	Life Stage Activity
Tanner Crab	M	x	x	x	x	x					x	x	x	x	x	x	x				x	x	x	x	x	x	x		x	x	<10	>30	M
	LJ	x	x	x	x	x					x	x	x	x	x	x	x				x	x	x	x	x	x	x		x	x	<10	>30	LJ
	EJ	x	x	x	x	x					x	x	x	x	x	x	x				x	x	x	x	x	x	x		x	x	<10	>30	EJ
	L																														<10	>30	L
	E	x	x	x	x	x					x	x	x	x	x	x	x				x	x	x	x	x	x	x		x	x	<10	>30	E

6.3 Biological Diversity

The concept of biological diversity is generally used to denote the variety of living things in an ecosystem. The definition of biological diversity considers three levels: genetic, species, and ecosystem diversity. There is potential for other ecological impacts of this proposal. Reduced bottom trawl and crab pot effort may result in reduced unobserved mortality on fish, crabs, and other benthic organisms. This issue, and other potential ecological effects of trawling and pot fishing, has been thoroughly discussed in previous analyses (e.g., EFH amendment analyses; NPFMC 1999).

Adoption of Alternative 2 is expected to allow the Bering Sea Tanner crab stock to rebuild to the Bmsy level within 10 years. Adoption of the revised harvest strategy should result in more spawning biomass as more larger male crab would be conserved. This higher spawning biomass would be expected to produce good year-classes when environmental conditions are favorable. Protection of habitat and/or reduction of bycatch would be expected to reduce mortality on juvenile crabs, allowing a higher percentage of each year-class to contribute to spawning (and future landings). Any or all of these actions proposed under Alternative 2 would be expected to improve the status of this stock, thus promoting biological diversity.

6.4 Bycatch Impacts

Analysis of Tanner crab PSC limits for groundfish trawl fisheries indicates that most trawl fisheries do not harvest up to the PSC limits currently established for Zone 2 because the fisheries are closed before the Tanner crab PSC limits are reached. Reaching these limits would increase the impacts on Tanner crabs, particularly at low stock sizes, and would increase conservation concerns that have been expressed by the Crab Plan team about the status of Tanner crabs in the Pribilof Islands area. Note however, that bycatch of Tanner crab in groundfish fisheries is small relative to total abundance. Bycatch mortality due to groundfish fisheries has ranged between 1.2 million and 2.0 million Tanner crabs during the 1994-98 period. This equates to 0.77% to 1.0% of the total stock. From a mortality standpoint, this is similar to mortality associated with other groundfish fishery PSC species such as herring (1%), halibut (1.3% trawl and longline combined) and chum salmon (<1%), but is more than red king crab (0.1%) and C. opilio crab (0.1%), yet less than chinook salmon (2%-4%) (Witherell et al., 2000).

The options to reduce the Zone 2 limit would maintain tighter control on the allowable bycatch of Tanner crabs, particularly when the stock is at low levels. However, because bycatch mortality caused by trawl fisheries is small relative to other sources of mortality, reductions in bycatch limits may not result in measurable improvements to crab stock abundance. Witherell and Harrington (1996) evaluated alternative measures to reduce the impacts of trawling and dredging on BSAI crab stocks, and concluded that a reduction in bycatch limits would conserve some crab, but would have little overall impact on crab stocks.

If bycatch mortality of Tanner crabs taken by all fisheries (groundfish, crab, scallop) was reduced to zero, the projected rebuilding period would be shortened from 8 years (rebuilding time with no fishing) to 7 years (rebuilding time with no fishing and no bycatch)(note: the 10 year rebuilding time frame allows for bycatch and some fishing). This one year reduction in rebuilding time period would come at the expense of essentially prohibiting most commercial fisheries in the North Pacific.

6.5 Endangered Species Act Considerations

The Endangered Species Act of 1973 as amended (16 U.S.C. 1531 *et seq*; ESA), provides for the conservation of endangered and threatened species of fish, wildlife, and plants. The program is administered jointly by the NMFS for most marine mammal species, marine and anadromous fish species, and marine plants species and by the USFWS for bird species, and terrestrial and freshwater wildlife and plant species.

The designation of an ESA listed species is based on the biological health of that species. The status determination is either threatened or endangered. Threatened species are those likely to become endangered in the foreseeable future [16 U.S.C. § 1532(20)]. Endangered species are those in danger of becoming extinct throughout all or a significant portion of their range [16 U.S.C. § 1532(20)]. Species can be listed as endangered without first being listed as threatened. The Secretary of Commerce, acting through NMFS, is authorized to list marine fish, plants, and mammals (except for walrus and sea otter) and anadromous fish species. The Secretary of the Interior, acting through the USFWS, is authorized to list walrus and sea otter, seabirds, terrestrial plants and wildlife, and freshwater fish and plant species.

In addition to listing species under the ESA, the critical habitat of a newly listed species must be designated concurrent with its listing to the "maximum extent prudent and determinable" [16 U.S.C. § 1533(b)(1)(A)]. The ESA defines critical habitat as those specific areas that are essential to the conservation of a listed species and that may be in need of special consideration. Federal agencies are prohibited from undertaking actions that destroy or adversely modify designated critical habitat. Some species, primarily the cetaceans, which were listed in 1969 under the Endangered Species Conservation Act and carried forward as endangered under the ESA, have not received critical habitat designations.

Federal agencies have an affirmative mandate to conserve listed species (Rohlf 1989). One assurance of this is Federal actions, activities or authorizations (hereafter referred to as Federal action) must be in compliance with the provisions of the ESA. Section 7 of the Act provides a mechanism for consultation by the Federal action agency with the appropriate expert agency (NMFS or USFWS). Informal consultations, resulting in letters of concurrence, are conducted for Federal actions that have no adverse affects on the listed species. Formal consultations, resulting in biological opinions, are conducted for Federal actions that may have an adverse affect on the listed species. Through the biological opinion, a determination is made as to whether the proposed action poses "jeopardy" or "no jeopardy" of extinction to the listed species. If the determination is that the action proposed (or ongoing) will cause jeopardy, reasonable and prudent alternatives may be suggested which, if implemented, would modify the action to no longer pose the jeopardy of extinction to the listed species. These reasonable and prudent alternatives must be incorporated into the Federal action if it is to proceed. A biological opinion with the conclusion of no jeopardy may contain a series of management measures intended to further reduce the negative impacts to the listed species. These management alternatives are advisory to the action agency [50 CFR. 402.24(j)]. If a likelihood exists of any taking[2] occurring during promulgation of the action, an incidental take statement may be appended to a biological opinion to provide for the amount of take that is expected to occur from normal promulgation of the action. An incidental take statement is not the equivalent of a permit to take.

Ten species occurring in the BSAI crab management areas are currently listed as endangered or threatened under the ESA. The group includes seven great whales, one pinniped, two seabirds, and one albatross. In summary, species listed under the ESA are present in the action area and, as detailed below. The NMFS is the expert agency for ESA listed marine mammals. The USFWS is the expert agency for ESA listed seabirds.

Listed Species. The following species are currently listed as endangered or threatened under the ESA and occur in the BSAI:

Endangered

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[2] the term "take" under the ESA means "harass, harm, pursue, hunt, shoot, wound, kill, trap, capture or collect, or attempt to engage in any such conduct" [16 U.S.C. § 1538(a)(1)(B)].

Northern Right Whale	*Balaena glacialis*
Bowhead Whale	*Balaena mysticetus*
Sei Whale	*Balaenoptera borealis*
Blue Whale	*Balaenoptera musculus*
Fin Whale	*Balaenoptera physalus*
Humpback Whale	*Megaptera novaeangliae*
Sperm Whale	*Physeter macrocephalus*
Short-tailed Albatross	*Diomedia albatrus*
Steller Sea Lion	*Eumetopias jubatus*

Threatened

Spectacled Eider	*Somateria fishcheri*
Steller's Eider	*Polysticta stelleri*

Section 7 Consultations. Because crab fisheries are federally regulated activities, any negative effects of the fisheries on listed species or critical habitat and any takings that may occur are subject to ESA section 7 consultation.

Seabirds:
In 1994, NMFS prepared a Biological Assessment for the king and Tanner crab FMP, which analyzes the potential takes of listed seabirds in these fisheries and conducted an informal Section 7 consultations with USFWS (NMFS 1994). According to the Biological Assessment, the Tanner crab fishery is not known to result in any significant impact to the short-tailed albatross, Steller's eider, or Spectacled eider. Nor does the fishery compete for any crab species commonly preyed upon by marine birds. NMFS determined that the crab fisheries will have no adverse impact on any listed seabird nor will they delay in any way the recovery of those species, except the C. opilio fishery which may adversely impact the Spectacled Eider. The outcome of the Biological Assessment and informal consultations with FWS was the initiation of formal section 7 consultation on the impacts of the C. opilio fishery on Spectacled Eider. The conclusion of which was that USFWS concurred with NMFS's determination that the C. opilio crab fishery is not likely to adversely affect threatened or endangered species under the jurisdiction of the USFWS, including the threatened spectacled eider (FWS 1998). No new information has become available which indicates that the crab fisheries may affect a listed species of seabird.

Marine Mammals:
In 1990, NMFS conducted a section 7 consultation on the king and Tanner crab FMP for the humpback whale, blue whale, sei whale, fin whale, bowhead whale, right whale, sperm whale, and the Steller sea lion (NMFS 1990). NMFS concluded that the BSAI commercial king and Tanner crab fisheries are not likely to adversely affect these endangered species or their critical habitat.

6.6 Marine Mammal Protection Act

The king and Tanner crab fisheries in the Bering Sea/Aleutian Islands are classified as Category III fisheries under the Marine Mammal Protection Act. A fishery that interacts only with non-strategic stocks and whose level of take has an insignificant impact on the stocks is placed in Category III. An observer program has been in existence since 1988 for the Alaskan crustacean pot fisheries. No marine mammal species have been recorded as taken incidentally in the fisheries according to records that date back to 1990.

6.7 Coastal Zone Management Act

Implementation of each of the alternatives would be conducted in a manner consistent, to the maximum extent practicable, with the Alaska Coastal Management Program within the meaning of Section 30(c)(1) of the Coastal Zone Management Act of 1972 and its implementing regulations.

6.8 Conclusions or Finding of No Significant Impact

None of the alternatives for Amendment 11 are likely to significantly affect the quality of the human environment, and the preparation of an environmental impact statement for the proposed action is not required by Section 102(2)(C) of the National Environmental Policy Act or its implementing regulations.

Assistant Administrator for Fisheries, NOAA

6/8/00

Date

7.0 Economic and Socioeconomic Impacts of Alternatives

This section provides information about the economic and socioeconomic impacts of the alternatives including identification of the individuals or groups that may be affected by the action, the nature of these impacts, quantification of the economic impacts if possible, and discussion of the trade offs between qualitative and quantitative benefits and costs.

The Tanner crab stock in the Bering Sea is currently defined as overfished. This analysis presents alternatives to rebuild the Tanner crab stock taking into account the status and biology of the stock. In June 1998, the Council adopted Amendment 7 to the BSAI King and Tanner Crab FMP. The Amendment established MSY point estimates, along with minimum stock size thresholds (MSST) for individual crab stocks. Overfishing was defined as a fishing mortality rate in excess of natural mortality (M=0.2 for king crabs, M=0.3 for Tanner crabs) or a biomass that falls below MSST. Because the current Tanner crab spawning biomass (64.2 million pounds of biomass in 1997) is below MSST (94.8 million pounds of biomass), the stock was deemed "overfished" on March 3, 1999 based on the guidelines, and requires that a rebuilding plan be developed within one year as required under Section 304 of the Magnuson-Stevens Act. The proposed action is being considered to rebuild Bering Sea Tanner crab to the MSY level.

7.1 Description of Fleet, Fishery, & Industry

A description of the crab fishery and fishing industry is provided in the Crab FMP, the Crab Stock Assessment and Fishery Evaluation (SAFE) report (e.g., NPFMC 1998), and the annual area management reports produced by the Alaska Department of Fish and Game. The 1999 Groundfish Economic SAFE contains the latest information on the groundfish fishing industry. The Scallop fishery information is provided in the Scallop SAFE. Copies of these documents are available on request from the Council office.

The most recent description of the groundfish fishery is contained in the Economic Status of the Groundfish Fisheries Off Alaska. The report includes information on the catch and value of the fisheries, the numbers and sizes of fishing vessels and processing plants, and other economic variables that describe or affect the performance of the fisheries. Catch of groundfish in the Bering Sea has remained relatively stable over the past 10 years, averaging about 1.8 million metric tons, consisting primarily of pollock. About 2,000 vessels fish for groundfish in the BSAI and GOA each year. Data for 1997 indicate that in the BSAI area, 137 vessels fished with hook and line, 84 vessels fished with groundfish pot gear, and 167 vessels fished with trawls. Catch in the domestic groundfish fisheries off Alaska totaled over 2 million metric tons in 1997, worth $583 million in ex-vessel value. The value of resulting products was over $1.1 billion.

The economics of BSAI crab fisheries are summarized in ADF&G's Annual Area Management Reports (e.g., Morrison 1997). Total value of the three major Bering Sea crab fisheries in recent years is about $180 million to $260 million per year. Most vessels that participate in Tanner crab fisheries also participate in the Snow crab and Bristol Bay red king crab fisheries. Since 1982, the snow crab fishery has generated much higher values

Economic data from the Bering Sea Tanner crab fishery, 1989-1998. Catch includes about 1% deadloss.

Year	Catch	# of vessels	price per lb	total exvessel ($)	Ave $ per vessel
1989	7.0	109	2.90	20,300,000	186,000
1990	64.6	179	1.50	90,000,000	503,000
1991	31.8	255	1.50	47,300,000	185,000
1992	35.1	294	1.69	58,800,000	200,000
1993	16.9	296	1.90	31,600,000	107,000
1994	7.8	183	3.75	28,500,000	156,000
1995	4.2	196	2.80	11,700,000	60,000
1996	1.8	135	2.50	4,500,000	33,000
1997	0		No Commercial Fishery		
1998	0		No Commercial Fishery		
1999	0		No Commercial Fishery		

than the other crab fisheries. Although snow crab landings had dropped drastically since the peak in 1991 (325 million lbs.), price increased such that average gross ex-vessel value increased to over $710,000 per vessel in the 1995 snow crab fishery. In the Tanner crab fishery, price did not keep up with reduced landings since 1992, and gross ex-vessel value was only $60,000 per vessel in 1995. Assuming that all vessels in the snow crab fishery also fished for Tanner crab in 1995, vessels averaged about $770,000 in ex-vessel value. The Bristol Bay red king crab fishery did not open in 1995 or 1996. Ex-vessel values had averaged about $175,000 per vessel per year in that fishery. The Tanner crab fishery did not open in 1997, 1998, or 1999. Exvessel values had averaged about $100,000 to $500,000 per vessel for Tanner crab during the early 1990's when the stock was abundant.

In evaluating the alternatives to the status quo, it is informative to know what crab bycatch in groundfish and crab fisheries costs the directed crab fisheries. The answer to this question can be derived from the adult equivalent exercise made in a previous section of this document. If groundfish fisheries caught no crab incidentally, the crab fishery may increase total ex-vessel revenues by about $5.4 million to $7 million. Similarly, if crab fisheries caught no crab incidentally, the crab fishery may increase total ex-vessel revenues by about $4.2 million to $36 million.

Value of Tanner crab bycatch in groundfish and crab fisheries to directed Tanner crab fisheries, based on 1994 and 1997 data.

Fishery	Equivalents	weight	price/lb	value ($)
1994				
Groundfish	1,227,481	2.3	2.50	7,058,016
Crab	6,309,052	2.3	2.50	36,277,049
			Total =	**$43,335,065**
1997				
Groundfish	943,896	2.3	2.50	5,427,402
Crab	727,023	2.3	2.50	4,180,382
			Total =	**$9,607,784**

This represents an estimate of opportunity costs. Assuming there are about 275 crab vessels, these crab would equate to about $35,000 to $158,000 per vessel in gross ex-vessel value. Potential costs of proposed alternative crab PSC limits for trawl fisheries and reductions in crab bycatch in crab fisheries can be measured against potential benefits to crab fisheries.

The following tables present data summarizing the number of vessels by gear and area that harvested Alaska groundfish, scallops and crab in 1996. More recent data were not readily available. However, the number of vessels participating in 2000 would expected to be less than, but not significantly different from the number of vessels participating in 1996. More detailed information on projected fleet size can be found in the License Limitation Program analysis (NPFMC 1998). This information about estimated number of entities in crab fisheries will be used to determine the universe of small entities that could be significantly negatively impacted by any regulation. These data include some vessels that would not be considered "small entities" for purposes of the RFA because their gross annual revenue exceeds $3 million, although the preponderance of vessels experience annual revenues less than this amount.

Number of vessels that caught groundfish in the BSAI area in 1996, by vessel length class (measured by length overall (LOA) in feet), catcher type, and gear.

	<60'	60-124'	>125'	Total
Catcher vessels				
Fixed gear	64	125	17	206
Trawl gear	6	91	31	128
Catcher/processors				
Fixed gear	1	21	32	54
Trawl gear	0	7	55	62
Total all vessels	71	244	135	450

Number of vessels that caught groundfish in the GOA area in 1996, by vessel length class (measured by length overall (LOA) in feet), catcher type, and gear.

	<60'	60-124'	>125'	Total
Catcher vessels				
Fixed gear	1116	179	7	1302
Trawl gear	63	82	17	162
Catcher/processors				
Fixed gear	4	13	11	28
Trawl gear	0	7	30	37
Total all vessels	1183	281	65	1529

Number of vessels that caught crab in the BSAI area in 1996, by vessel length class (measured by length overall (LOA) in feet), catcher type, and gear.

	Catcher vessels			Catcher/
	<60'	60-124'	>125'	proc.s
Bristol Bay red king	0	130	62	4
Bering Sea Tanner	0	102	40	4
Bering Sea Snow crab	0	154	70	15
Norton Sound red king	41	0	0	0

The Crab Vessel License Limitation Program

The North Pacific Fishery Management Council (NPFMC or Council) approved License Limitation Programs (LLPs) for its Groundfish and Crab Fishery Management Plans (FMPs) on June 17, 1995. The U.S. Secretary of Commerce (SOC) approved the proposed rule implementing the Groundfish and Crab LLPs on September 12, 1997. The final rule was approved on October 1, 1998. Fishing under the final LLPs is expected to begin in January 2000. In 1998, the Crab LLP was further amended to include changes in the basic eligibility criteria for crab, in the form of additional recent participation criteria. These changes were adopted by the Council as Amendment 10 to the Crab FMP in October, 1998.

Under the original qualifying criteria, 365 vessels are projected to qualify for crab licenses in areas excluding Norton Sound. Of the total projected qualifiers, Alaskans currently own 125 vessels and 240 are currently owned by residents of other states. Participation declined from 349 vessels in 1995 to 299 in 1996 and 282 in 1997. Through February 7, 1998, 219 vessels had participated. The lower number in 1998 probably reflects the fact that only a few weeks of the fishing year had passed. Throughout the recent period a total of 410 unique vessels have participated: 19 vessels as catcher processors and 391 as catcher vessels. The largest decline appears for seine combination catcher vessels. The number of participants reported in the data dropped from 70 in 1995 to 7 in 1997. The numbers of participants in other vessel classes varied within a much narrower range. The number of Alaskan residents participating in the crab fisheries has declined throughout the period, while the number of participating residents of other states fell in 1996 and then rose in 1997. The number of crab vessels with endorsements for the BSAI Tanner crab fishery under the original LLP was 323 vessels.

In 1998 the Council adopted Amendment 10 to the Crab FMP, which would require recent participation in the BSA king and tanner crab fisheries in order to qualify for a license under the Crab LLP. The recent participation requirement would apply to the general license only; if a vessel satisfies the recent participation criteria chosen, it would receive its original license and all of the species/area endorsements for which it qualified under the original criteria. No new species/area endorsements could be earned during the recent qualification. The specific alternative adopted by the Council in October, 1998, was Alternative 9, which required participation at least once between 1996 and February 7, 1998. The Council also included the following four exemptions to this requirement:

1. Vessels with only a Norton Sound Endorsement
2. All vessels that are < 60' LOA and are qualified under the original LLP
3. Vessels that made landings in the Bering Sea and Aleutian Islands crab fishery in 1998, on or before February 7, 1998, and for which the owner acquires license limitation rights from a vessel that meets the general qualification period (GQP) and endorsement qualification period (EQP) landings requirements. The owner must have acquired these rights or entered into a contract to acquire the rights by 8:36 a.m. Pacific time on October 10, 1998.
4. A vessel that was lost or destroyed and which made a landing (or its replacement vessel) in the Bering Sea and Aleutian Islands crab fishery from the time it left the fishery and January 1, 2000, would be deemed to have met the recent participation criteria and would be issued the general license and all species/area endorsements earned under the original crab LLP.

The table below shows the endorsements for crab vessels that qualified under proposed Amendment 10. A total of 265 vessels will be endorsed for the Tanner crab fishery, if this amendment is adopted by the Secretary.

Table. Endorsements for crab fishing licenses under the crab license limitation program, adopted by the Council as Amendment 10, October 1998.

	BSAI Tanner	Adak Brown	Adak Red	Bristol Bay Red	Dutch H. Brown	Pribilofs Blue/Red	St. Matt. Blue/Red
Factory Trawlers	6		1	5		2	2
Other Fixed-gear Cps	28	5	2	28	3	14	20
Pot CVs 125'+	42	5	5	42	5	22	35
Pot CVs 60'-124'	132	10	16	132	8	84	96
Seine Combination Cvs	1			1		2	
Trawl CVs 125'+	13	1	1	12	1	5	5
Trawl CVs 60'-124'		43		2	43		14
20							
CV / CP Licenses							
Catcher Vessels	249	18	26	248	15	136	170
Catcher Processors		16	3	1	15	2	7
8							
Grand Total	**265**	**21**	**27**	**263**	**17**	**143**	**178**

7.2 Expected Effects of Each Alternative

The Tanner crab fishery would be impacted under all the alternatives. Positive benefits to the crab fleet would be realized when Tanner crab stocks rebuild to stock sizes that can produce MSY. Proposed actions that reduce crab harvests would be expected to result in short term losses to the fleet. However, it should be noted that the fishery has been closed since 1997, so no additional costs would be incurred. The new harvest strategy adopted by the Board is expected to result in lower harvests during the rebuilding period, but is expected to provide sustainable yields in future years. Additionally, any alternatives to reduce Tanner crab bycatch in other crab fisheries such as C. opilio crab would be expected to have added costs; however the GHL for these other stocks would still be expected to be harvested.

The groundfish trawl fisheries would be impacted under alternatives that impose more restrictive Tanner crab bycatch limits. This can occur even if the overall PSC limit is not reduced below what is currently taken. This is because bycatch limits are apportioned among fisheries pre-season, and reaching one of these limits shuts down a fishery for the remainder of the season. In a perfect world, managers could know exactly how much crab would be taken in each fishery, and could apportion the PSC limit exactly. This is far from possible, however. In the end, some fisheries are apportioned more PSC than the fishery requires, and other fisheries are not apportioned enough. Although groundfish trawl fisheries can potentially be impacted under the current Zone 2 PSC limits, the excess PSC allows for some error in the preseason specification of the allocation. A reduction in the Tanner crab PSC limit would increase the possibility of a mis-allocation, resulting in a fishery closure for no measurable conservation benefit for the Tanner crab stock.

Tanner crab PSC limits in Zone 2 is based on Tanner crab abundance. Since the PSC limits are based on stock abundance, as the stock decreases, the PSC limit decreases. Therefore, the Tanner crab bycatch in the trawl fisheries will never be more that 1.2% of the estimated population of Tanner crab. In recent years the bycatch of Tanner crab in the trawl fisheries has been less than 1% of the estimated population. Reducing the bycatch to a level below 1% of the population will not measurably benefit the rebuilding of the crab stock. Reducing the bycatch limit to 0.75% of the population or to 0.50% of the population could not be shown to measurably improve the status of the stock primarily because the actual bycatch is already in this range of percentage of abundance. So, reducing the PSC limit will not actually reduce bycatch in the groundfish fishery in any measurable level. However, reducing the PSC limits most likely will economically disadvantage sectors of the groundfish fleet because of the way the PSC is allocated among the different groundfish fisheries, as discussed below.

So the question is: how much would a mis-allocation cost, and what sector of the fishery would likely bear these costs. Most likely, it would be the flatfish target trawl fisheries that would be impacted by any decrease in Tanner crab PSC caps, although all groundfish trawl target fisheries could potentially be impacted. Note that the flatfish fisheries account for about 90% of the Zone 2 Tanner crab PSC, so this is the sector that would likely be most impacted. The 1996 BSAI flatfish catch was worth \$ 47 million (from Economic SAFE). About half of the flatfish are caught in the Zone 2 area based on preliminary examination of observer data. So the flatfish in Zone 2 would have an exvessel value of about \$ 24 million. If we further assume that 80% is taken in directed flatfish fisheries, then the directed flatfish fishery in Zone 2 is worth \$ 19 million exvessel. This figure can be used to estimate costs to the fishery. For example, a PSC mis-allocation of 10% may cost the flatfish fleet \$ 1.9 million exvessel if the catch could not be made up outside Zone 2. Note however, that flatfish are taken at high CPUE outside the crab bycatch zones (Fritz et al. 1998), and the flatfish fishery generally shuts down when halibut PSC limits are achieved. A bycatch limit established at 0.5% of abundance may result in Zone 2 groundfish catch reductions of 24%, equating to about \$ 4.75 million exvessel. Therefore, it is possible to conclude that a reduction in PSC limits will cause economic hardship to a sector of the groundfish fleet by closing that fishery before the TAC is harvested. Further, it is not possible to conclude that a reduction in the PSC limit will help in the rebuilding of the crab stock because the amount of bycatch taken is minimal and a reduction in PSC will not reduce the actual amount of bycatch.

Major costs to the groundfish trawl fisheries would be incurred if additional areas were closed to trawling to protect crab habitat. In some cases, groundfish TACs would not be achieved because the fleet would be pushed from areas where the fish occur, or other bycatch limits would become constraining as the fleet is pushed into other areas. In other cases, groundfish TACs would still be taken, but the costs of harvesting would increase as the fleets would be forced to fish in less productive areas requiring additional operating expenses.

The scallop fishery would be impacted only if alternatives were adopted that closed additional areas to dredging to protect crab habitat. The State established the PSC limits for this fishery, and this analysis shown that these bycatch limits do not impose a large biological impact to the Bering Sea Tanner crab stock at its current population size.

7.3 Impacts on Communities

National Standard 8 of the Magnuson-Stevens Act mandates that conservation and management shall, consistent with the conservation requirements of this Act (including the prevention of overfishing and rebuilding of overfished stocks), take into account the importance of fishery resources to fishing communities in order to provide for the sustained participation of such communities, and to the extent practicable, minimize adverse economic impacts on such communities.

Many of the coastal communities participate in the crab and groundfish fisheries is one way or another, whether it be processing, support businesses, have a harbor, or are home to fishermen and processing workers. Major groundfish and crab ports in Alaska that process catch from the Bering Sea include Dutch Harbor, St. Paul, Akutan, Sand Point, King Cove, and Kodiak. Additionally, Seattle, Washington is home port to many catcher and catcher-processor vessels. Summary information on these communities is provided below; more detailed information about these communities is provided in the "Faces of the Fisheries" (NPFMC 1994).

Saint Paul -Saint Paul a supply and processing port for a portion of the Bering Sea groundfish and crab fleets. Major improvements to the harbor, including a dock expansion and breakwater, have allowed continual development of this community as a shipping and fishing town. There are fish processing plants, along with cold storage and warehouse facilities. The local fleet fishes primarily for halibut; local processor produce crab and several species of groundfish.

In addition to seafood harvesting and processing, employment on Saint Paul includes government administration, education, native corporation , and other service related jobs. The community is also developing tourism; visitors come from all over to see fur seals and sea bird rookeries. Subsistence hunting, fishing and gathering has always been an important part of life on the Pribilof Islands.

Dutch Harbor/Unalaska -Dutch Harbor/Unalaska has been called *"... the most prosperous stretch of coastline in Alaska."* With 27 miles of ports and harbors and several hundred local businesses, most of them servicing, supporting, or relying on the seafood industry, this city is the heart of the Bering Sea fisheries. Dutch Harbor is not only the top ranked fishing port in terms of the tonnage of fish landed in Alaska, but has held that distinction for the Nation, as a whole, each year since 1989, and ranked at or near the top in terms of value of fish landed over the same period.

Historically, Dutch Harbor was principally dependent upon non-groundfish (primarily king and Tanner crab) landings and processing for the bulk of its economic activity. These non-groundfish species continue to be important components of a diverse processing complex in Dutch Harbor. In 1997, for example, nearly 2 million pounds of salmon, more than 1.7 million pounds of herring, and 34 million pounds of crabs were reportedly processed in this port. Since the mid-1980s, groundfish and particularly pollock has accounted for the vast majority of landings in Dutch Harbor/Unalaska. Again, utilizing 1997 catch data, over 93.5% of total pounds landed and processed in this port were groundfish, 83% of which were pollock.

The facilities and related infrastructure in Dutch Harbor/Unalaska support fishing operations in the eastern Bering Sea, Aleutian Islands and GOA management areas. At least eight shore-based processors in this port receive and process fish caught in all three areas, and the wider community is linked to, and substantially dependent upon, serving both the inshore and at-sea sectors of the fishing industry. While Dutch Harbor has been characterized as one of the world's best natural harbors, it offers few alternative opportunities for economic activity beyond fisheries and fisheries support. Its remote location, limited and specialized infrastructure and transportation facilities, and high cost make attracting non-fishery related industrial and/or commercial investment doubtful, at least in the short-run.

Akutan -Akutan ranks as the second most significant landings port for groundfish, most of which is pollock, on the basis of tons delivered and has been characterized as a unique community in terms of its relationship to the BSAI fisheries. According to a recent social impact assessment, prepared for the Council, while Akutan is the site of one of the largest of the onshore pollock processing plants in the region, the community is geographically and socially separate from the plant facility.

While the community of Akutan derives economic benefits from its proximity to the large Trident Seafoods shore plant (and a smaller permanently moored processing vessel, operated by Deep Sea Fisheries, which handles only crab), the entities have not been integrated in the same manner as other landings ports and communities. The community derives some economic benefits from the fisheries, including a 1% raw fish tax from the nearby plant. Alternative economic opportunities of any kind are extremely limited.

Kodiak -Kodiak supports at least nine processing operations which receive pollock harvested from the GOA and, to a lesser extent, the eastern Bering Sea and Aleutian Islands management areas, and four more which process exclusively non-groundfish species. The port also supports several hundred commercial fishing vessels, ranging in size from small skiffs to large catcher/processors and everything in between. According to data supplied by the City, "The Port of Kodiak is 'home port' to 770 commercial fishing vessels. Not only is Kodiak the state's largest fishing port, it is also home to some of Alaska's largest trawl, longline, and crab vessels."

Kodiak has a diversified seafood processing sector. The port historically was very active in the crab fisheries and, although these fisheries have declined from their peaks in the late-1970s and early-1980s, Kodiak continues to support shellfish fisheries, as well as significant harvesting and processing operations for groundfish (particularly flatfish and pollock) Pacific halibut, herring, sablefish, and the five Pacific salmon species.

Kodiak often ranks near the top of the list of U.S. fishing ports, on the basis of landed value, and is frequently regarded as being involved in a wider variety of fisheries than any other community on the North Pacific coast. In 1997, for example, the port recorded salmon landings of just under 44 million pounds, with an estimated exvessel value of over $12 million. Approximately 4.3 million pounds of Pacific herring were landed in Kodiak with an exvessel value of more than $713,000. Crab landings exceeded 1.1 million pounds and were valued exvessel at more than $2.7 million.

In addition to seafood harvesting and processing, the Kodiak economy includes sectors such as transportation (being regarded as the transportation hub for southwest Alaska), federal/state/local government, tourism, and timber (the forest products industry, based upon Sitka spruce, is an important and growing segment of the Kodiak economy). The community is also home to the largest Coast Guard base in the U.S.

Sand Point and King Cove - Sand Point and King Cove, like Akutan, are part of the Aleutians East Borough. Both Sand Point and King Cove have had extensive historical linkages to commercial fishing and fish processing, and currently support resident commercial fleets delivering catch to local plants. These local catches are substantially supplemented by deliveries from large, highly mobile vessels, based outside of the two small Gulf of Alaska communities. King Cove possesses a deep water harbor which provides moorage for approximately 90 vessels of various sizes, in an ice-free port. Sand Point, with a 25 acre/144 slip boat harbor and marine travel-lift, is home port to what some have called " the largest fishing fleet in the Aleutians" (NPFMC, 1994).

For decades, each of these the two communities has concentrated principally on salmon fisheries. For example, in 1997, both Sand Point and King Cove recorded salmon landings of several million pounds. In addition, King Cove had significant landings of Pacific herring and crabs. Recently, each community has actively sought to diversify its fishing and processing capabilities. Few employment alternatives to commercial fishing and fish processing exist, within the cash-economy, in these communities. However, subsistence harvesting is an important source of food, as well as a social activity, for local residents in both Sand Point and King Cove.

Summary of Impacts on Communities

Changes to BSAI crab fishery regulations to rebuild Tanner crab may impact communities in the North Pacific region. Changes to the harvest strategy would affect the crab fishermen from Seattle, Dutch Harbor, Kodiak, Homer, and other communities. However, these impacts would be expected to be short lived, as some fishing on the stock will be allowed during the rebuilding period (see section 5.4), and the stock is projected , with a 50% probability , to reach rebuilt status in 10 years. This fishery generated $20 million to $90 million (exvessel) annually during the last period of high abundance (1989-1994). The costs of reduced fishing opportunities during the rebuilding period may be more than offset by benefits gained from rebuilding the Tanner crab stock to its MSY level. Note that ADF&G does not allow directed Tanner crab fisheries when the stock is at low abundance, so exvessel value is $0. Once rebuilt, these coastal communities would once again have expanded opportunities (both fishing and processing) in this potentially lucrative fishery.

7.4 Qualitative Benefit Cost Analysis

Cost data for the proposed action fishery's harvesting and processing sectors are not currently available to NMFS. For this reason, we cannot complete a quantitative cost/benefit examination of the preferred alternative, nor derive comparative net benefit conclusions about the several competing alternatives and sub-options. However, this action will not eliminate the fishery or even reduce the annual groundfish TACs or further reduce crab GHLs beyond the harvest strategy adopted by Board regulations, we can conclude that the net benefits to the US economy would not decrease by $100 million annually once costs were included in the calculation. There may be distributional economic impacts among the various sectors of the industry's affected by this proposed action.

7.5 Discussion of affected small entities

Small Business Concerns

All crab catcher vessels could be considered small businesses, with annual receipts of less than $3 million. Under proposed Amendment 10 to the Crab FMP, a total of 249 catcher vessels would receive endorsements to participate in the Bering Sea Tanner crab fishery. No catcher vessels depend solely on the Tanner crab fisheries, most catcher vessels also fish for other crab species. The rebuilding plan would allow fishing during the rebuilding period once the mature female biomass is above 21 million pounds. This is expected to occur in some years after the rebuilding plan is implemented. The impacts of closing the Tanner crab fishery on the fleet would be minimized because the fishery has been closed since 1997 and in some years prior to 1997 the GHL was very low.

In addition, an unknown number of the 16 catcher-processor vessels endorsed for the Tanner crab fishery also could be considered small entities. Similarly, an unknown number of vessels fishing for and/or processing groundfish could be considered small entities.

Communities and Groups

In 1999, Community Development Quota (CDQ) was 5% of Bering Sea crab stocks; this increased to 7.5% beginning in 2000 per Magnuson-Stevens Act. In years of low GHLs, the CDQ quotas for Tanner crab would be very small, even with the allocation increase to 7.5%. Tanner crabs will generate much higher incomes for CDQ groups when the stock is rebuilt and GHLs are increased.

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9.0 AGENCIES AND INDIVIDUALS CONSULTED

NMFS-AKRO: Mary Furuness, John Sproul
ADF&G: Rance Morrison,, Al Spalanger, Peggy Murphy Jeff Barnhart, Wayne Donaldson
UAF: Tom Shirley, Mark Hermann

Public: John Gauvin, John Hendershedt, Teresa Kandianis, Francine Bennis, Ed Paulsen, Tom Casey, Arni Thomson

Advisory Groups: BSAI Crab Plan Team, Alaska Board of Fisheries, NPFMC Scientific and Statistical Committee, NPFMC Advisory Panel

10.0 LIST OF PREPARERS

NPFMC: Dave Witherell, Linda Roberts (graphics)
ADF&G: Dave Ackley, Gordon Kruse, Doug Pengilly, Jie Zheng
NMFS: Bob Otto, Jack Turnock, Gretchen Harrington

11.0 Tables

Table 1 Annual abundance estimates (millions of crabs) for Tanner crabs from NMFS bottom trawl surveys, 1976-1998.

	Males				Females			
	Small	Pre-rec	Legal		Small	Large		
Size[1](mm)	<110	110-137	≥138[2]		<85	≥85		Grand
Width(in)	<4.3	4.3-5.5	≥5.5	Total	<3.4	≥3.4	Total	Total
1976	180.2	136.6	109.5	426.3	174.7	220.4	395.1	821.4
1977	255.0	116.3	92.1	463.4	328.4	215.8	544.2	1,007.6
1978	124.2	81.2	45.6	251.0	116.1	73.3	189.4	440.4
1979	133.1	47.7	31.5	212.3	122.6	42.1	164.7	377.0
1980	453.3	65.0	31.0	549.3	326.9	106.8	433.7	983.0
1981	303.8	24.0	14.0	341.8	324.2	79.1	403.3	745.1
1982	88.8	46.9	10.1	145.8	126.4	83.6	210.0	355.8
1983	146.3	32.0	6.7	185.0	180.1	45.4	225.5	410.5
1984	85.1	21.2	5.8	112.1	107.0	33.4	140.4	252.5
1985	31.1	9.4	4.4	45.0	24.2	15.6	39.8	84.8
1986	110.4	12.9	3.1	126.4	68.2	13.7	81.9	208.3
1987	229.9	22.0	5.9	257.8	192.4	35.5	227.8	485.6
1988	287.3	62.8	14.3	364.4	184.8	81.0	265.8	630.2
1989	403.0	110.9	33.6	547.5	338.6	63.8	402.4	949.9
1990	286.1	87.4	45.1	418.6	266.5	97.4	363.9	782.5
1991	267.2	115.8	35.1	418.1	232.1	116.8	348.9	767.0
1992	121.0	112.7	41.8	275.5	98.9	63.9	162.8	438.3
1993	76.6	70.5	20.6	167.7	57.6	29.6	87.2	254.9
1994	47.9	43.2	15.4	106.6	57.9	27.5	85.4	192.0
1995	40.4	35.7	10.0	86.1	66.6	37.2	103.8	189.9
1996	52.6	26.7	9.2	88.5	59.3	27.7	87.1	175.6
1997	65.6	9.9	3.4	78.9	70.1	10.0	80.1	159.0
1998	74.2	12.1	2.2	88.5	61.4	6.5	67.9	156.5
Limits[3]								
Lower	54.9	9.1	1.4	68.2	40.5	4.4	46.2	114.4
Upper	93.5	15.1	3.0	108.9	82.3	8.7	89.7	198.6
±%	26	25	37	23	34	33	32	27

1 Carapace width (mm).

2 ≥ 135mm (5.3 in) prior to 1987

3 Mean ± 2 standard errors for most recent year.

11.0 Tables

Table 1	Annual abundance estimates (millions of crabs) for Tanner crabs from NMFS bottom trawl surveys, 1976-1998.
Table 2	Bycatch of crab in 1996 BSAI groundfish fisheries by species, gear type, target, and regulatory area. Note that the "other Tanner crab" category is primarily C. opilio.
Table 3	Bycatch of crab in 1997 BSAI groundfish fisheries by species, gear type, target, and regulatory area. Note that the "other Tanner crab" category is primarily C. opilio.
Table 4	Bycatch of crab in 1998 BSAI groundfish fisheries by species, gear type, target, and regulatory area. Note that the "other Tanner crab" category is primarily C. opilio.
Table 5	Mortality of male Tanner crabs, as measured by adult equivalents, using 1994 and 1995 bycatch data.
Table 6	Mortality of male Tanner crabs, as measured by adult equivalents, using 1996 and 1997 bycatch data.
Table 7	Mortality of male Tanner crabs, as measured by adult equivalents, using 1998 bycatch data.
Table 8	Mortality of female Tanner crabs, as measured by adult equivalents, using 1994 and 1995 bycatch data.
Table 9	Mortality of female Tanner crabs, as measured by adult equivalents, using 1996 and 1997 bycatch data.
Table 10	Mortality of female Tanner crabs, as measured by adult equivalents, using 1998 bycatch data.

Table 2 Bycatch of crab in 1996 BSAI groundfish fisheries by species, gear type, target, and regulatory area. Note that the "other Tanner crab" category is primarily C. opilio.

1996 crab bycatch data		**red king**	**bairdi**	**o.Tanner**
by gear and target				
Hook & Line				
	P. cod	1,457	17,497	88,989
	other	84	46	895
	Total all targets	1,541	17,543	89,884
Groundfish Pot				
	P. cod	74,134	262,016	177,504
	other	0	0	8
	Total all targets	74,134	262,016	177,512
Trawl	Atka mackerel	5,543	610	65
	bottom pollock	3,361	70,861	21,069
	P. cod	3,412	182,719	110,125
	other flatfish	0	121,829	275,683
	flathead sole	199	292,860	1,038,063
	midwater pollock	2,572	18,555	42,329
	rock sole	9,761	403,646	178,026
	yellowfin sole	6,118	741,575	1,971,411
	other	1	3,376	6,841
	Total all targets	30,967	1,836,031	3,643,612
Total all gears/targets		106,642	2,115,590	3,911,008

1996 crab bycatch data		**red king**	**bairdi**	**o.Tanner**
by area (all gears/targets)				
Regulatory Area				
	508	109	39	3
	509	29,346	962,348	317,706
	512	12,966	12,238	27,993
	513	1,468	686,725	2,726,671
	514	4,812	10,224	127,827
	516	47,157	37,780	5,517
	517	1,119	270,778	427,337
	518	24	912	804
	519	0	582	1,203
	521	3,557	108,977	268,959
	523	23	2,103	2,329
	524	136	15,216	4,349
	530	0	0	0
	541	301	7,525	238
	542	78	115	55
	543	5,545	27	16
Total all gears/targets		106,641	2,115,589	3,911,007

Table 3 Bycatch of crab in 1997 BSAI groundfish fisheries by species, gear type, target, and regulatory area. Note that the "other Tanner crab" category is primarily C. opilio.

1997 crab bycatch data		red king	bairdi	o.Tanner
by gear and target				
Hook & Line				
	P. cod	4,465	11,428	140,624
	other	12	14	622
	Total all targets	4,477	11,442	141,246
Groundfish Pot				
	P. cod	21,102	38,775	412,859
	other	0	0	0
	Total all targets	21,102	38,775	412,859
Trawl	Atka mackerel	0	0	0
	bottom pollock	137	10,723	127,563
	P. cod	2,211	246,281	465,172
	other flatfish	71	35,731	72,553
	midwater pollock	0	6,525	88,589
	rock sole	38,405	469,948	568,631
	flathead sole	0	146,481	582,386
	yellowfin sole	9,886	1,000,633	3,365,135
	other	1	1,415	6,179
	Total all targets	50,711	1,917,737	5,276,208
Total all gears/targets		76,290	1,967,954	5,830,313

1997 crab bycatch data	red king	bairdi	o.Tanner
by area (all gears/targets)			
Regulatory Area			
508	0	0	0
509	15,956	844,510	1,304,240
512	8,761	488	4
513	3,161	803,065	3,441,822
514	2,601	6,119	31,216
516	45,623	12,259	1,331
517	79	244,454	775,358
518	43	756	136
519	10	3,549	3,949
521	83	33,307	190,709
523	0	343	2,151
524	0	15,881	79,292
530	0	0	0
541	1	3,170	58
542	7	51	40
543	0	0	4
Total all gears/targets	76,325	1,967,952	5,830,310

Table 4 Bycatch of crab in 1998 BSAI groundfish fisheries by species, gear type, target, and regulatory area. Note that the "other Tanner crab" category is primarily C. opilio.

1998 crab bycatch data		red king	bairdi	o.Tanner
by gear and target				
Hook & Line				
	P. cod	3,006	5,907	152,453
	other	13	36	1,393
	Total all targets	3,019	5,943	153,846
Groundfish Pot				
	P. cod	3,993	40,609	395,290
	other	0	0	3
	Total all targets	3,993	40,609	395,293
Trawl	Atka mackerel	0	121	1,084
	bottom pollock	5,078	19,314	68,449
	P. cod	3,646	106,692	259,027
	other flatfish	28	31,881	70,155
	midwater pollock	9,276	37,742	56,165
	flathead sole	1,761	208,536	672,140
	rock sole	13,246	214,264	477,327
	yellowfin sole	8,738	851,866	2,476,741
	other	230	7,400	41,560
	Total all targets	42,003	1,477,816	4,122,648
Total all gears/targets		49,015	1,524,368	4,671,787

1998 crab bycatch data	red king	bairdi	o.Tanner
by area (all gears/targets)			
Regulatory Area			
508	0	0	0
509	36,509	545,828	1,078,032
512	558	33	0
513	1,717	575,995	2,503,323
514	1,059	1,088	57,317
516	7,255	31,342	14,859
517	181	284,807	623,813
518	3	574	45
519	28	21,801	39,931
521	894	51,136	340,034
523	4	172	3,978
524	55	10,231	10,284
530	0	0	0
541	4	1,230	139
542	624	126	24
543	125	6	10
Total all gears/targets	49,015	1,524,369	4,671,789

Table 5 Mortality of male Tanner crabs, as measured by adult equivalents, using 1994 and 1995 bycatch data.

Fishery	1994 male Tanners Gear or Target	Total number impacted	Number MALES impacted	Ave. width (mm)	Approx. average age (years)	Discard mortality rate	Number killed	Approx. years to recruit (males)	Mortality in adult equivalents
Groundfish	Trawl	2,496,761	1,872,571	125	7	0.80	1,498,057	2	842,657
	Hook&line	24,546	18,410	130	7	0.45	8,284	2	4,660
	Pot	23,675	17,756	110	6	0.30	5,327	3	2,247
						total	1,511,668		849,564
Scallop	Dredge	245,000	122,500	100	6	0.40	49,000	3	20,672
Crab	Tanner crab harvest	3,351,639	3,351,639	150	9	1.00	3,351,639	0	3,351,639
	BB red king (bycatch)	0	0	130	7	0.08	0	2	0
	EBS Tanner (bycatch)	9,582,400	5,939,100	130	7	0.20	1,187,820	2	668,149
	EBS Snow (bycatch)	9,211,500	6,918,600	130	7	0.25	1,729,650	2	972,928
	Pribilof Hair (bycatch)	209,300	65,500	130	7	0.08	5,240	2	2,948
	Prib red/blue (bycatch)			130	7	0.08	0	2	0
						total	6,274,349		4,995,663
					Totals		7,835,017		5,865,899

Fishery	1995 male Tanners Gear or Target	Total number impacted	Number MALES impacted	Ave. width (mm)	Approx. average age (years)	Discard mortality rate	Number killed	Approx. years to recruit (males)	Mortality in adult equivalents
Groundfish	Trawl	2,212,181	1,659,136	125	7	0.80	1,327,309	2	746,611
	Hook&line	24,636	18,477	130	7	0.45	8,315	2	4,677
	Pot	63,038	47,279	110	6	0.30	14,184	3	5,984
						total	1,349,807		757,272
Scallop	Dredge	0	0	100	6	0.40	0	3	0
Crab	Tanner crab harvest	1,877,303	1,877,303	150	9	1.00	1,877,303	0	1,877,303
	BB red king (bycatch)	0	0	130	7	0.08	0	2	0
	EBS Tanner (bycatch)	10,367,000	5,326,000	130	7	0.20	1,065,200	2	599,175
	EBS Snow (bycatch)	5,128,000	3,699,000	130	7	0.25	924,750	2	520,172
	Pribilof Hair (bycatch)	402,300	98,000	130	7	0.08	7,840	2	4,410
	Prib red/blue (bycatch)			130	7	0.08	0	2	0
						total	3,875,093		3,001,060
					Totals		5,224,900		3,758,332

Table 6 Mortality of male Tanner crabs, as measured by adult equivalents, using 1996 and 1997 bycatch data.

Fishery	1996 male Tanners Gear or Target	Total number impacted	Number MALES impacted	Ave. width (mm)	Approx. average age (years)	Discard mortality rate	Number killed	Approx. years to recruit (males)	Mortality in adult equivalents
Groundfish	Trawl	1,836,031	1,377,023	125	7	0.80	1,101,619	2	619,660
	Hook&line	17,543	13,157	130	7	0.45	5,921	2	3,330
	Pot	262,016	196,512	110	6	0.30	58,954	3	24,871
						total	1,166,493		647,862
Scallop	Dredge	17,000	8,500	100	6	0.40	3,400	3	1,434
Crab	Tanner crab harvest	734,296	734,296	150	9	1.00	734,296	0	734,296
	BB red king (bycatch)	48,700	38,000	130	7	0.08	3,040	2	1,710
	EBS Tanner (bycatch)	1,115,300	770,300	130	7	0.20	154,060	2	86,659
	EBS Snow (bycatch)	3,204,000	2,439,000	130	7	0.25	609,750	2	342,984
	Pribilof Hair (bycatch)	220,000	95,000	130	7	0.08	7,600	2	4,275
	Prib red/blue (bycatch)			130	7	0.08	0	2	0
						total	1,508,746		1,169,924
					Totals		2,678,639		1,819,220

Fishery	1997 male Tanners Gear or Target	Total number impacted	Number MALES impacted	Ave. width (mm)	Approx. average age (years)	Discard mortality rate	Number killed	Approx. years to recruit (males)	Mortality in adult equivalents
Groundfish	Trawl	1,917,737	1,438,303	125	7	0.80	1,150,642	2	647,236
	Hook&line	11,442	8,582	130	7	0.45	3,862	2	2,172
	Pot	38,775	29,081	110	6	0.30	8,724	3	3,681
						total	1,163,228		653,089
Scallop	Dredge	28,000	14,000	100	6	0.40	5,600	3	2,363
Crab	Tanner crab harvest	0	0	150	9	1.00	0	0	0
	BB red king (bycatch)	208,900	200,000	130	7	0.08	16,000	2	9,000
	EBS Tanner (bycatch)	0	0	130	7	0.20	0	2	0
	EBS Snow (bycatch)	4,520,000	3,850,000	130	7	0.25	962,500	2	541,406
	Pribilof Hair (bycatch)	137,000	73,000	130	7	0.08	5,840	2	3,285
	Prib red/blue (bycatch)			130	7	0.08	0	2	0
						total	984,340		553,691
					Totals		2,153,168		1,209,143

Table 7 Mortality of male Tanner crabs, as measured by adult equivalents, using 1998 bycatch data.

Fishery	1998 male Tanners Gear or Target	Total number impacted	Number MALES impacted	Ave. width (mm)	Approx. average age (years)	Discard mortality rate	Number killed	Approx. years to recruit (males)	Mortality in adult equivalents
Groundfish	Trawl	1,477,816	1,108,362	125	7	0.80	886,690	2	498,763
	Hook&line	5,943	4,457	130	7	0.45	2,006	2	1,128
	Pot	40,609	30,457	110	6	0.30	9,137	3	3,855
						total	897,832		503,746
Scallop	Dredge	36,000	18,000	100	6	0.40	7,200	3	3,038
Crab	Tanner crab harvest	0	0	150	9	1.00	0	0	0
	BB red king (bycatch)	64,800	58,400	130	7	0.08	4,672	2	2,628
	EBS Tanner (bycatch)	0	0	130	7	0.20	0	2	0
	EBS Snow (bycatch)	4,092,000	3,548,000	130	7	0.25	887,000	2	498,938
	Pribilof Hair (bycatch)	137,000	73,000	130	7	0.08	5,840	2	3,285
	Prib red/blue (bycatch)			130	7	0.08	0	2	0
						total	897,512		504,851
					Totals		1,802,544		1,011,634

Table 8 Mortality of female Tanner crabs, as measured by adult equivalents, using 1994 and 1995 bycatch data.

Fishery	1994 female Tanners Gear or Target	Total number impacted	Number FEMALES impacted	Ave. width (mm)	Approx. average age (years)	Discard mortality rate	Number killed	Approx. years to maturity fem.	Mortality in adult equivalents
Groundfish	Trawl	2,496,761	624,190	85	5	0.80	499,352	1	374,514
	Hook&line	24,546	6,137	85	5	0.45	2,761	1	2,071
	Pot	23,675	5,919	85	5	0.30	1,776	1	1,332
						total	503,889		377,917
Scallop	Dredge	245,000	122,500	90	5	0.40	49,000	1	36,750
Crab	Tanner crab harvest	3,351,639	0	100	6	1.00	0	0	0
	BB red king (bycatch)	0	0	100	6	0.08	0	0	0
	EBS Tanner (bycatch)	9,582,400	3,643,300	100	6	0.20	728,660	0	728,660
	EBS Snow (bycatch)	9,211,500	2,292,900	100	6	0.25	573,225	0	573,225
	Pribilof Hair (bycatch)	209,300	143,800	100	6	0.08	11,504	0	11,504
	Prib red/blue (bycatch)			100	6	0.08	0	0	0
						total	1,313,389		1,313,389
					Totals		1,866,278		1,728,056

Fishery	1995 female Tanners Gear or Target	Total number impacted	Number FEMALES impacted	Ave. width (mm)	Approx. average age (years)	Discard mortality rate	Number killed	Approx. years to maturity fem.	Mortality in adult equivalents
Groundfish	Trawl	2,212,181	553,045	85	5	0.80	442,436	1	331,827
	Hook&line	24,636	6,159	85	5	0.45	2,772	1	2,079
	Pot	63,038	15,760	85	5	0.30	4,728	1	3,546
						total	449,936		337,452
Scallop	Dredge	0	0	90	5	0.40	0	1	0
Crab	Tanner crab harvest	1,877,303	0	100	6	1.00	0	0	0
	BB red king (bycatch)	0	0	100	6	0.08	0	0	0
	EBS Tanner (bycatch)	10,367,000	5,041,000	100	6	0.20	1,008,200	0	1,008,200
	EBS Snow (bycatch)	5,128,000	1,429,000	100	6	0.25	357,250	0	357,250
	Pribilof Hair (bycatch)	402,300	304,300	100	6	0.08	24,344	0	24,344
	Prib red/blue (bycatch)			100	6	0.08	0	0	0
						total	1,389,794		1,389,794
					Totals		1,839,730	—	1,727,246

Table 9 Mortality of female Tanner crabs, as measured by adult equivalents, using 1996 and 1997 bycatch data.

1996 female Tanners

Fishery	Gear or Target	Total number impacted	Number FEMALES impacted	Ave. width (mm)	Approx. average age (years)	Discard mortality rate	Number killed	Approx. years to maturity fem.	Mortality in adult equivalents
Groundfish	Trawl	1,836,031	459,008	85	5	0.80	367,206	1	275,405
	Hook&line	17,543	4,386	85	5	0.45	1,974	1	1,480
	Pot	262,016	65,504	85	5	0.30	19,651	1	14,738
						total	388,831		291,623
Scallop	Dredge	17,000	8,500	90	5	0.40	3,400	1	2,550
Crab	Tanner crab harvest	734,296	0	100	6	1.00	0	0	0
	BB red king (bycatch)	48,700	10,700	100	6	0.08	856	0	856
	EBS Tanner (bycatch)	1,115,300	345,000	100	6	0.20	69,000	0	69,000
	EBS Snow (bycatch)	3,204,000	765,000	100	6	0.25	191,250	0	191,250
	Pribilof Hair (bycatch)	220,000	125,000	100	6	0.08	10,000	0	10,000
	Prib red/blue (bycatch)			100	6	0.08	0	0	0
						total	271,106		271,106
					Totals		663,337		565,279

1997 female Tanners

Fishery	Gear or Target	Total number impacted	Number FEMALES impacted	Ave. width (mm)	Approx. average age (years)	Discard mortality rate	Number killed	Approx. years to maturity fem.	Mortality in adult equivalents
Groundfish	Trawl	1,917,737	479,434	85	5	0.80	383,547	1	287,661
	Hook&line	11,442	2,861	85	5	0.45	1,287	1	965
	Pot	38,775	9,694	85	5	0.30	2,908	1	2,181
						total	387,743		290,807
Scallop	Dredge	28,000	14,000	90	5	0.40	5,600	1	4,200
Crab	Tanner crab harvest	734,296	0	100	6	1.00	0	0	0
	BB red king (bycatch)	258,700	8,900	100	6	0.08	712	0	712
	EBS Tanner (bycatch)	1,115,300	0	100	6	0.20	0	0	0
	EBS Snow (bycatch)	3,204,000	670,000	100	6	0.25	167,500	0	167,500
	Pribilof Hair (bycatch)	137,000	64,000	100	6	0.08	5,120	0	5,120
	Prib red/blue (bycatch)			100	6	0.08	0	0	0
						total	173,332		173,332
					Totals		566,675		468,339

Table 10 Mortality of female Tanner crabs, as measured by adult equivalents, using 1998 bycatch data.

1998 female Tanners

Fishery	Gear or Target	Total number impacted	Number FEMALES impacted	Ave. width (mm)	Approx. average age (years)	Discard mortality rate	Number killed	Approx. years to maturity fem.	Mortality in adult equivalents
Groundfish	Trawl	1,477,816	369,454	85	5	0.80	295,563	1	221,672
	Hook&line	5,943	1,486	85	5	0.45	669	1	501
	Pot	40,609	10,152	85	5	0.30	3,046	1	2,284
						total	299,277		224,458
Scallop	Dredge	36,000	18,000	90	5	0.40	7,200	1	5,400
Crab	Tanner crab harvest	na	na	100	6	1.00	0	0	0
	BB red king (bycatch)	64,800	6,400	100	6	0.08	512	0	512
	EBS Tanner (bycatch)	0	0	100	5	0.20	0	0	0
	EBS Snow (bycatch)	4,092,000	544,000	100	6	0.25	136,000	0	136,000
	Pribilof Hair (bycatch)	137,000	64,000	100	6	0.08	5,120	0	5,120
	Prib red/blue (bycatch)			100	6	0.08	0	0	0
						total	141,632		141,632
					Totals		448,109		371,490

12.0 Figures

Figure 1 Distribution of small female Tanner crab from the 1998 NMFS summer trawl survey.

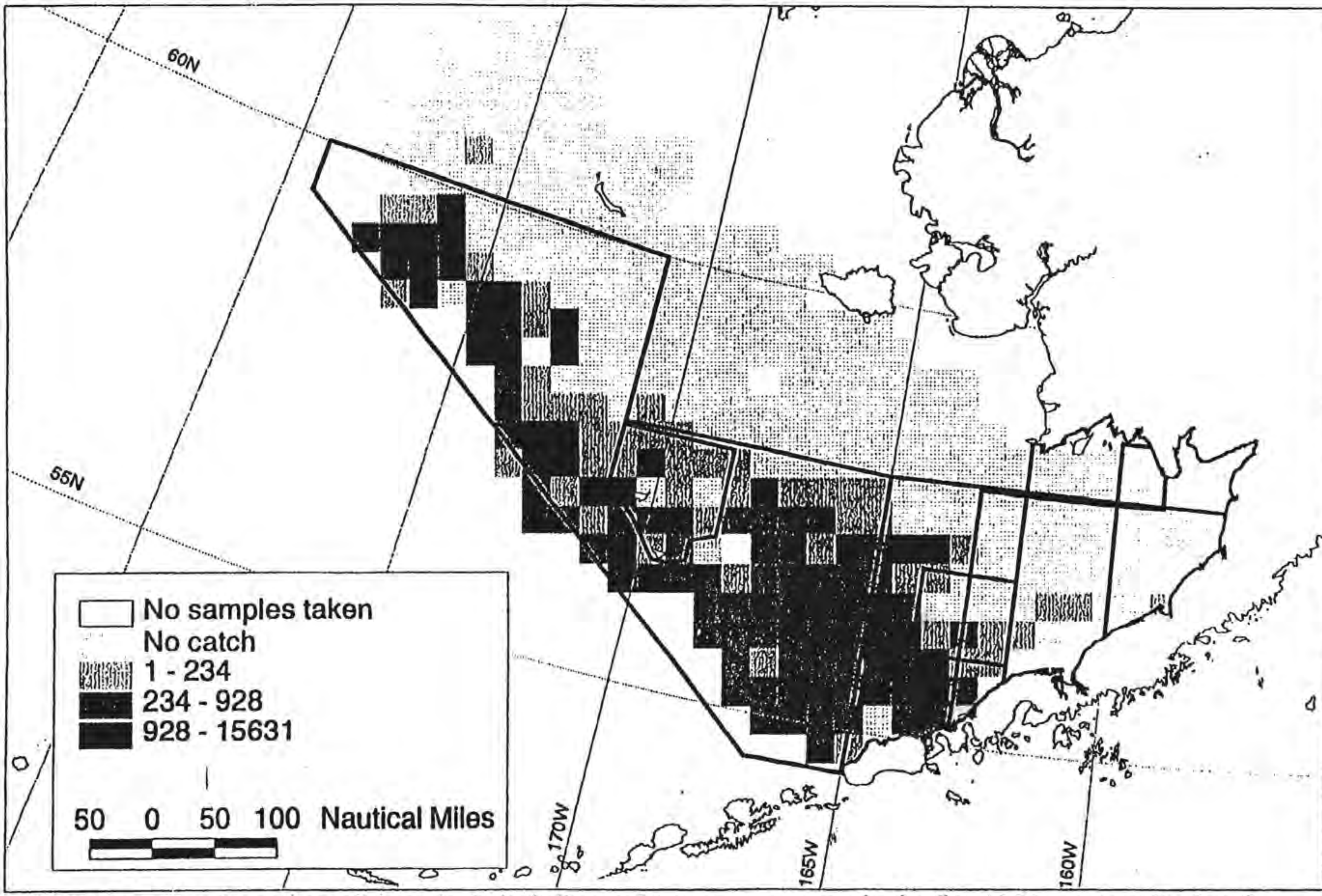


Figure xx. Number of small female C. bairdi caught per square nautical mile, 1998 eastern Bering Sea crab-groundfish survey.

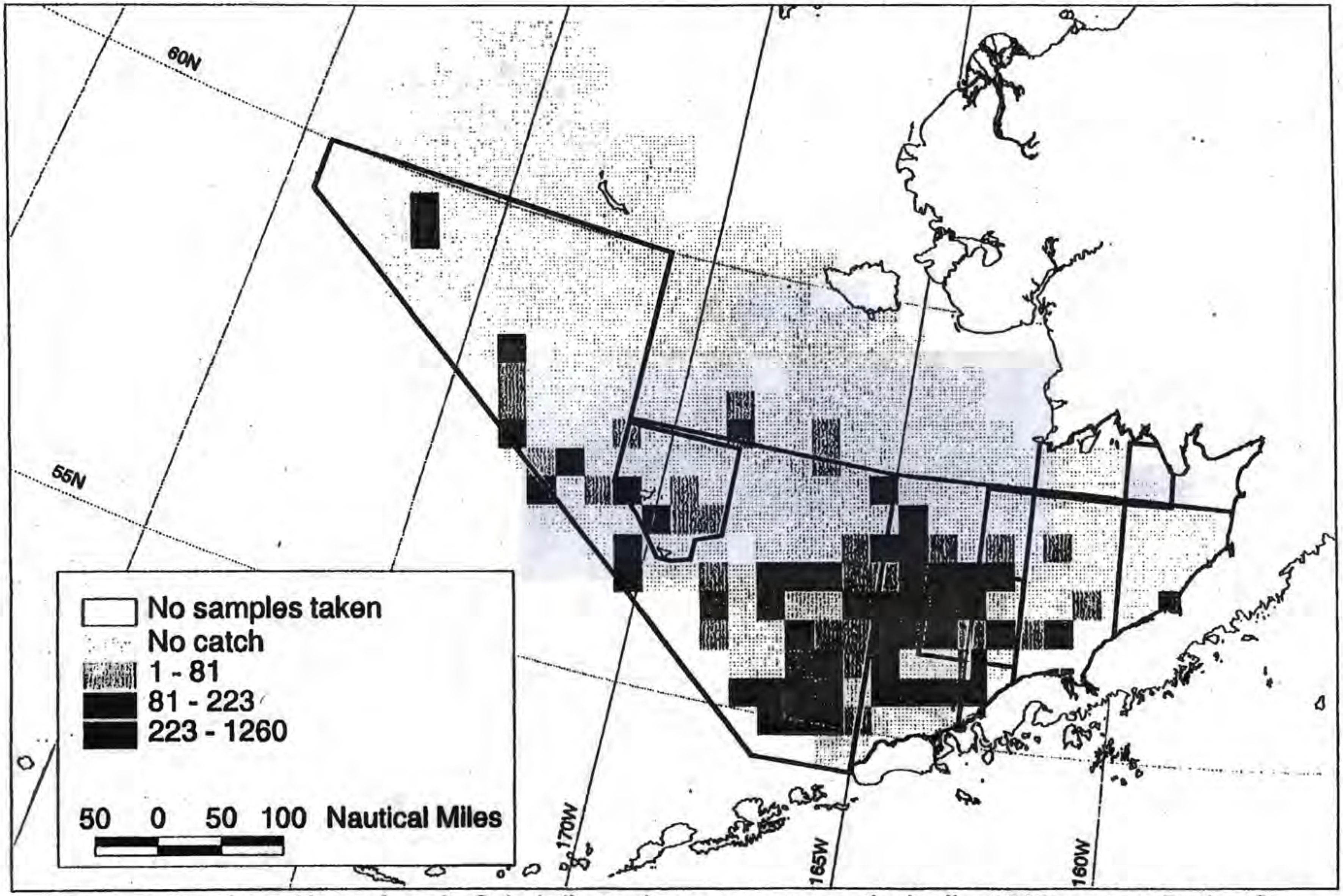


Figure xx. Number of large female C. bairdi caught per square nautical mile, 1998 eastern Bering Sea crab-groundfish survey.

Figure 3 : Distribution of small male C. bairdi from the 1998 NMFS summer trawl survey.

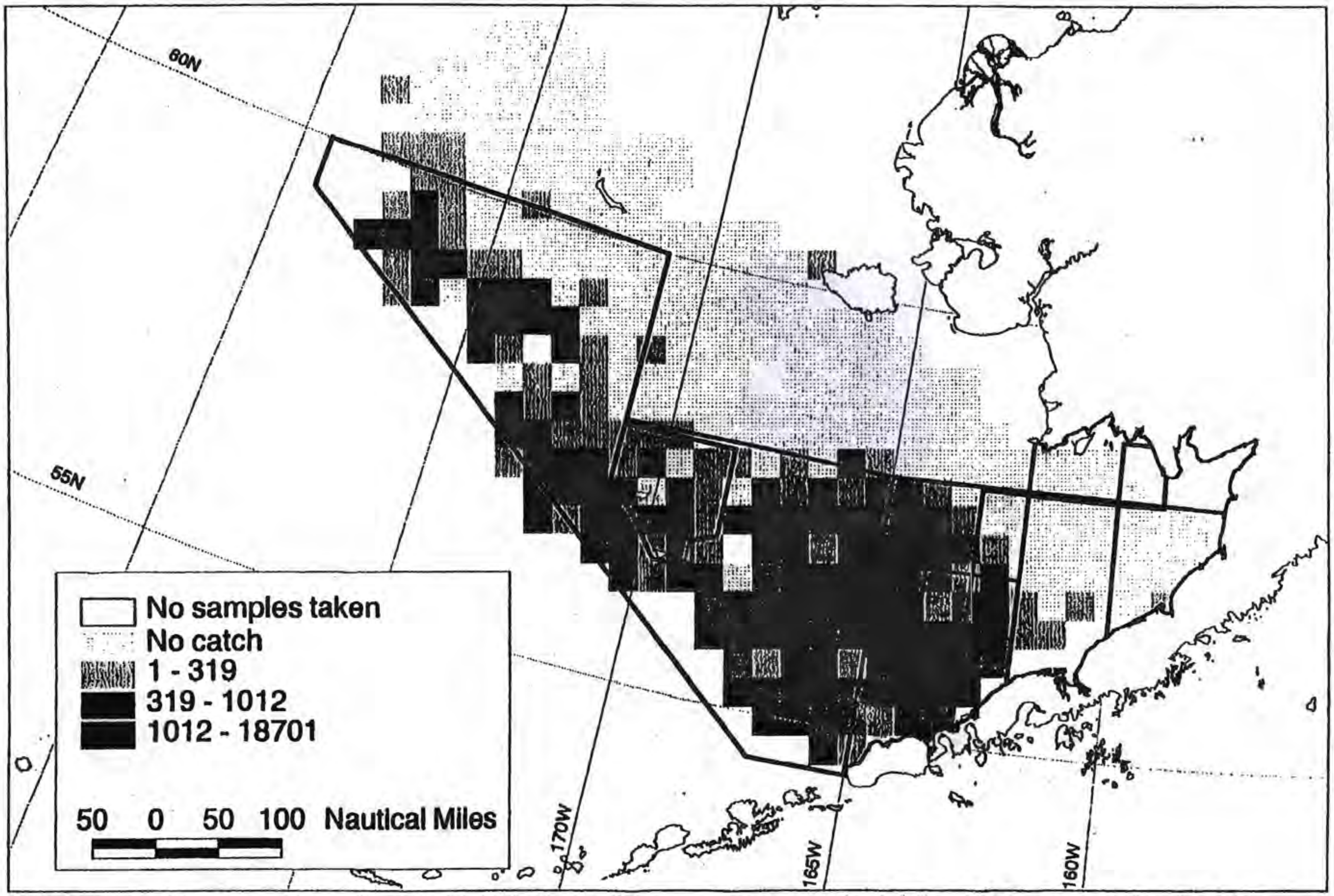


Figure xx. Number of small male C. bairdi caught per square nautical mile, 1998 eastern Bering Sea crab-groundfish survey.

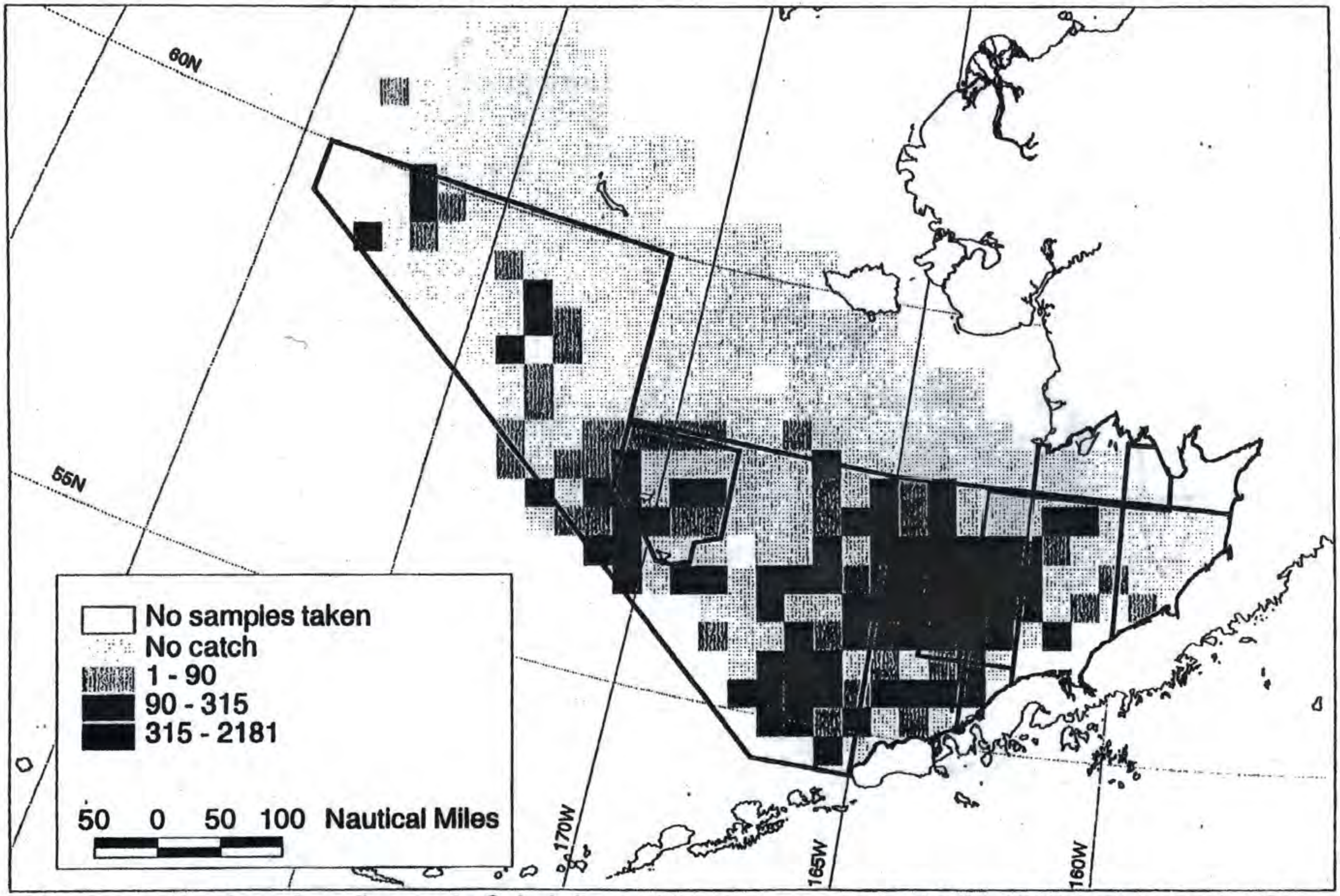


Figure xx. Number of medium male C. bairdi caught per square nautical mile, 1998 eastern Bering Sea crab-groundfish survey.

Figure 5 Distribution of large male C. bairdi from the 1998 NMFS summer trawl survey.

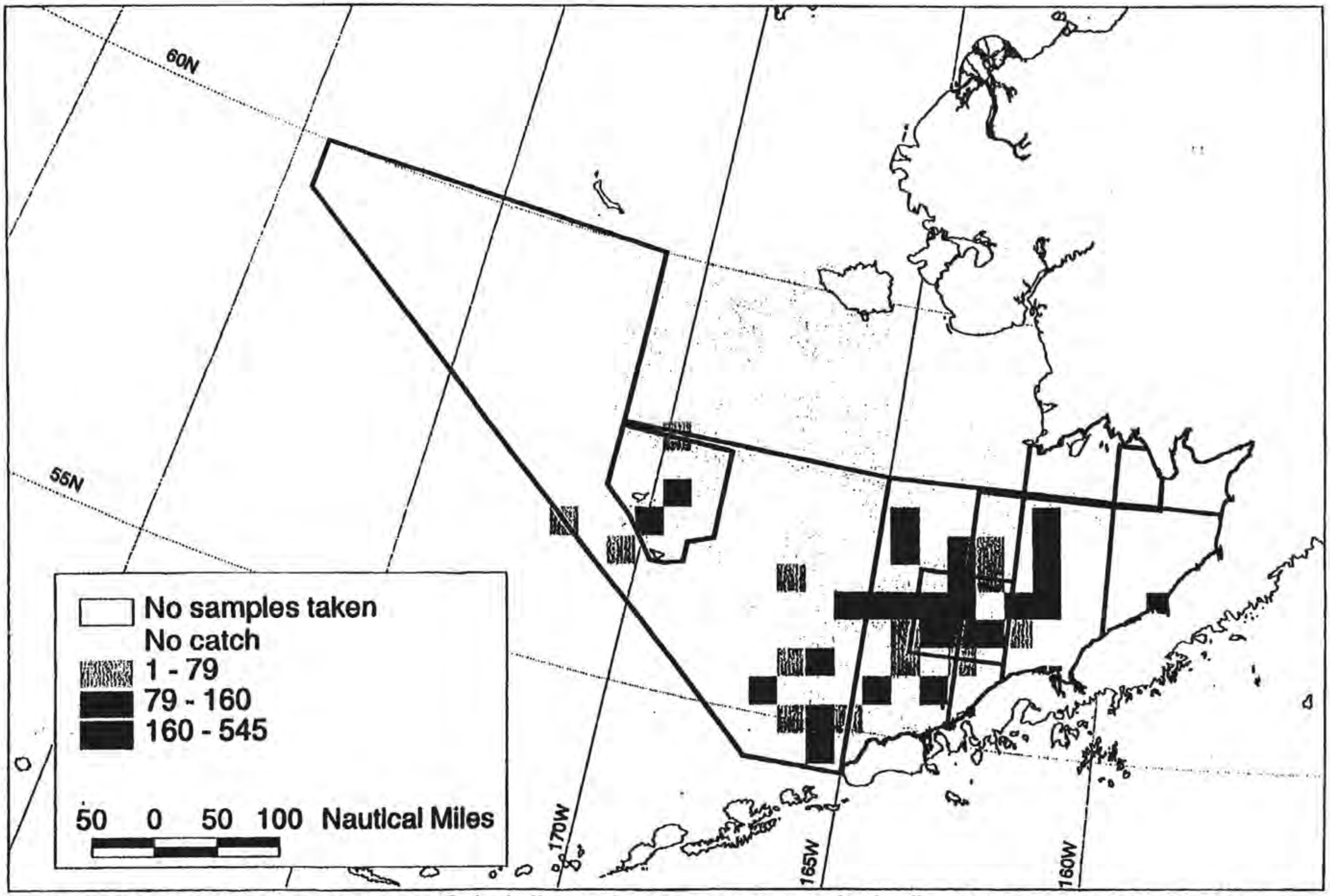


Figure xx. Number of large male C. bairdi caught per square nautical mile, 1998 eastern Bering Sea crab-groundfish survey.

Figure 6 Length Frequency of male C. bairdi from the 1996-98 NMFS summer trawl surveys.

Tanner Crab Width Frequency
Eastern District

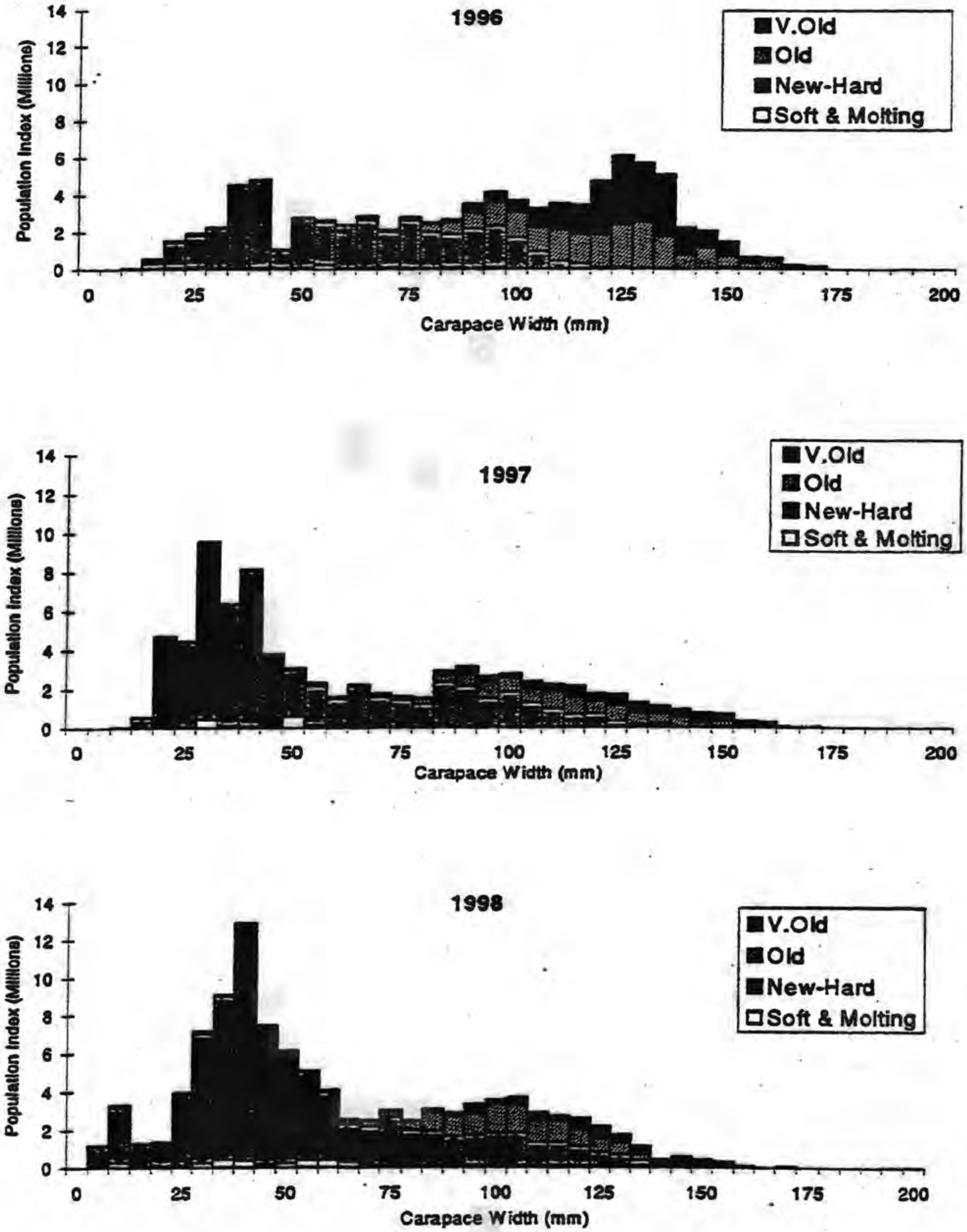


FIGURE Size-frequency of male Tanner crab (*C. bairdi*) in the Eastern District, by 5 mm width classes, 1996-1998.

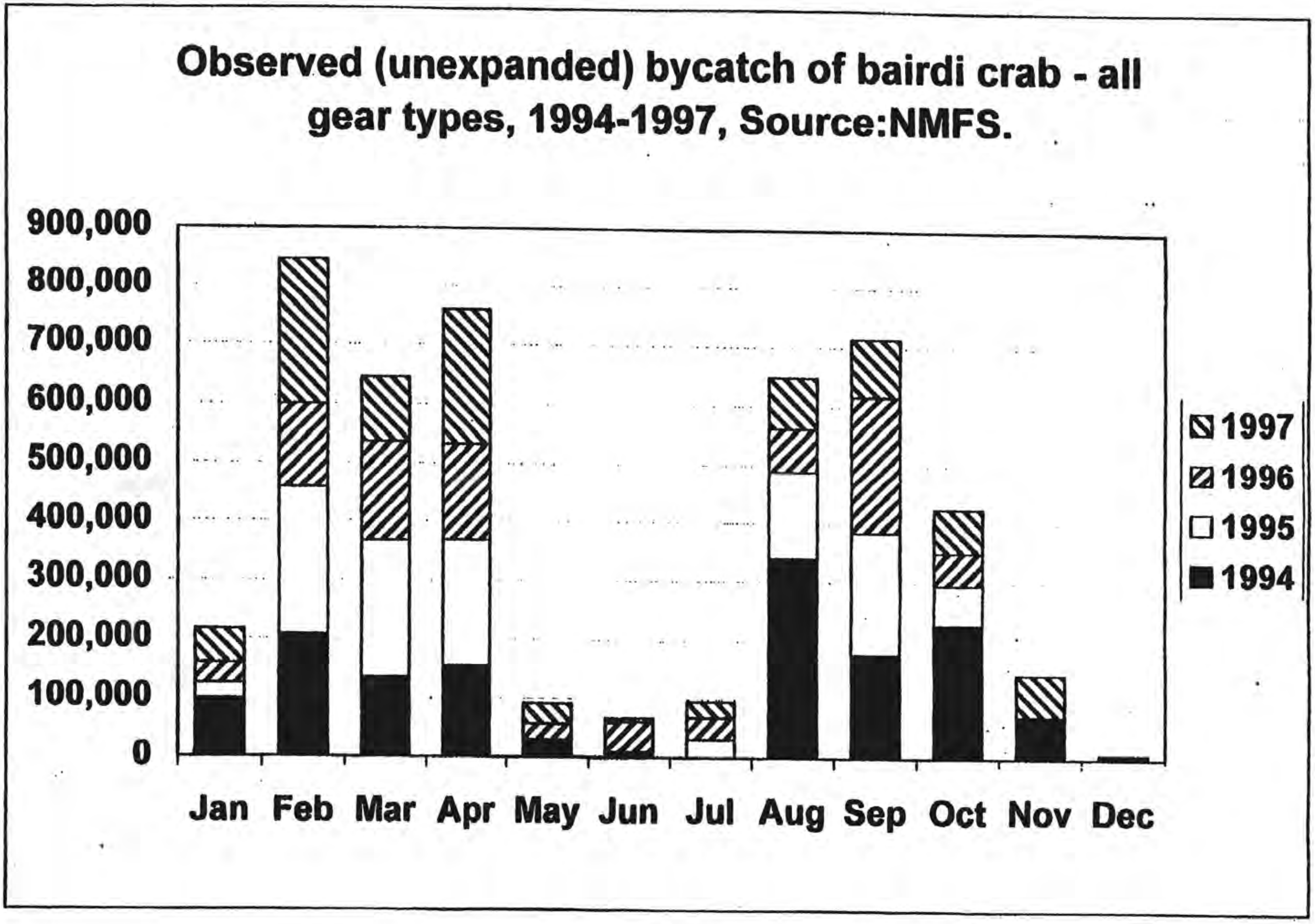


Figure 7 Bycatch of Tanner crab from all groundfish fisheries, by month 1994-1997. Unexpended data.

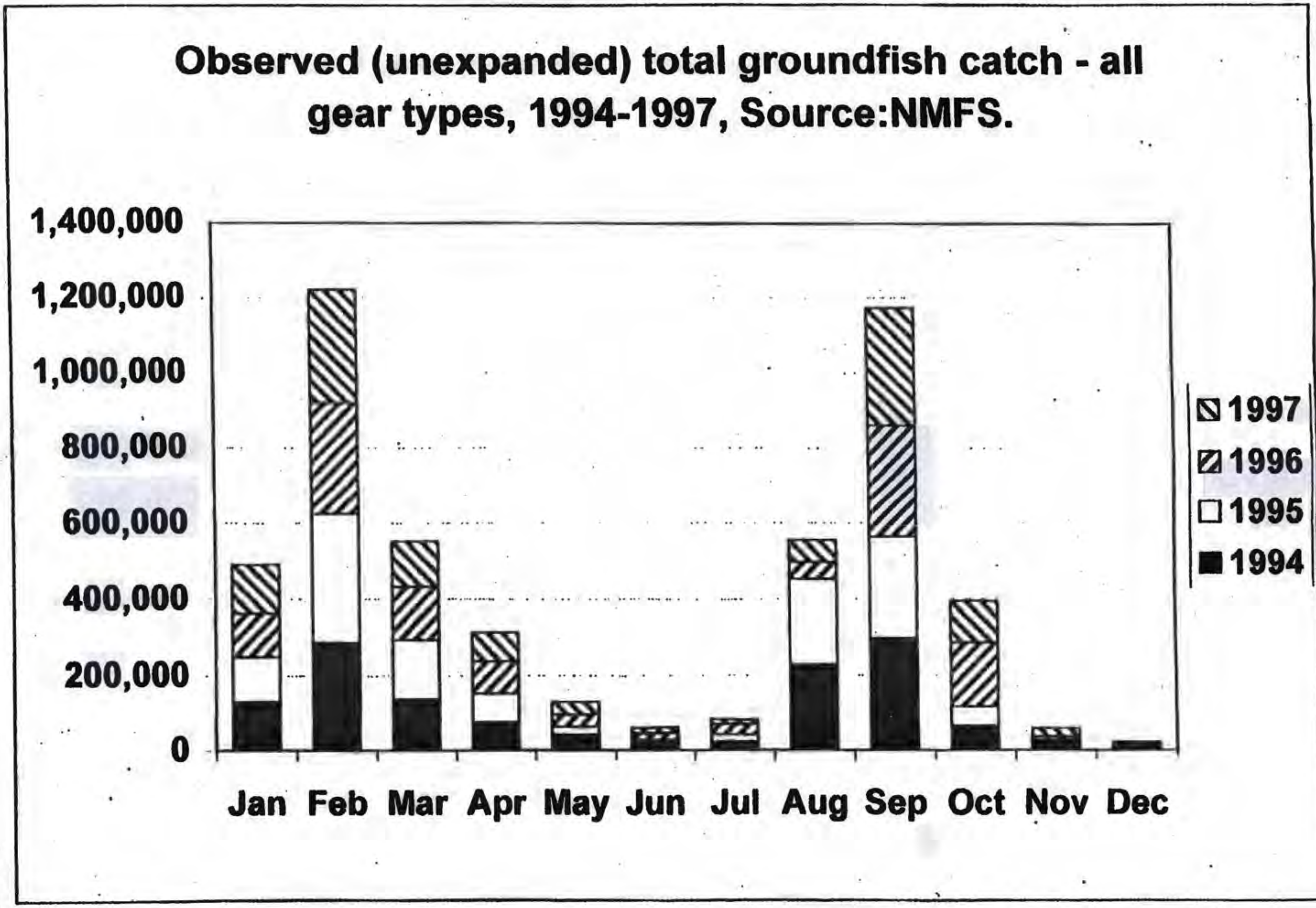


Figure 8 Total groundfish catch from all groundfish fisheries, by month 1994-1997. Unexpended data.

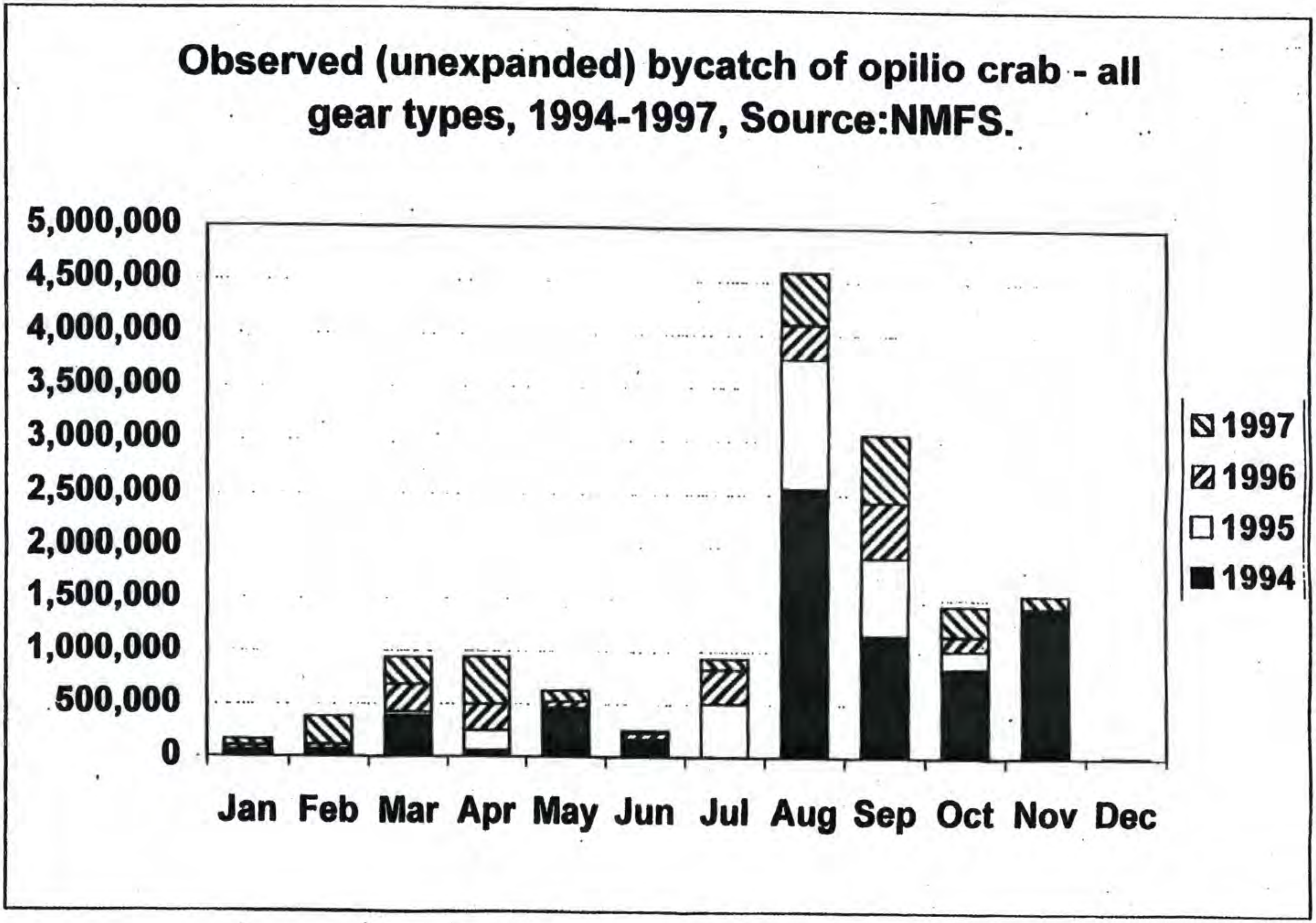


Figure 9 Bycatch of snow crab from all groundfish fisheries, by month 1994-1997. Unexpended data.

Figure 10 Reference map showing blocks relative to statistical areas and the red king crab savings area.

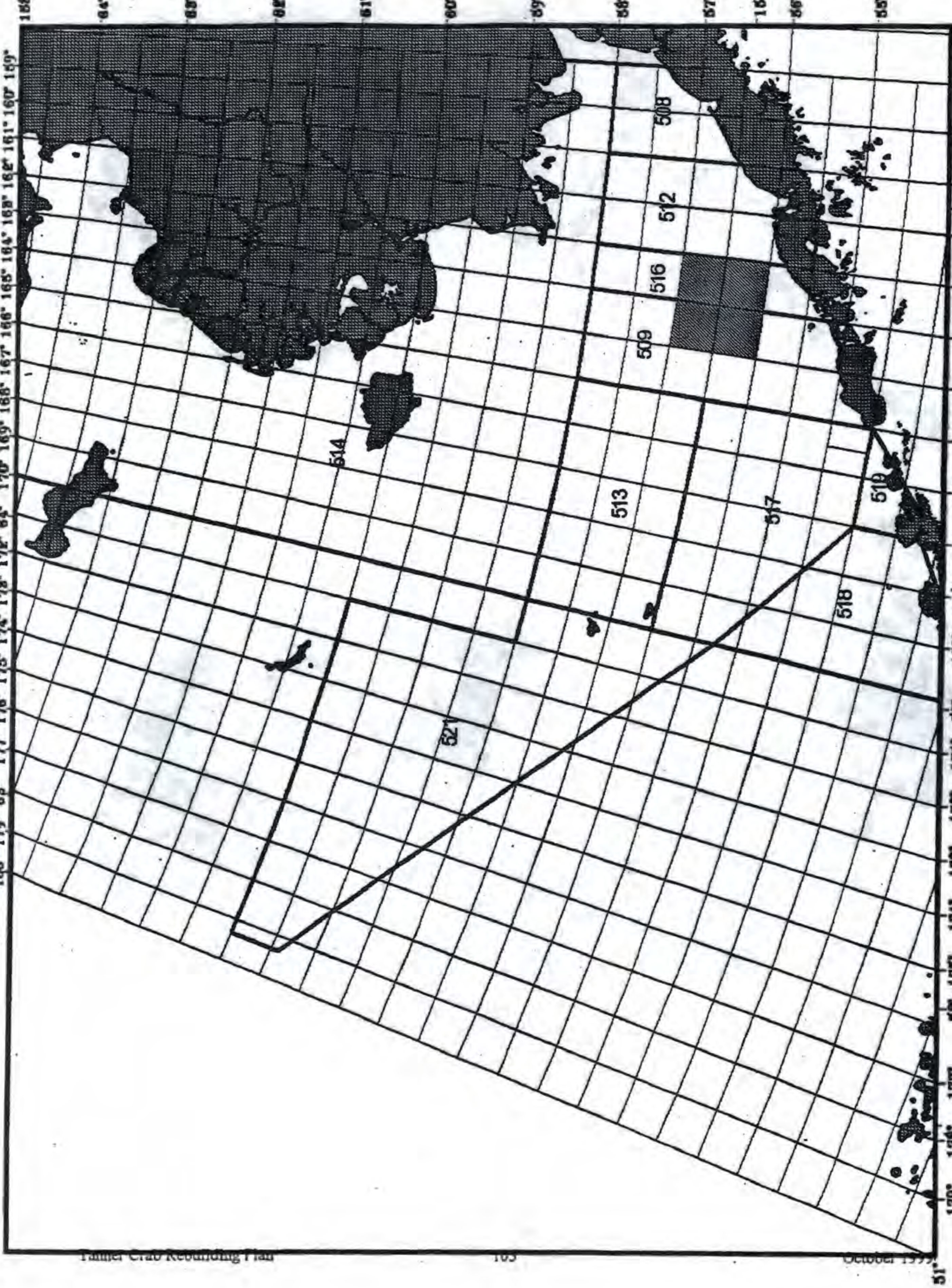


Figure 11 Total bycatch of Tanner crab from groundfish trawl fisheries 1994-1997.

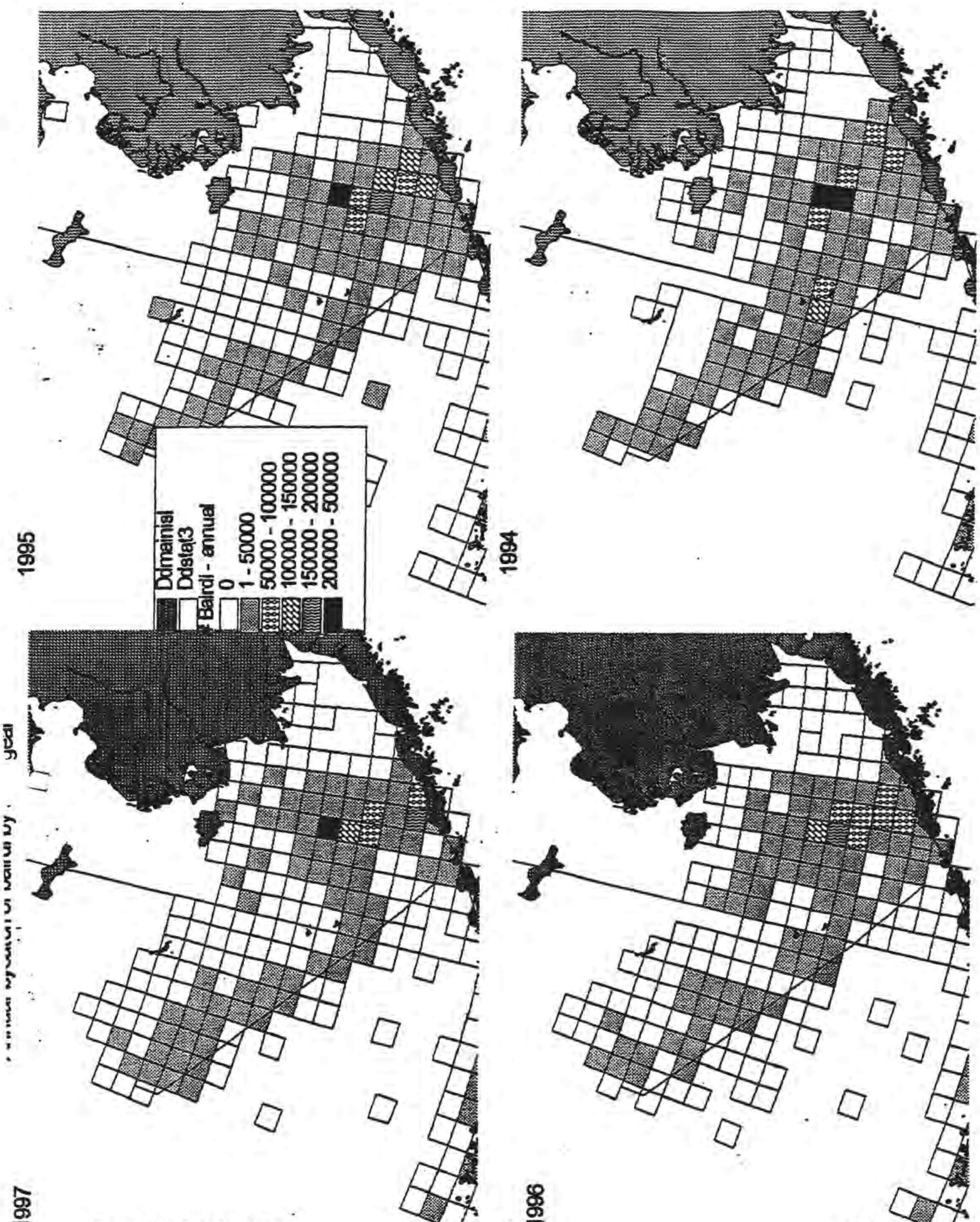


Figure 12 Bycatch rates of Tanner crab from groundfish trawl fisheries 1994-1997.

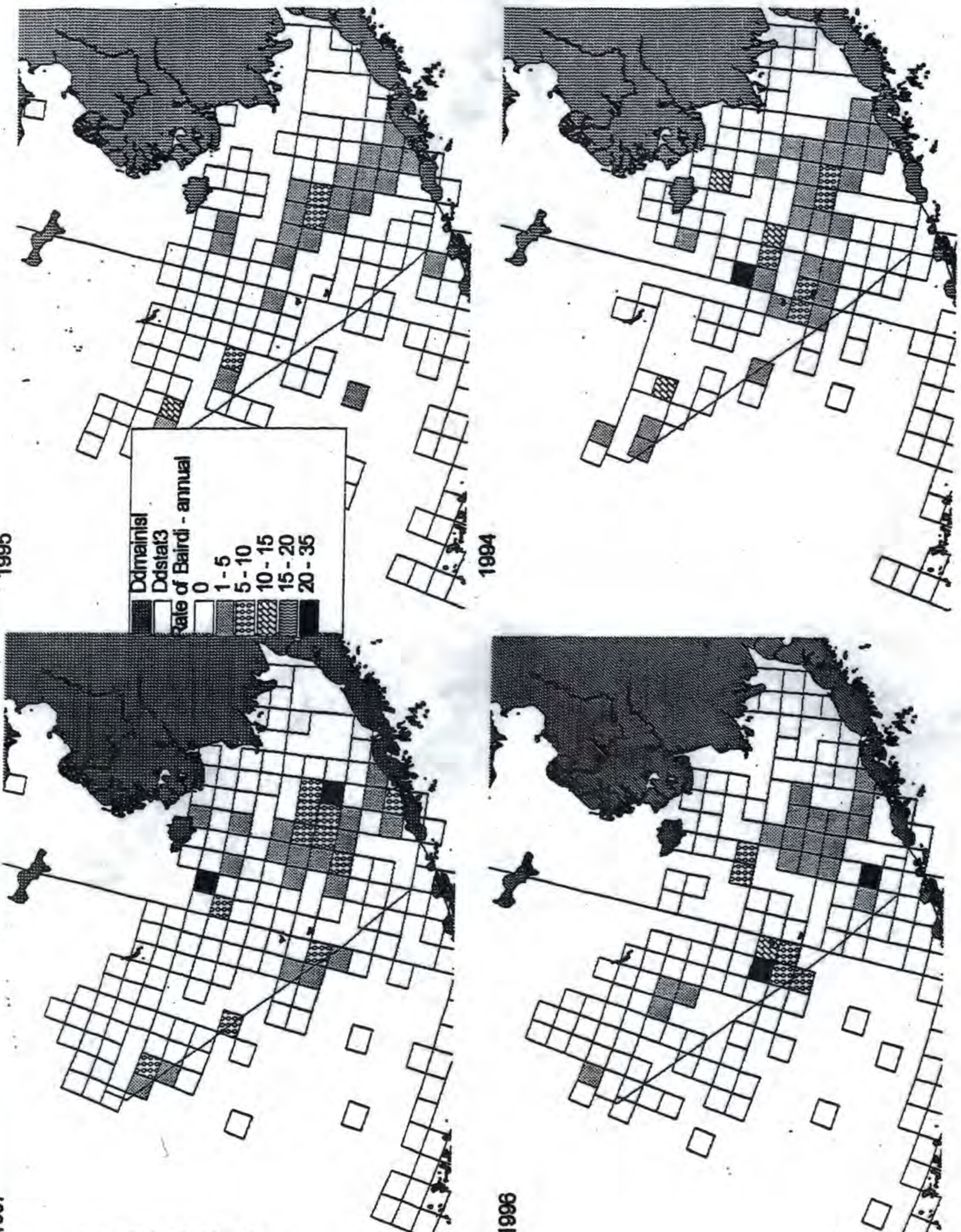


Figure 13 Total bycatch of Tanner crab from groundfish fixed gear fisheries 1994-1997.

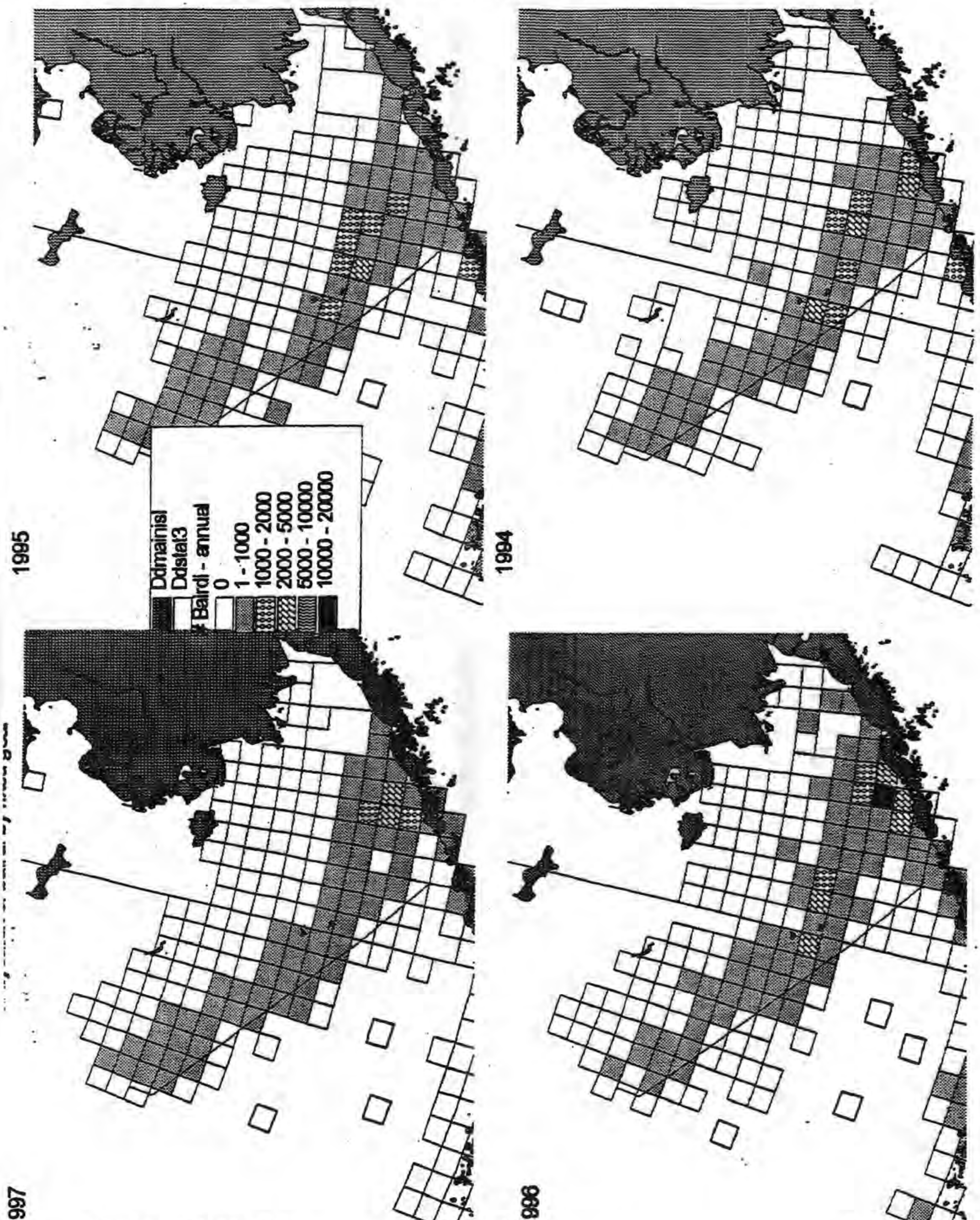


Figure 14 Bycatch rates of Tanner crab from groundfish fixed gear fisheries 1994-1997.

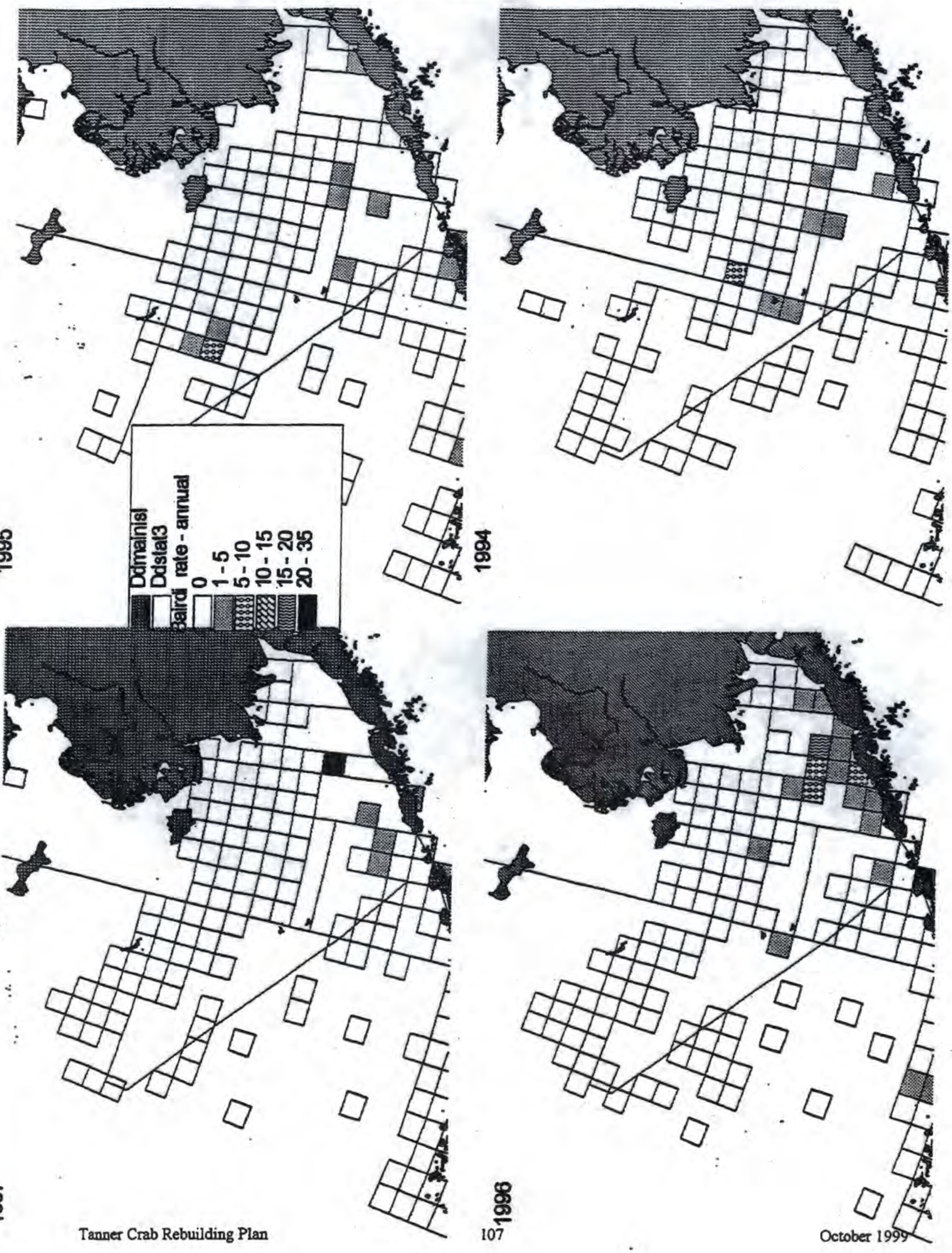


Figure 15 Total bycatch of snow crab from groundfish trawl fisheries 1994-1997.

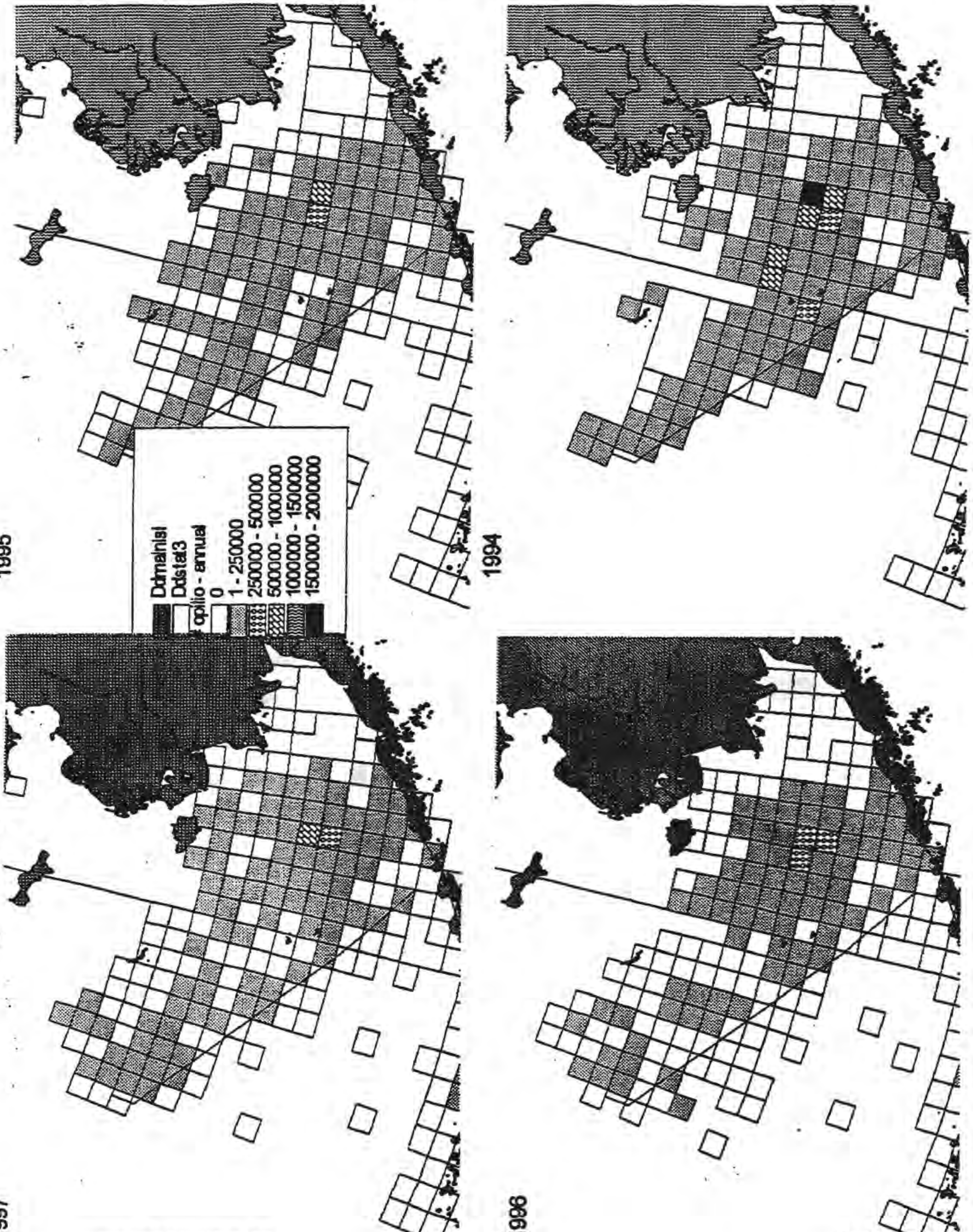


Figure 16 Total bycatch of snow crab from groundfish fixed gear fisheries 1994-1997.

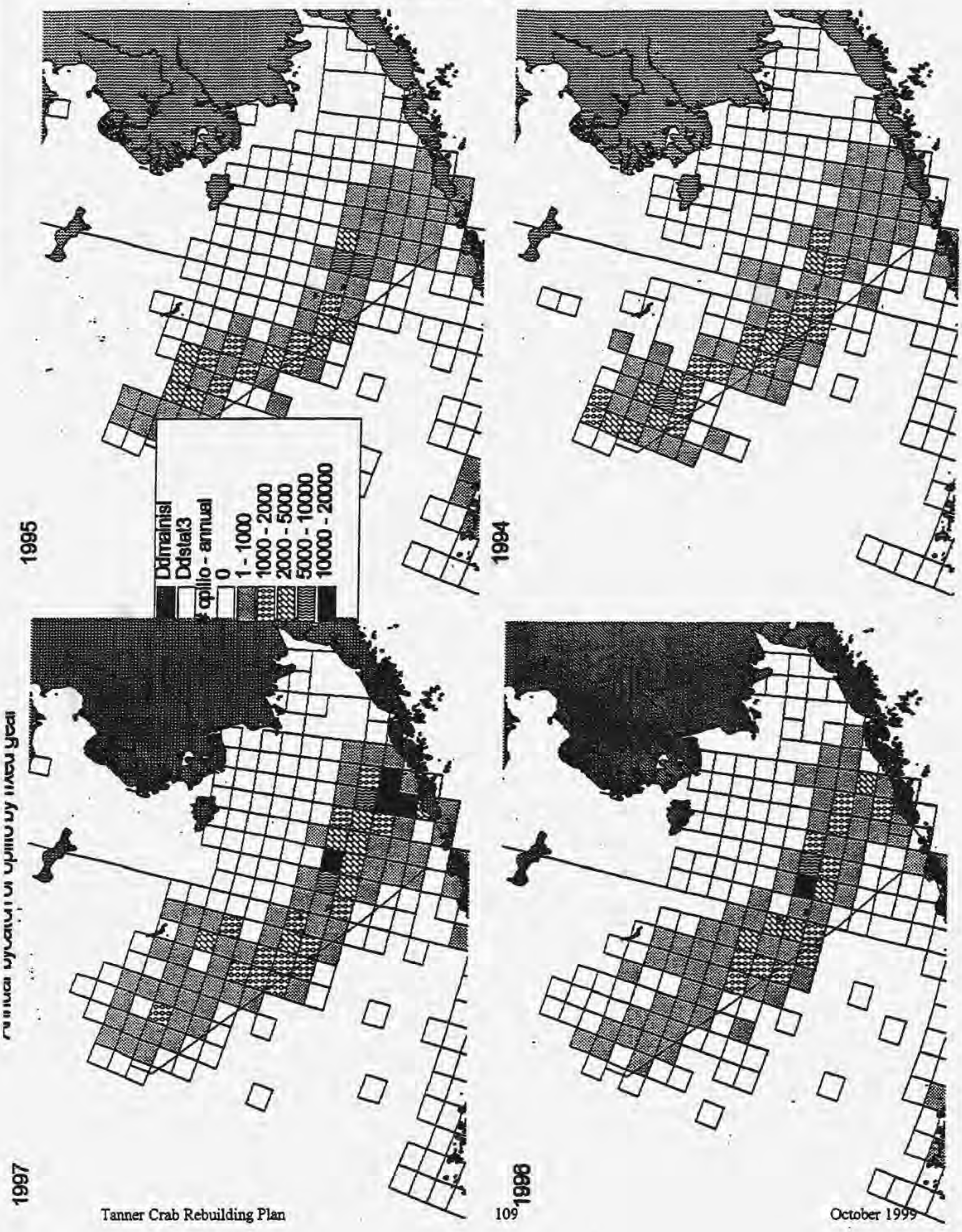
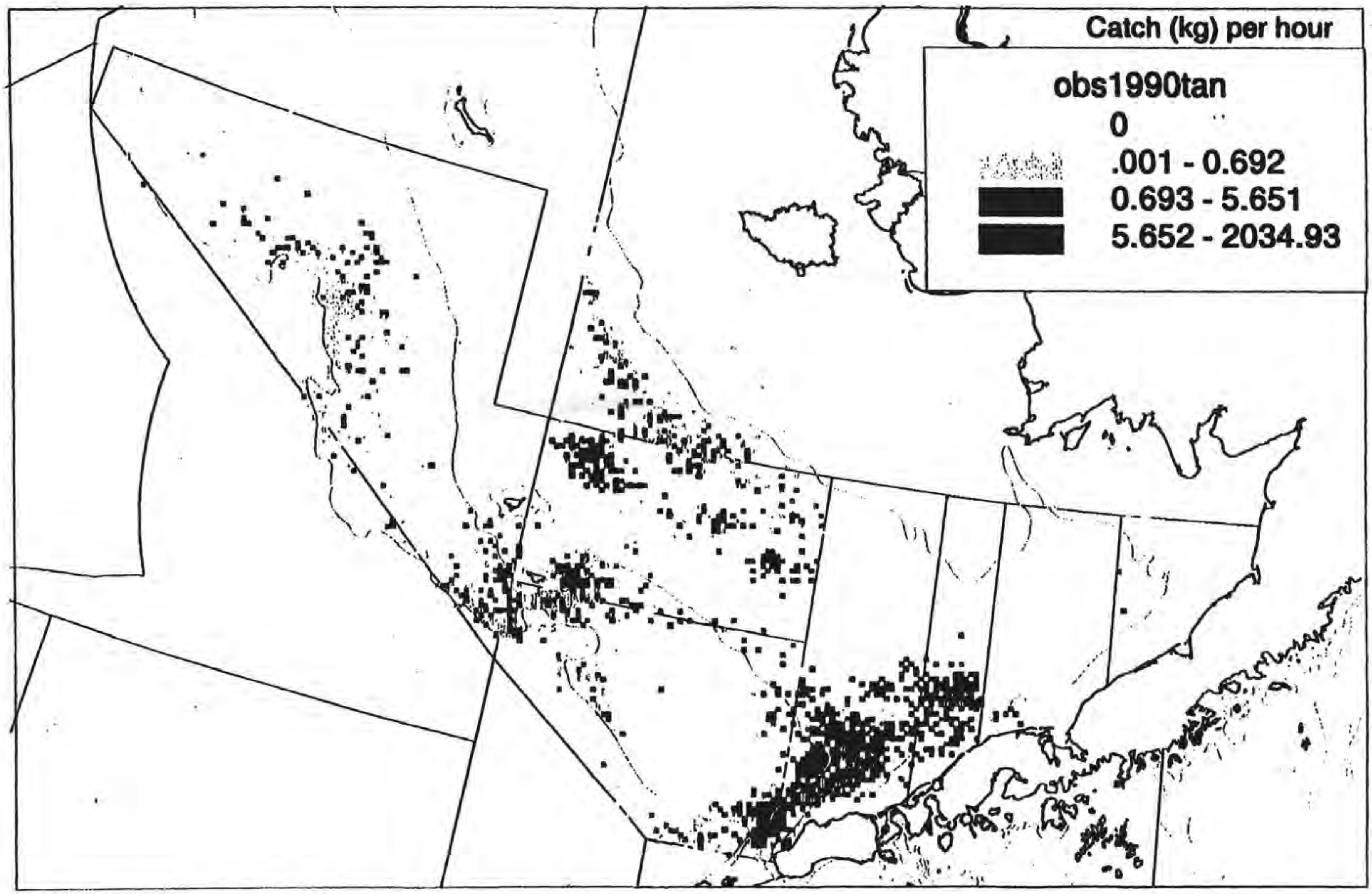
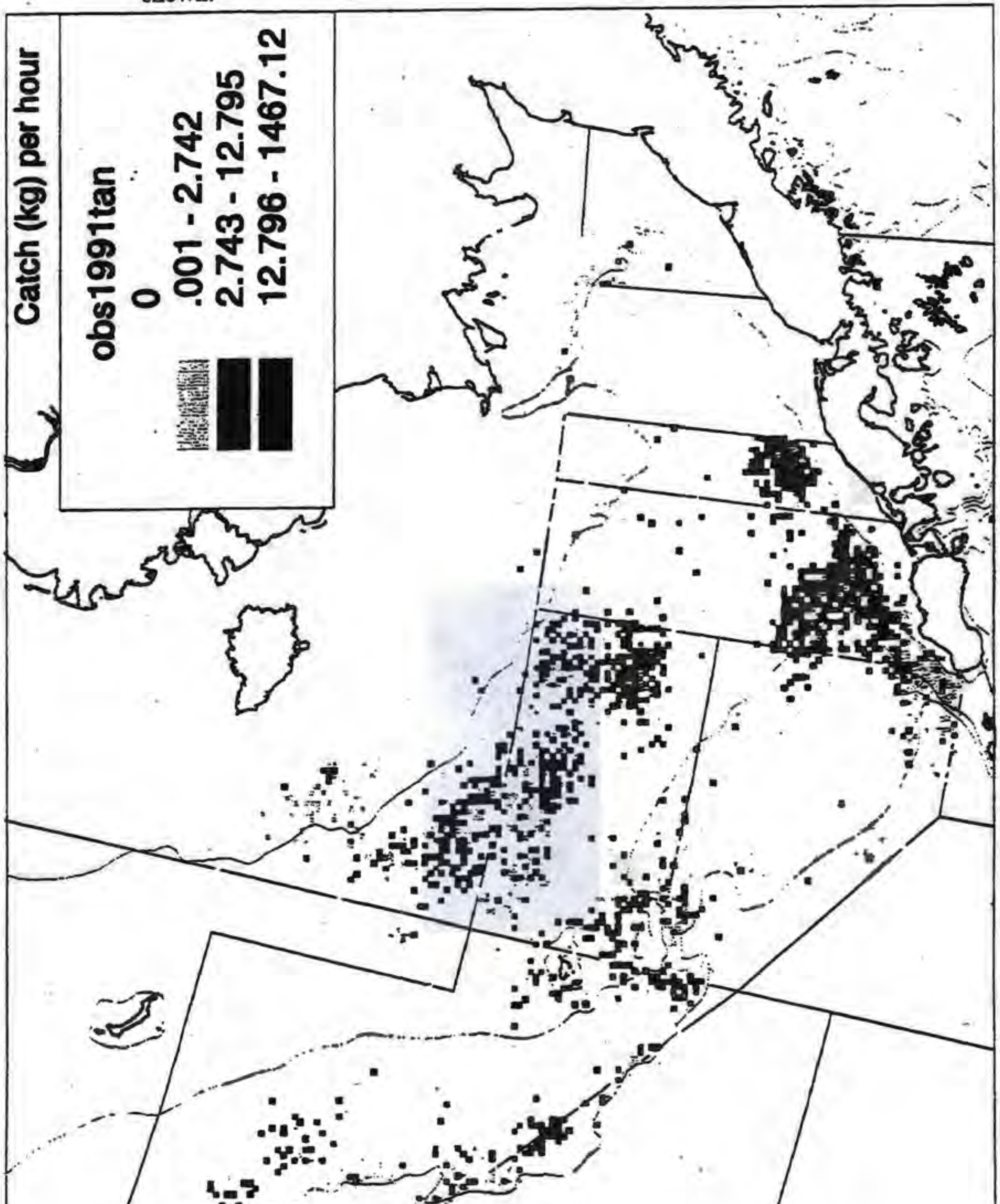


Figure 17 Tanner crab (C. bairdi) catch per hour summary from bottom trawl groundfish fishery data in the eastern Bering Sea. Non-zero CPUE data are grouped into lower, middle, and upper thirds of the distribution. Domestic data 1990. NPFMC management area boundaries are shown.



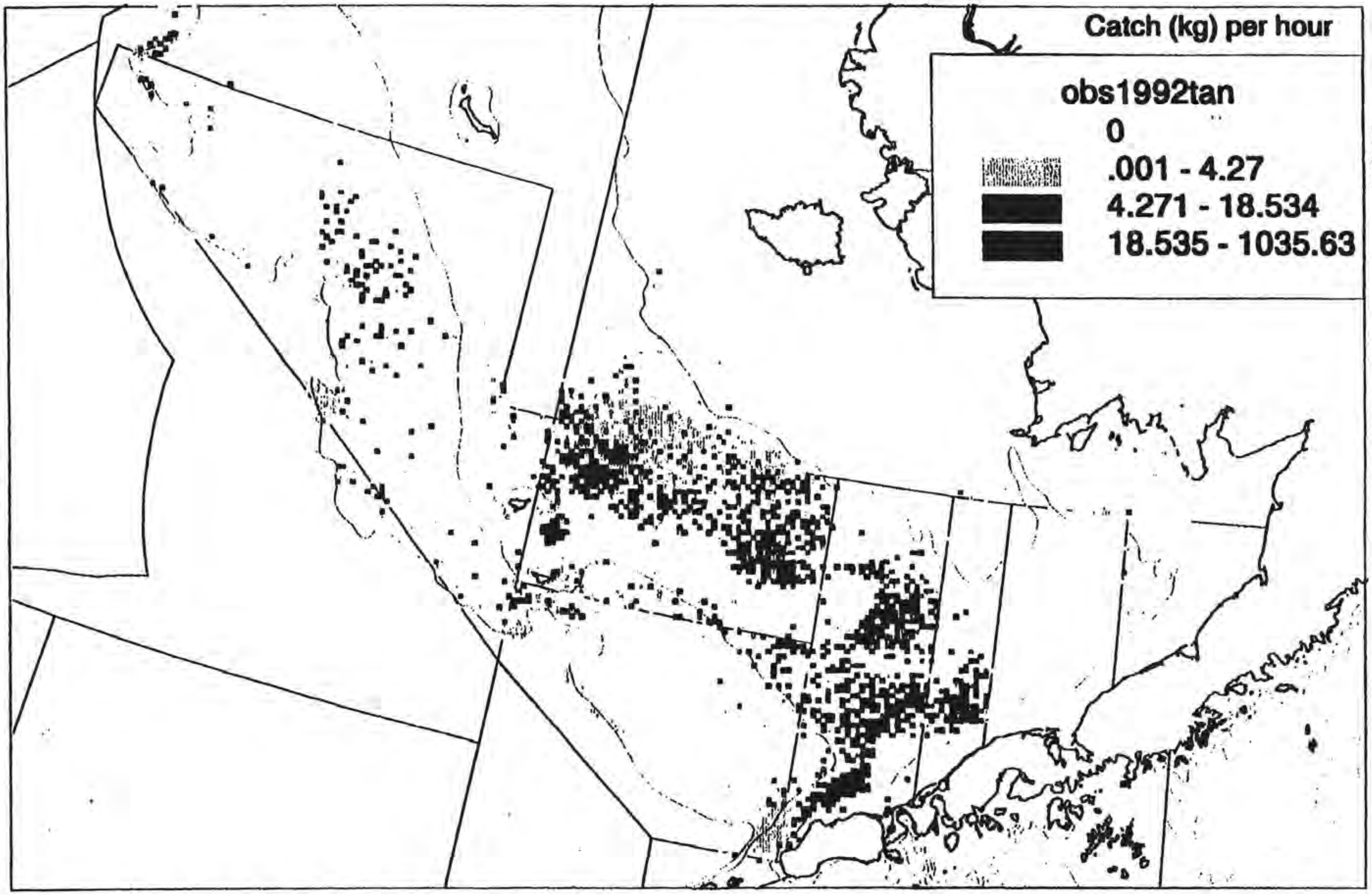
Tanner crab (C. bairdi) catch (kg) per hour summary from bottom trawl groundfish fishery data in the eastern Bering Sea. Non-zero CPUE data are grouped into lower, middle, and upper thirds of the distribution. Domestic data 1990. NPFMC management area boundaries are shown.

Figure 18 Tanner crab (C. bairdi) catch per hour summary from bottom trawl groundfish fishery data in the eastern Bering Sea. Non-zero CPUE data are grouped into lower, middle, and upper thirds of the distribution. Domestic data 1991. NPFMC management area boundaries are shown.



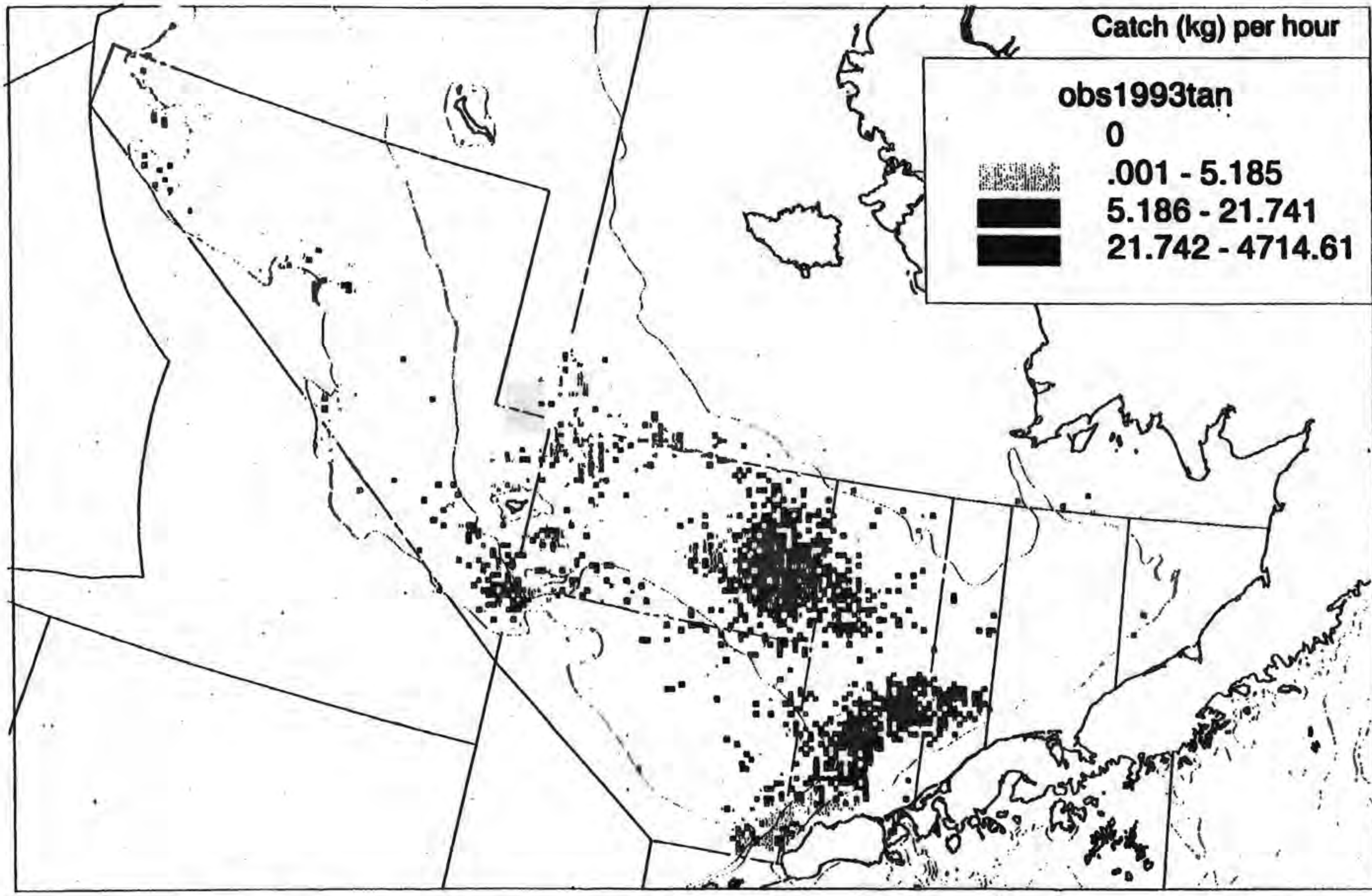
Tanner crab (C. bairdi) catch (kg) per hour summary from bottom trawl groundfish fishery data in the eastern Bering Sea. Non-zero CPUE data are grouped into lower, middle, and upper thirds of the distribution. Domestic data 1991. NPFMC management area boundaries are shown.

Figure 19 Tanner crab (C. bairdi) catch per hour summary from bottom trawl groundfish fishery data in the eastern Bering Sea. Non-zero CPUE data are grouped into lower, middle, and upper thirds of the distribution. Domestic data 1992. NPFMC management area boundaries are shown.



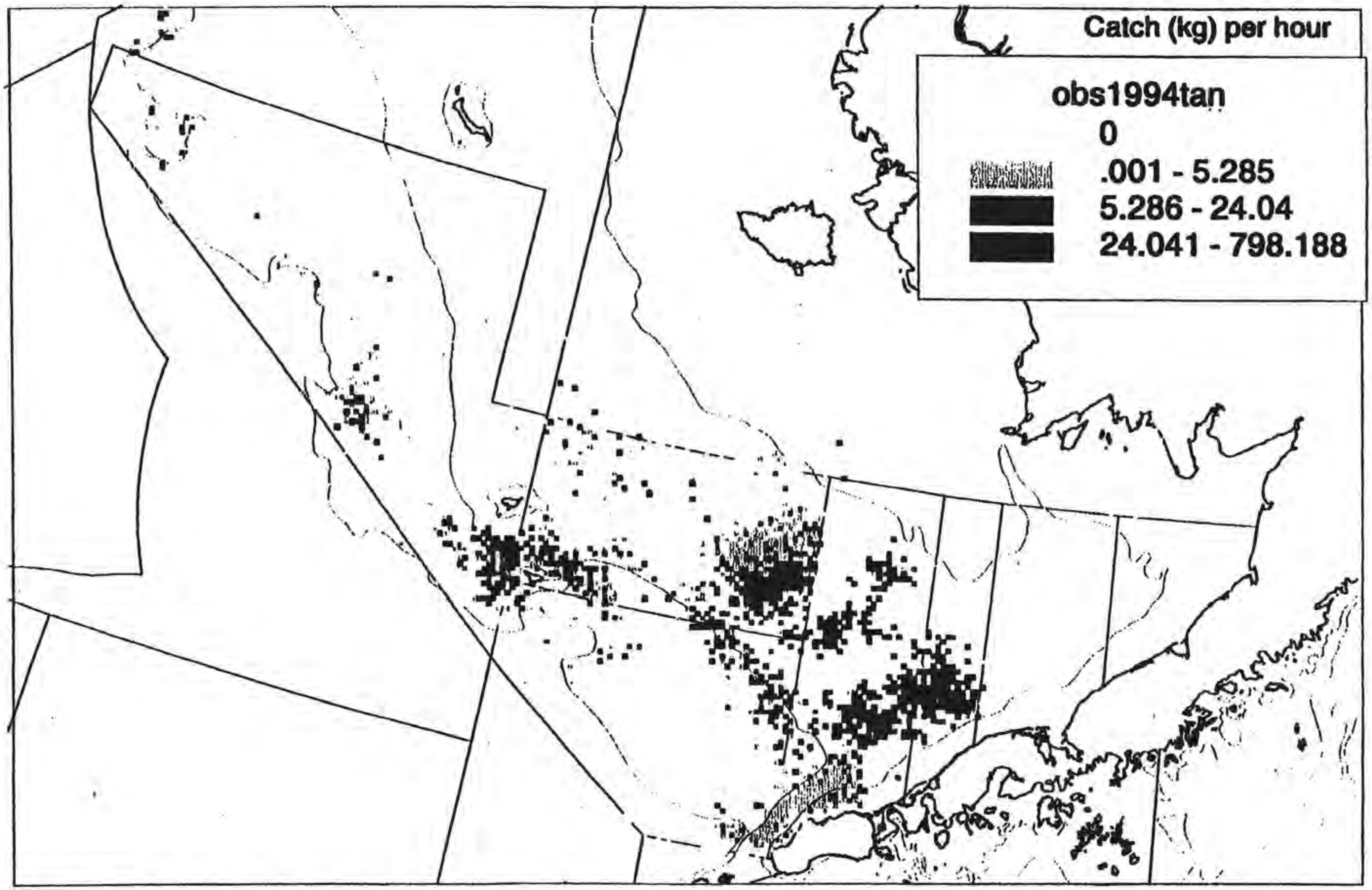
Tanner crab (C. bairdi) catch (kg) per hour summary from bottom trawl groundfish fishery data in the eastern Bering Sea. Non-zero CPUE data are grouped into lower, middle, and upper thirds of the distribution. Domestic data 1992. NPFMC management area boundaries are shown.

Figure 20 Tanner crab (C. bairdi) catch per hour summary from bottom trawl groundfish fishery data in the eastern Bering Sea. Non-zero CPUE data are grouped into lower, middle, and upper thirds of the distribution. Domestic data 1993. NPFMC management area boundaries are shown.



Tanner crab (C. bairdi) catch (kg) per hour summary from bottom trawl groundfish fishery data in the eastern Bering Sea. Non-zero CPUE data are grouped into lower, middle, and upper thirds of the distribution. Domestic data 1993. NPFMC management area boundaries are shown.

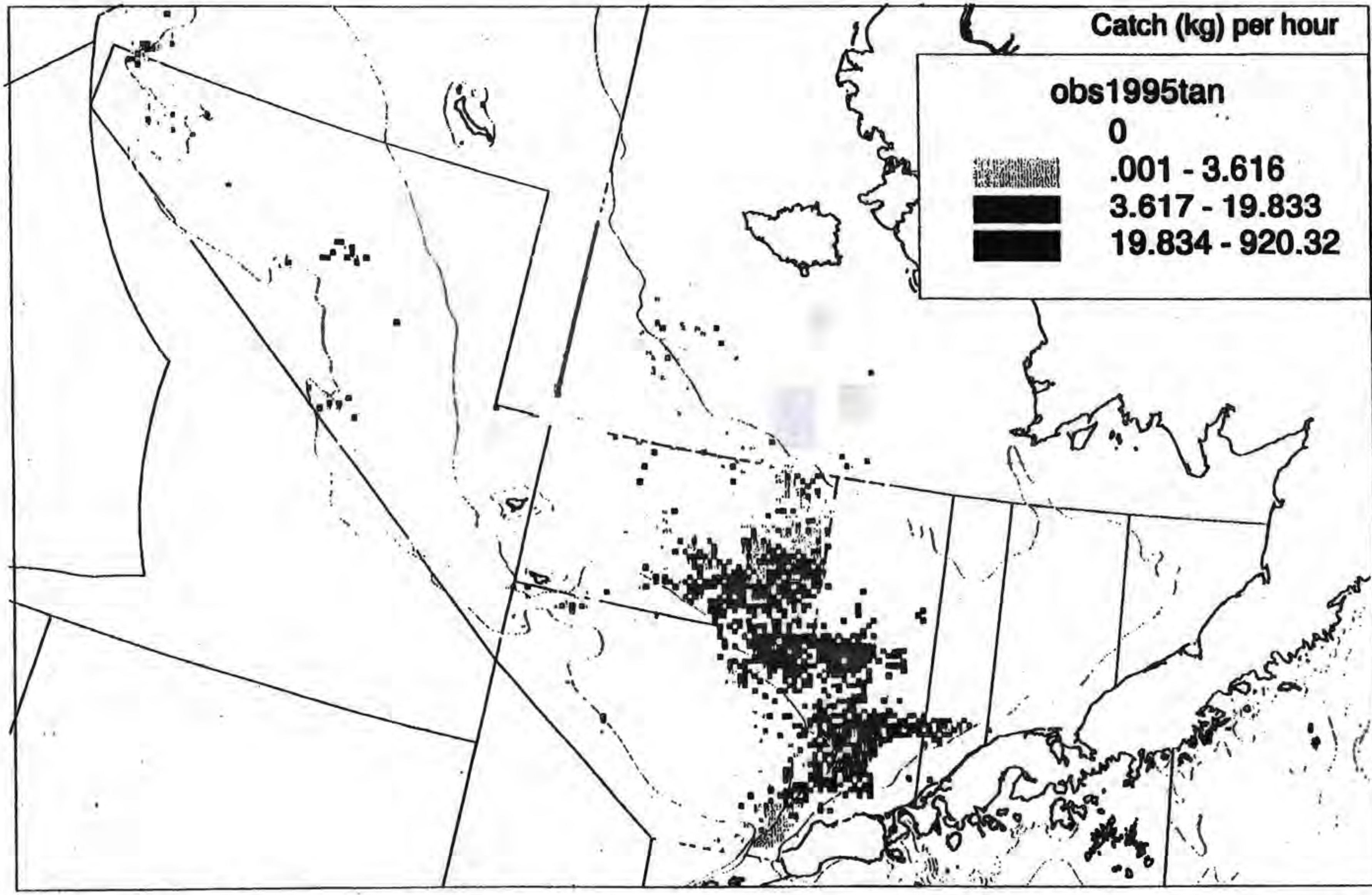
Figure 21 Tanner crab (C. bairdi) catch per hour summary from bottom trawl groundfish fishery data in the eastern Bering Sea. Non-zero CPUE data are grouped into lower, middle, and upper thirds of the distribution. Domestic data 1994. NPFMC management area boundaries are shown.



Tanner crab (C. bairdi) catch (kg) per hour summary from bottom trawl groundfish fishery data in the eastern Bering Sea. Non-zero CPUE data are grouped into lower, middle, and upper thirds of the distribution. Domestic data 1994. NPFMC management area boundaries are shown.

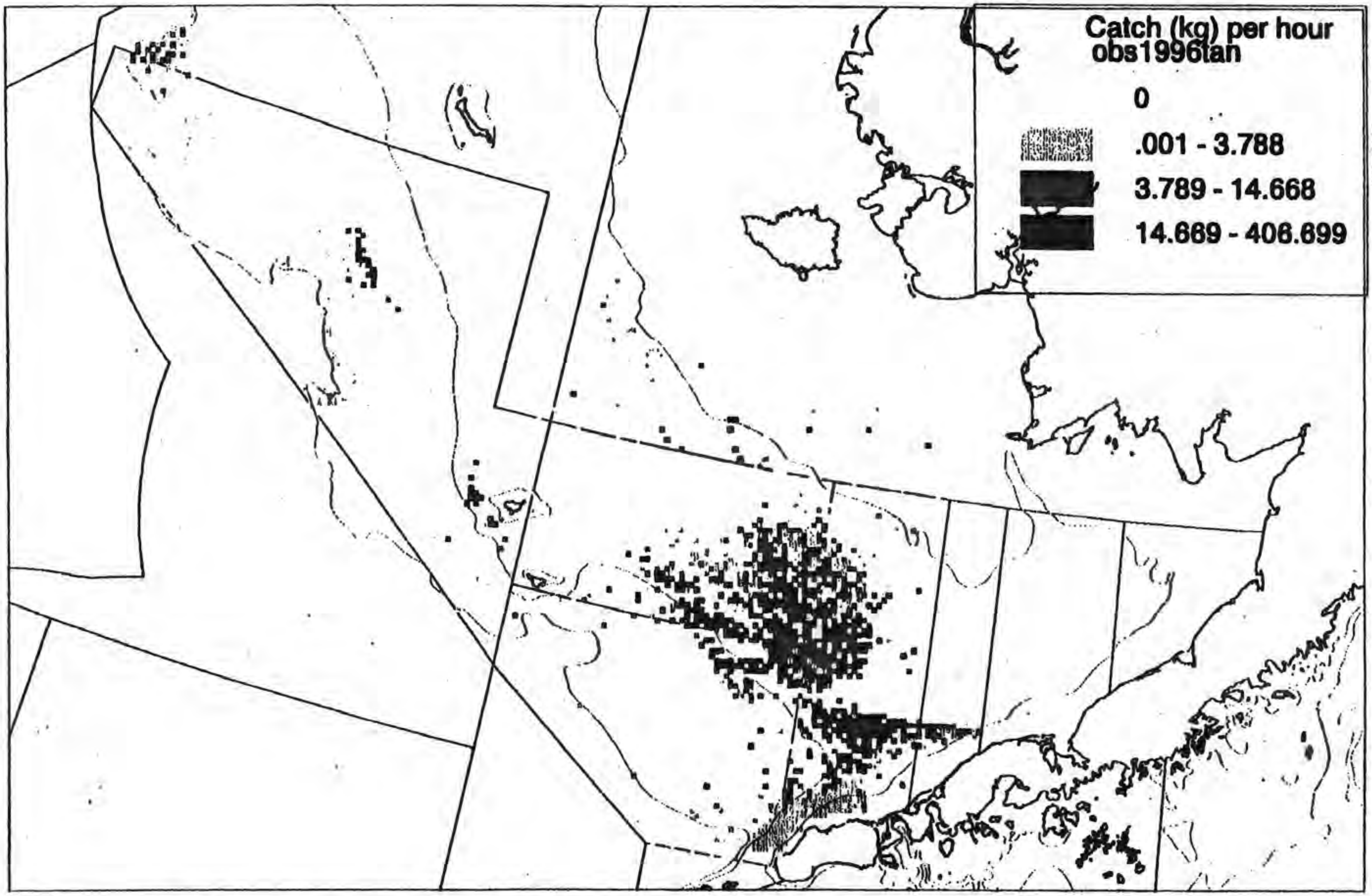
Figure 22

Tanner crab (C. bairdi) catch per hour summary from bottom trawl groundfish fishery data in the eastern Bering Sea. Non-zero CPUE data are grouped into lower, middle, and upper thirds of the distribution. Domestic data 1995. NPFMC management area boundaries are shown.



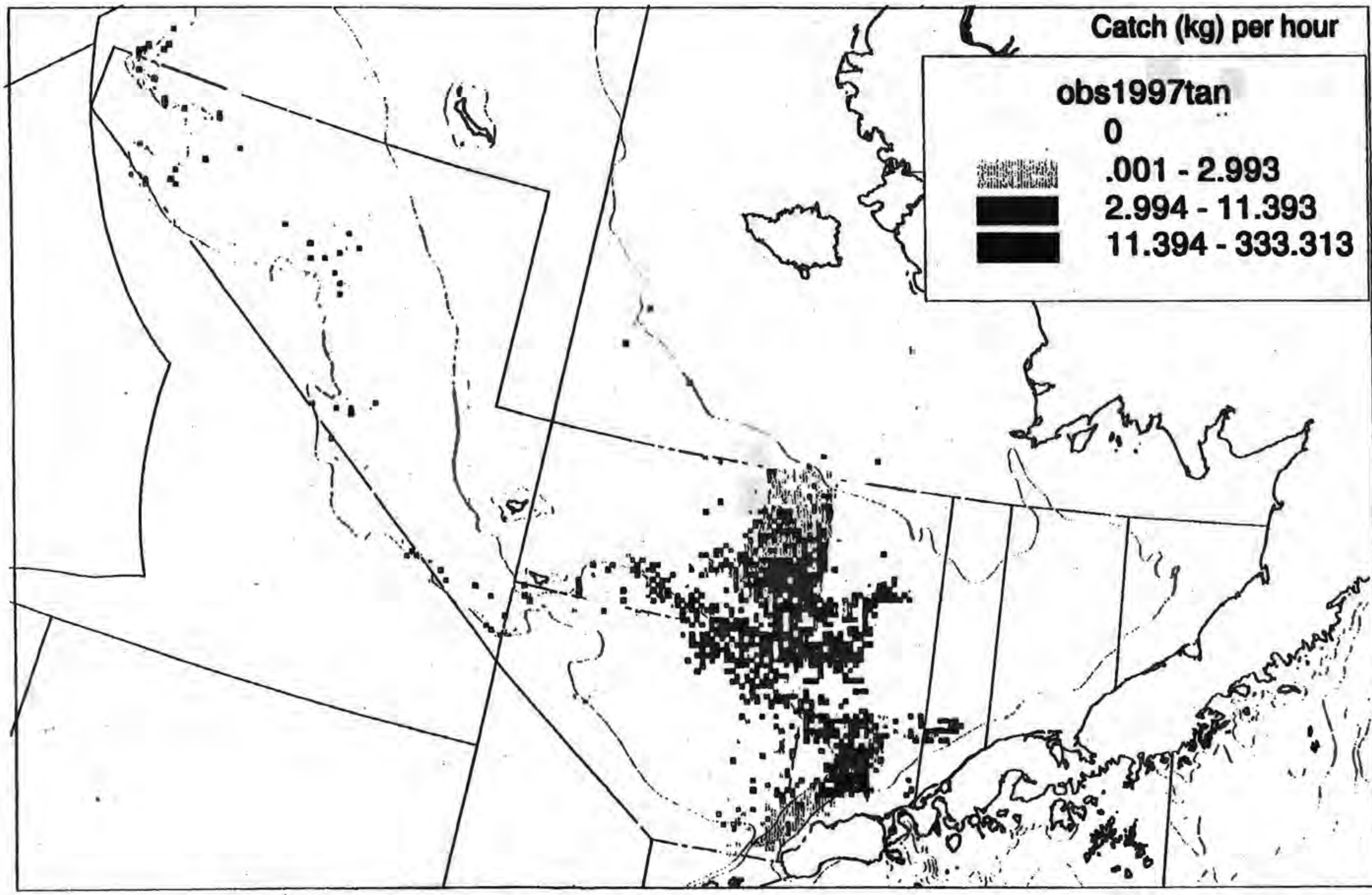
Tanner crab (C. bairdi) catch (kg) per hour summary from bottom trawl groundfish fishery data in the eastern Bering Sea. Non-zero CPUE data are grouped into lower, middle, and upper thirds of the distribution. Domestic data 1995. NPFMC management area boundaries are shown.

Figure 23 Tanner crab (C. bairdi) catch per hour summary from bottom trawl groundfish fishery data in the eastern Bering Sea. Non-zero CPUE data are grouped into lower, middle, and upper thirds of the distribution. Domestic data 1996. NPFMC management area boundaries are shown.



Tanner crab (C. bairdi) catch (kg) per hour summary from bottom trawl groundfish fishery data in the eastern Bering Sea. Non-zero CPUE data are grouped into lower, middle, and upper thirds of the distribution. Domestic data 1996. NPFMC management area boundaries are shown.

Figure 24 Tanner crab (C. bairdi) catch per hour summary from bottom trawl groundfish fishery data in the eastern Bering Sea. Non-zero CPUE data are grouped into lower, middle, and upper thirds of the distribution. Domestic data 1997. NPFMC management area boundaries are shown.



Tanner crab (C. bairdi) catch (kg) per hour summary from bottom trawl groundfish fishery data in the eastern Bering Sea. Non-zero CPUE data are grouped into lower, middle, and upper thirds of the distribution. Domestic data 1997. NPFMC management area boundaries are shown.

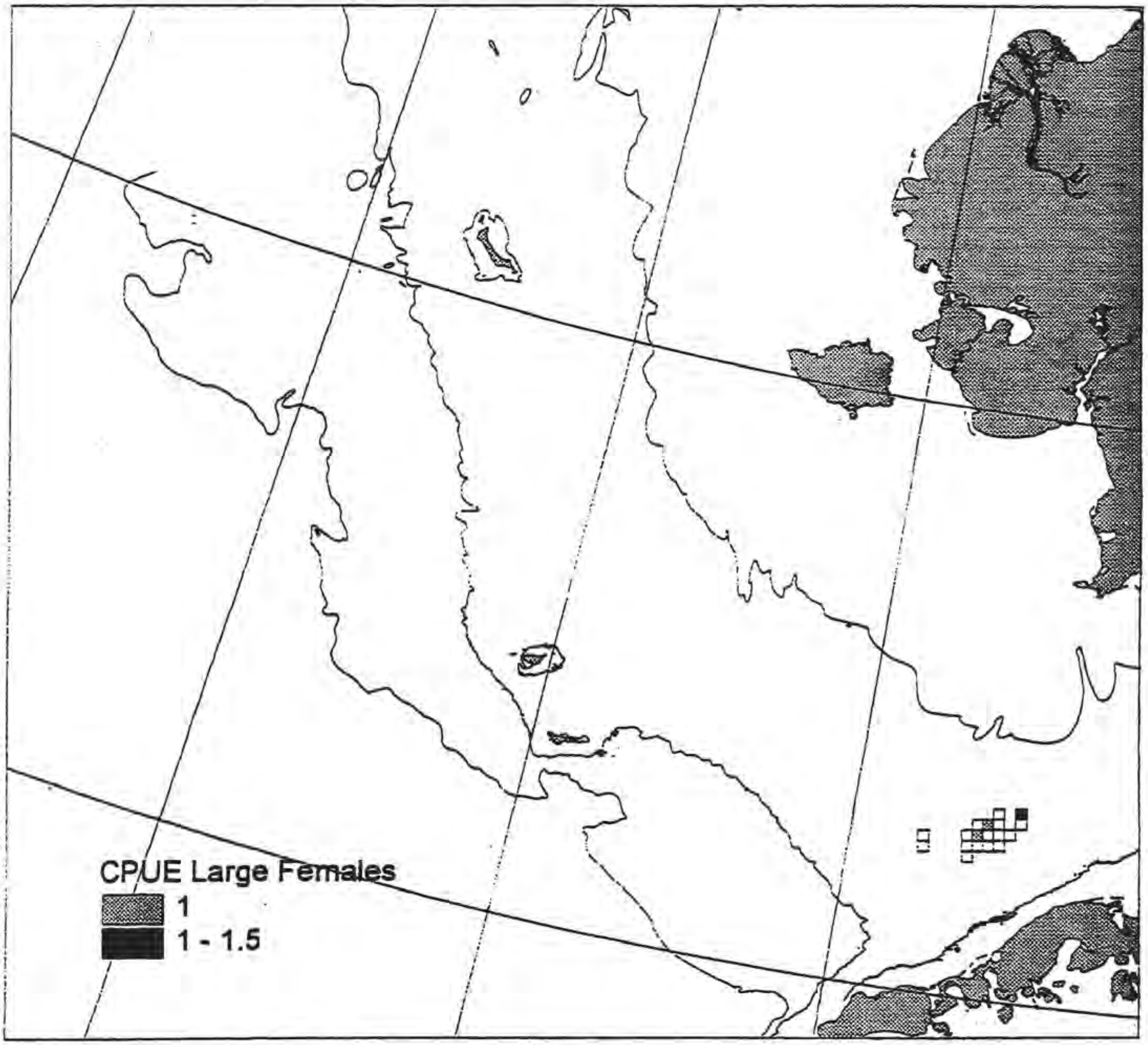


Figure 25. Distribution of C. bairdi bycatch from shellfish observer data collected during the 1996 Bristol Bay red king crab fishery.

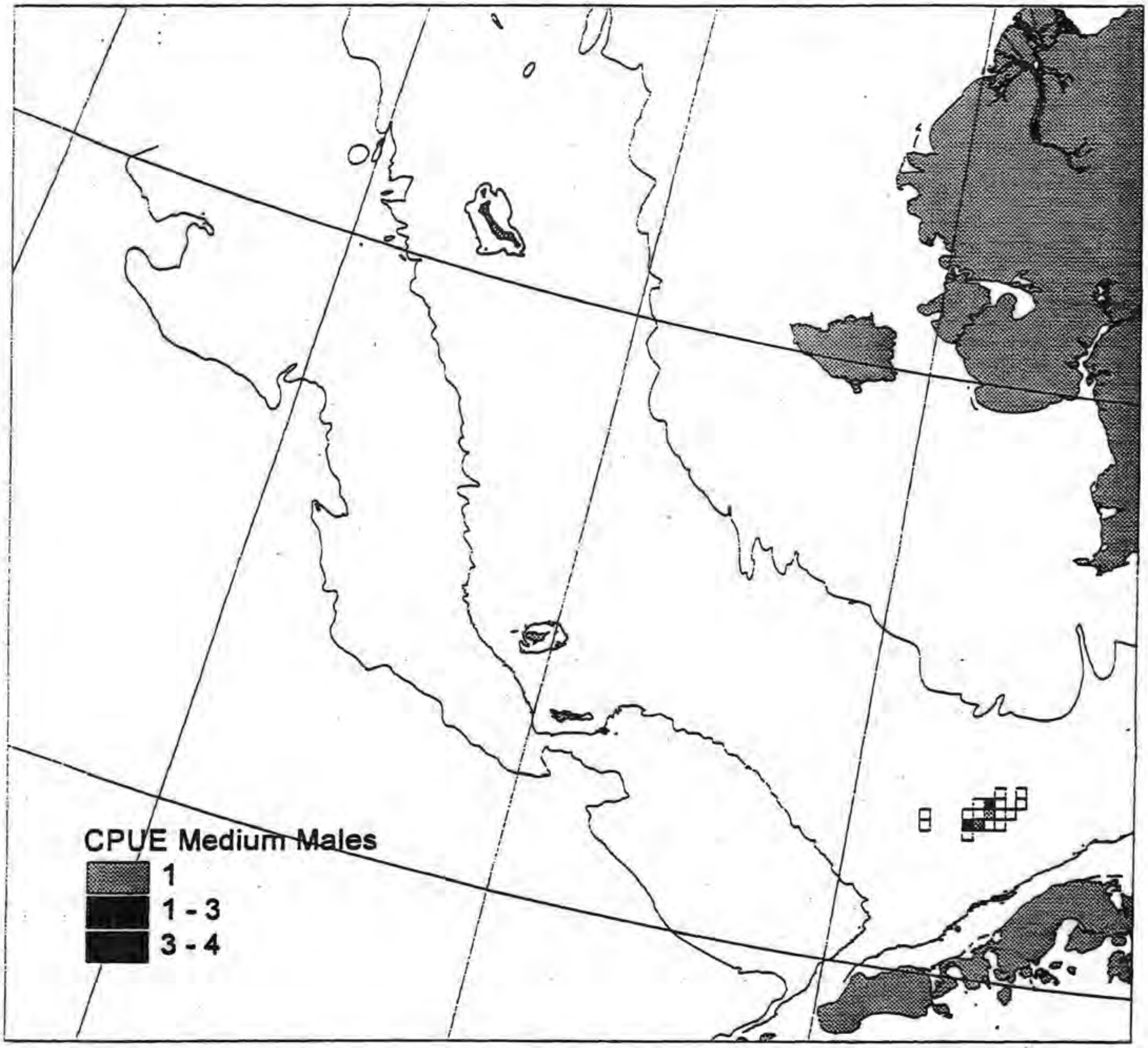


Figure 26. Distribution of C. bairdi bycatch from data collected by shellfish observers during the 1996 Bristol bay red king crab fishery.

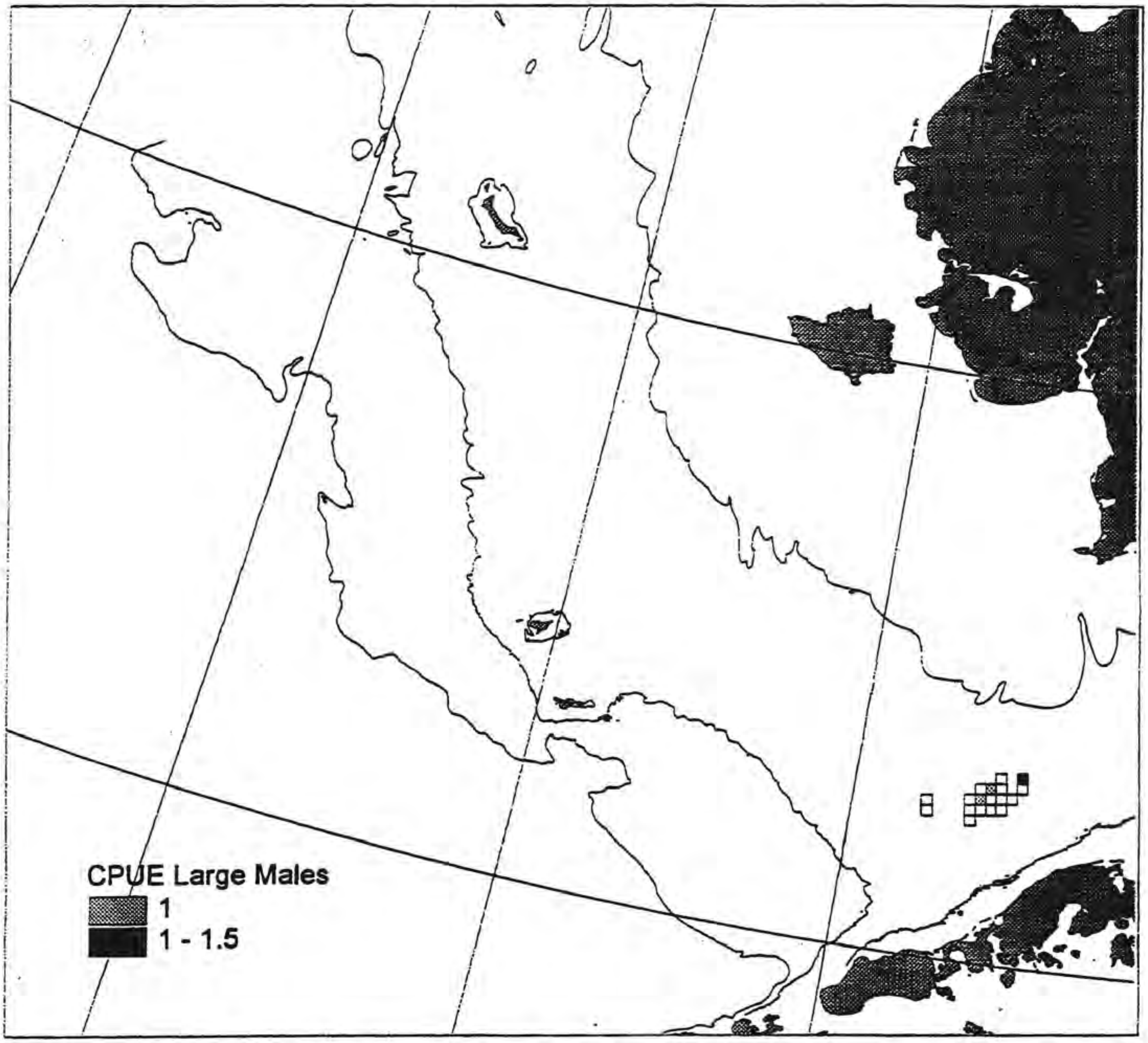


Figure 27. Distribution of C. bairdi bycatch from data collected by shellfish observers during the 1996 Bristol Bay red king crab fishery.

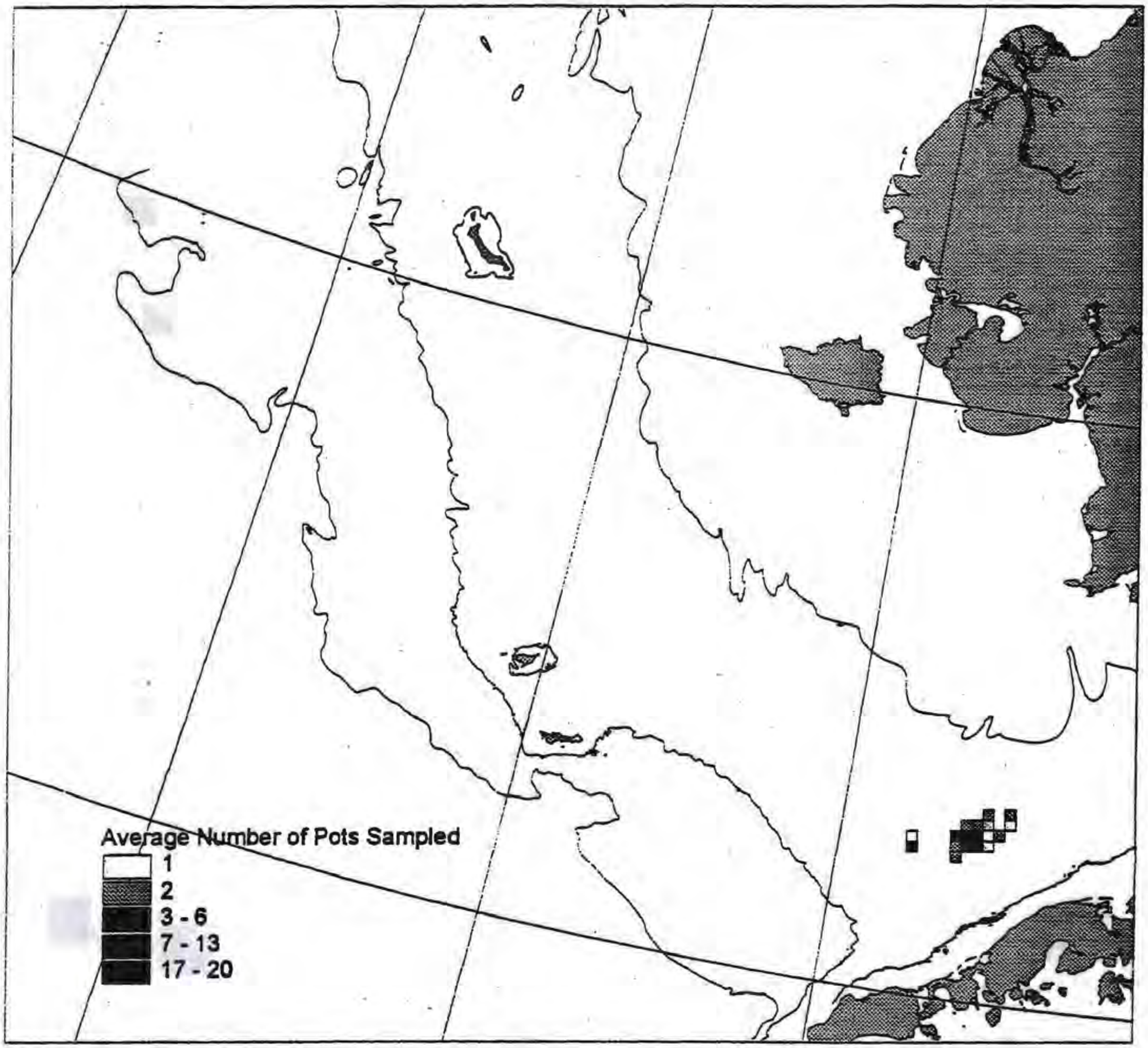


Figure 28. Average number of pots sampled by shellfish observers during the 1996 Bristol Bay red king crab fishery.

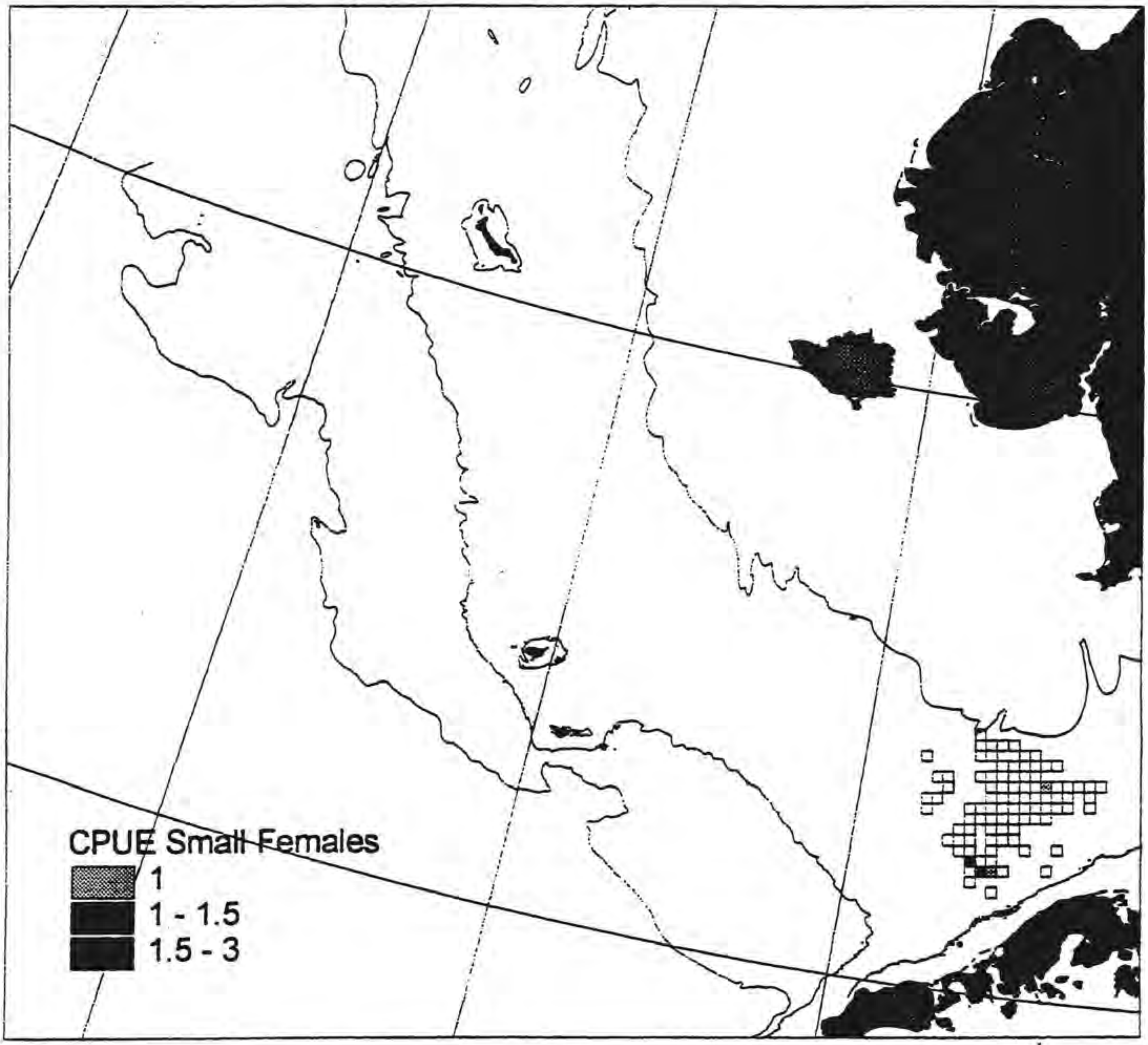


Figure 29. Distribution of C. bairdi bycatch from data collected by shellfish observers during the 1997 Bristol Bay red king crab fishery.

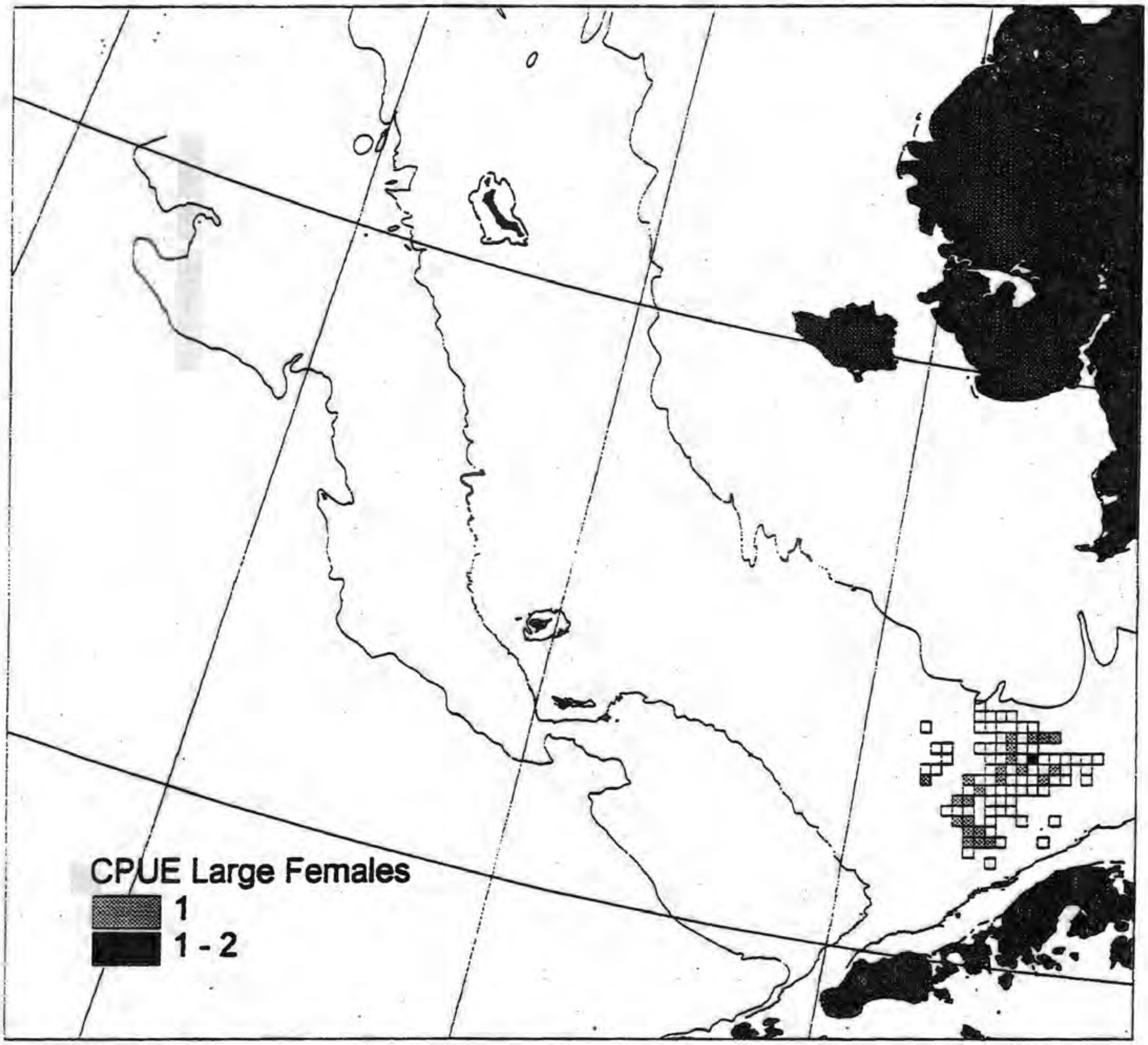


Figure 30. Distribution of C. bairdi bycatch from data collected by shellfish observers during the 1997 Bristol Bay red king crab fishery.

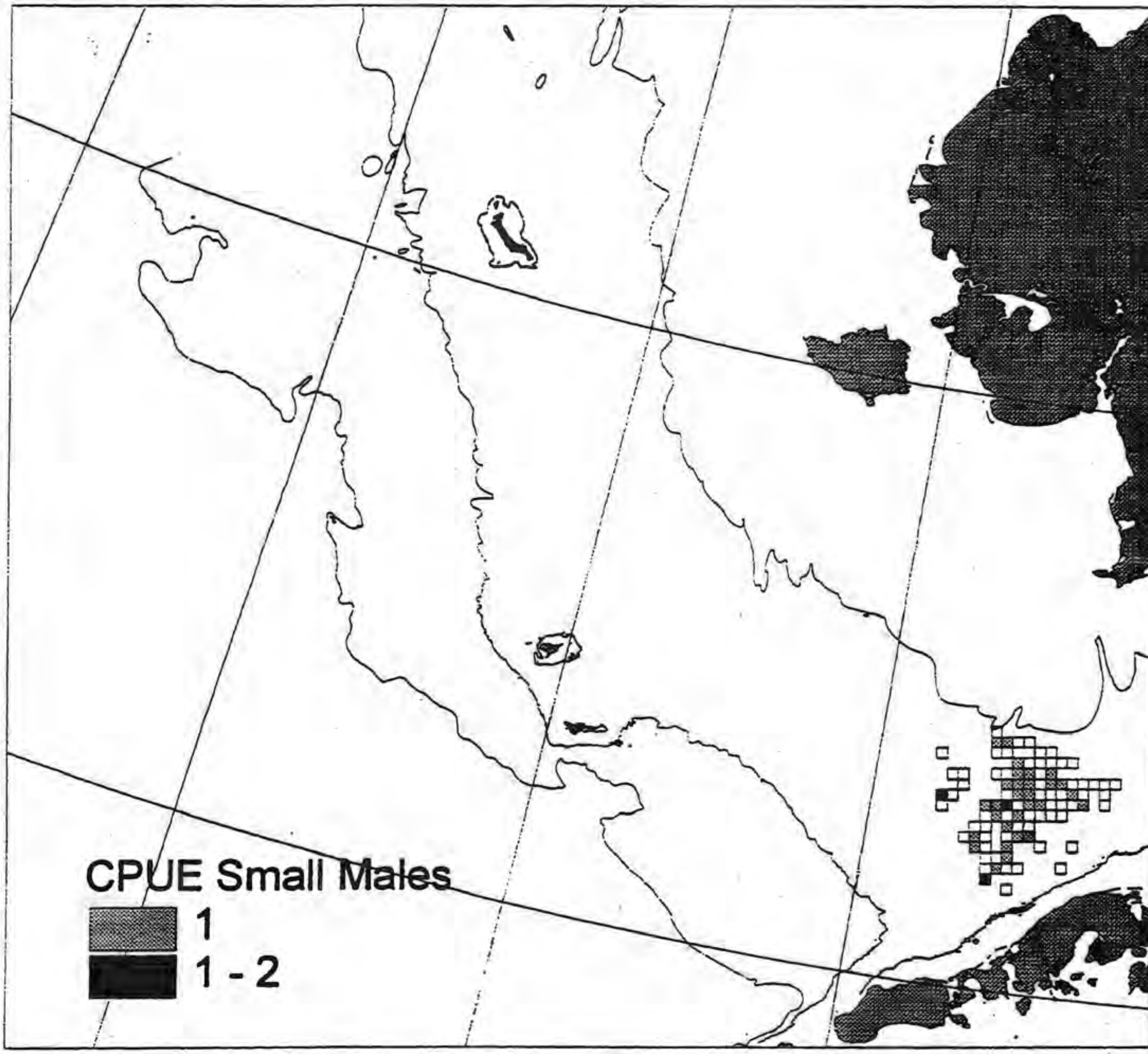


Figure 31. Distribution of C. bairdi bycatch from data collected by shellfish observers during the 1997 Bristol Bay red king crab fishery.

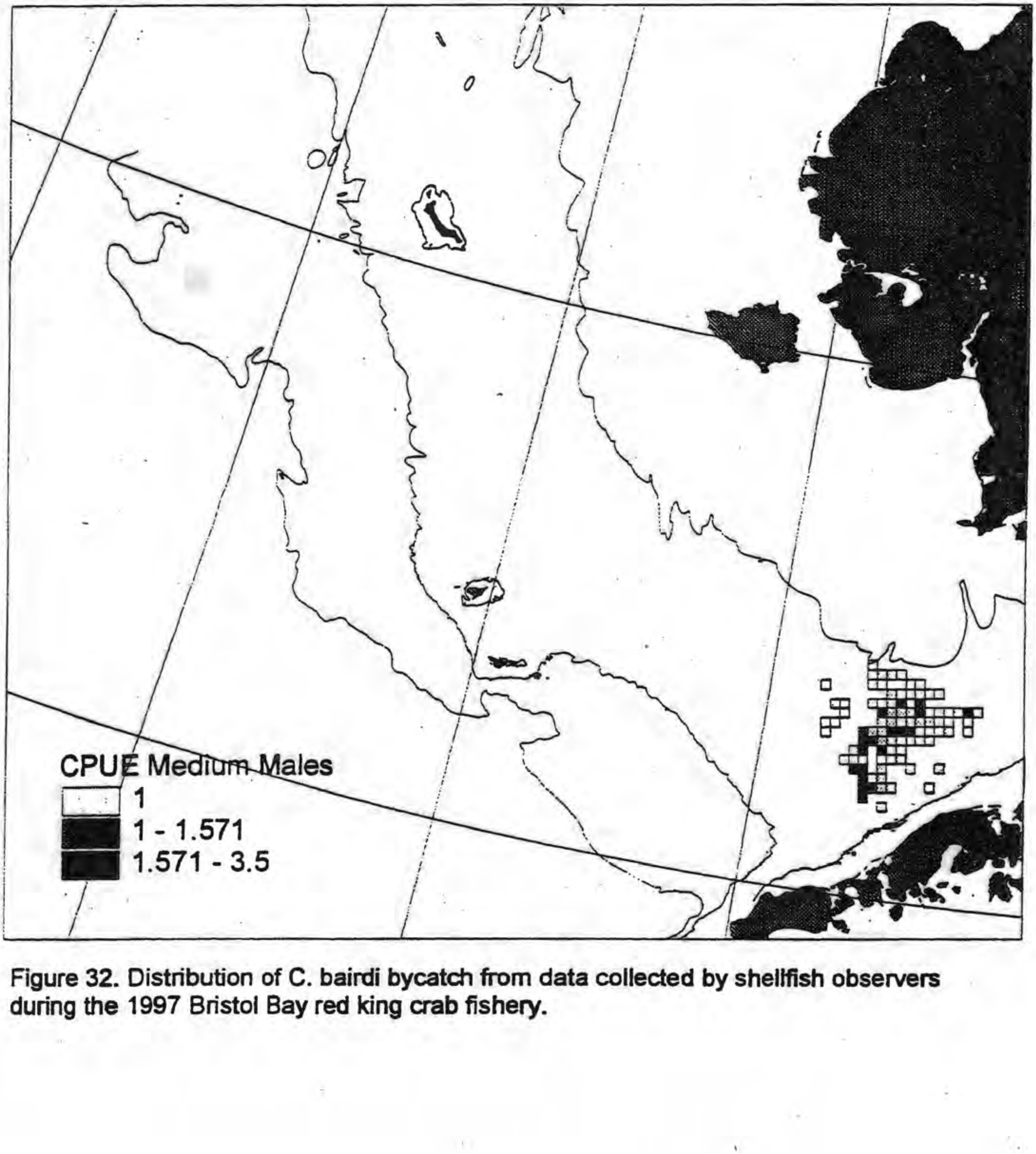


Figure 32. Distribution of C. bairdi bycatch from data collected by shellfish observers during the 1997 Bristol Bay red king crab fishery.

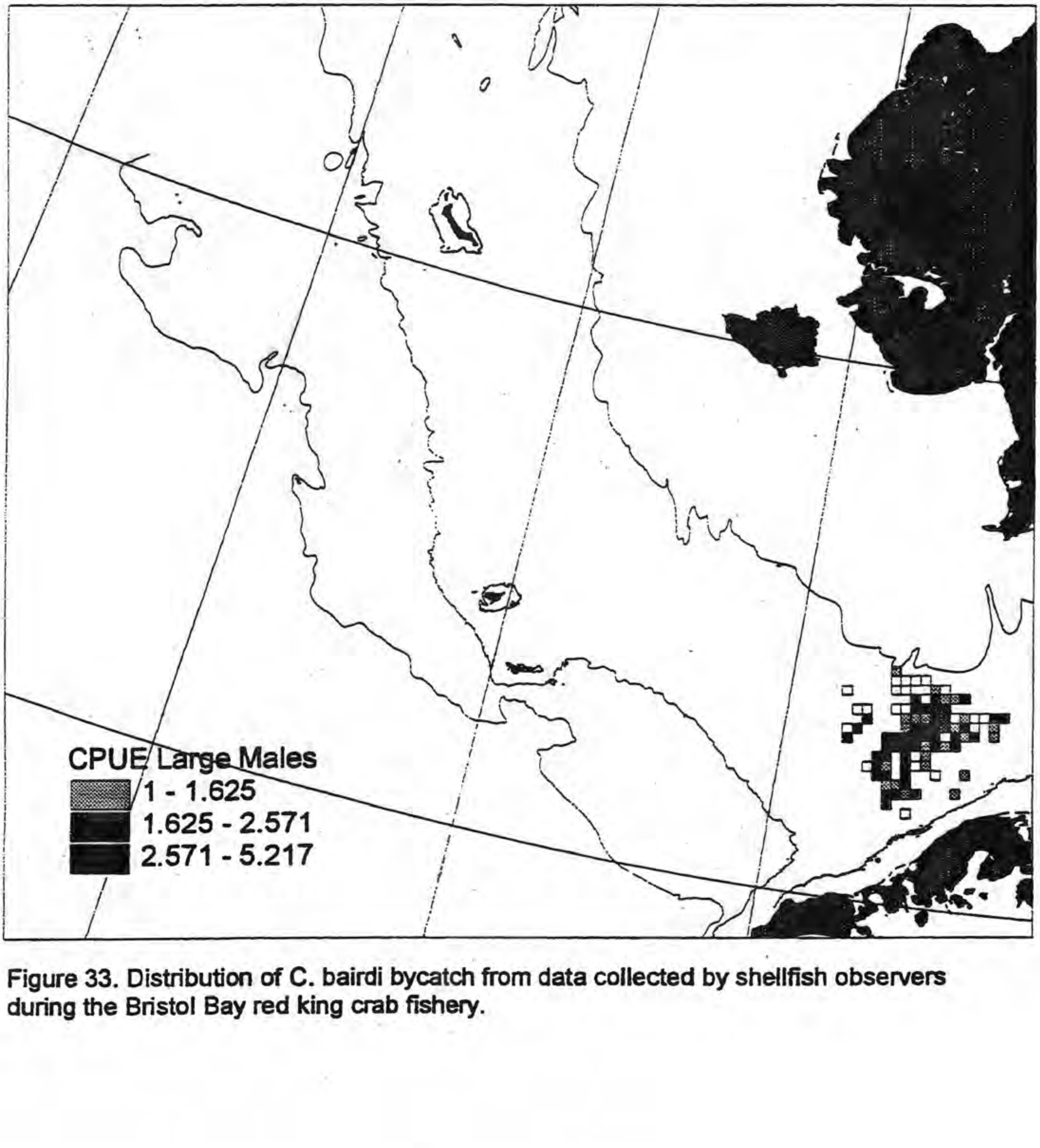


Figure 33. Distribution of C. bairdi bycatch from data collected by shellfish observers during the Bristol Bay red king crab fishery.

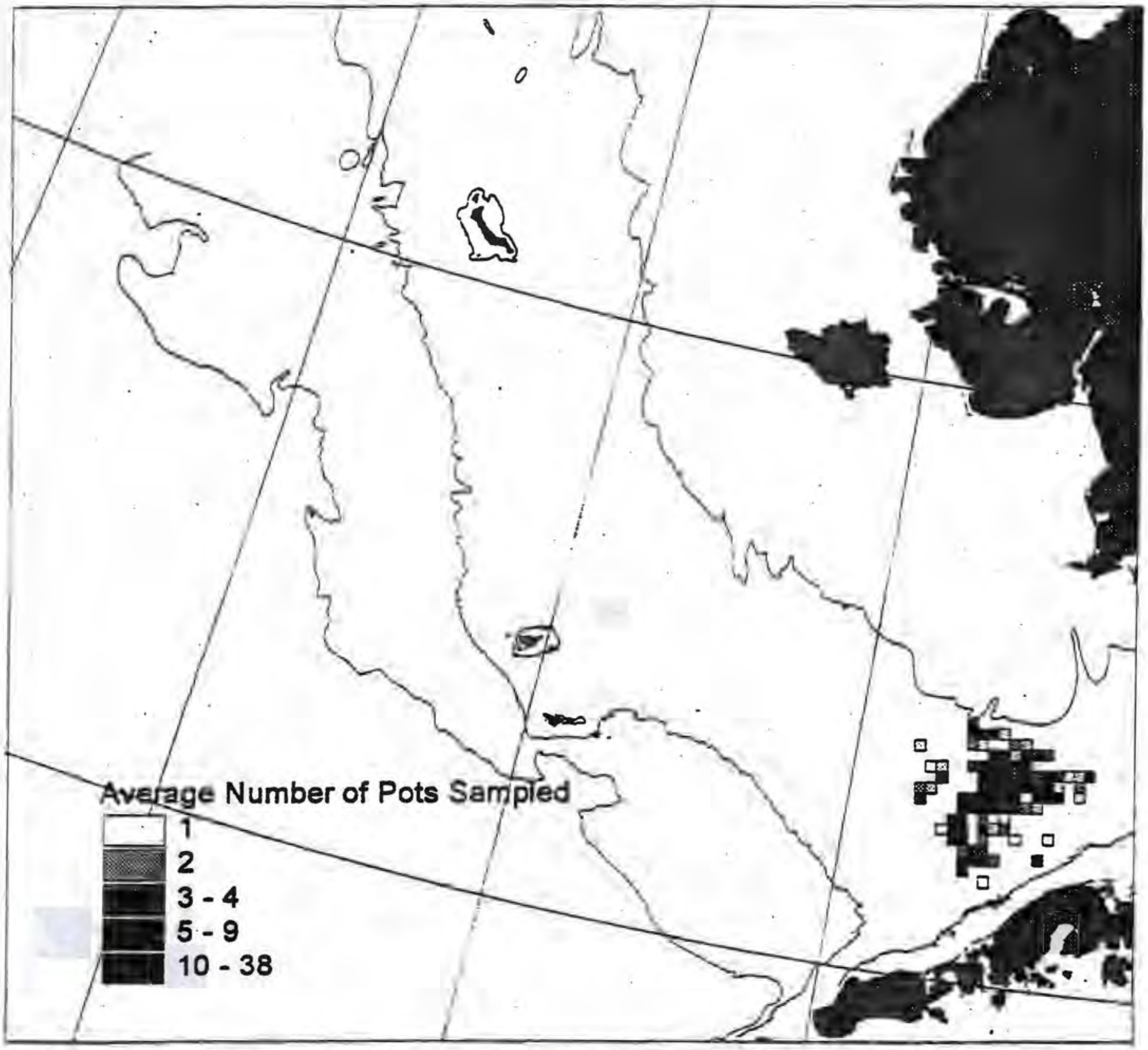


Figure 34. Distribution of C. bairdi bycatch from data collected by shellfish observers during the 1997 Bristol Bay red king crab fishery.

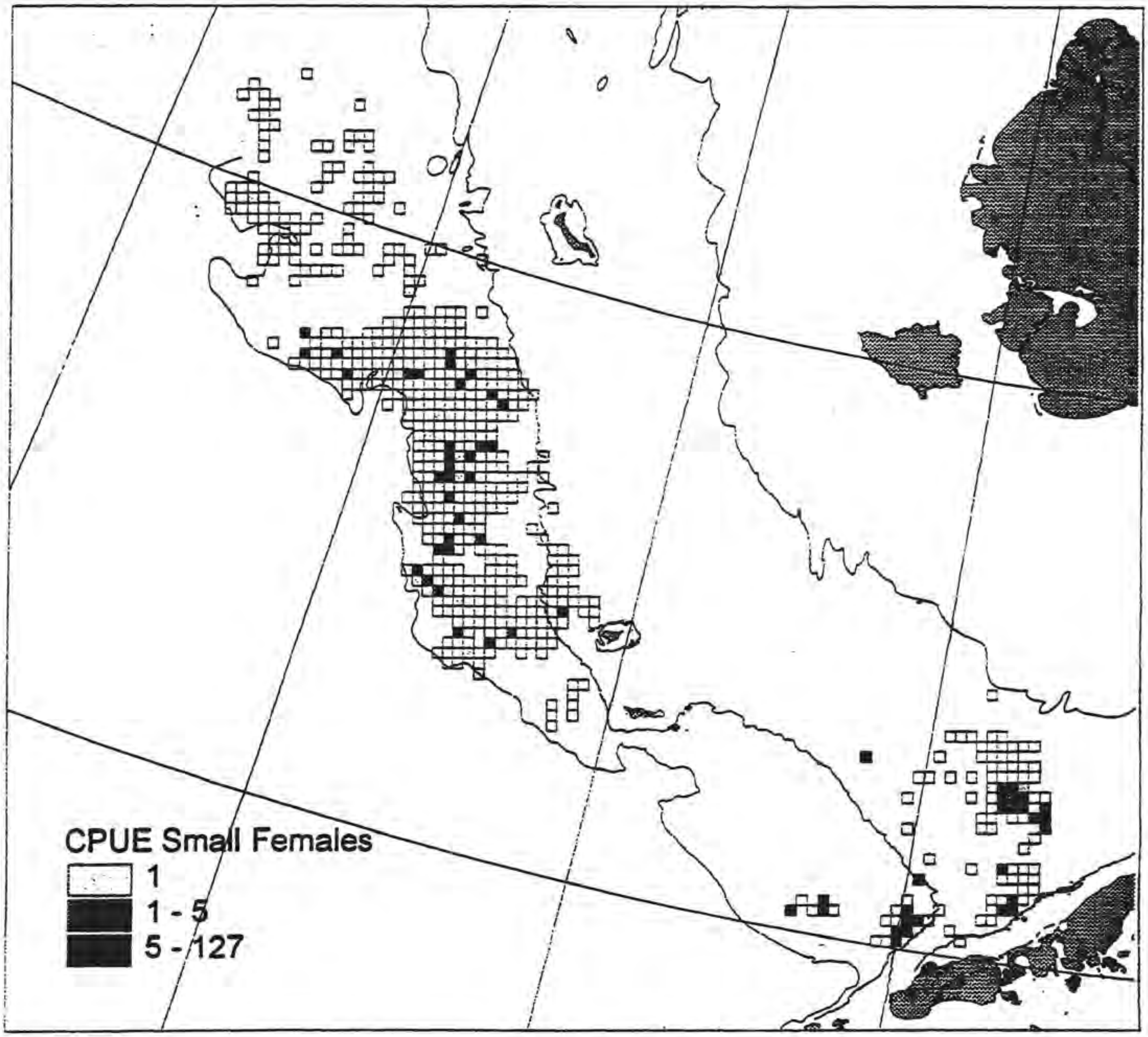


Figure 35. Distribution of C. bairdi bycatch from data collected by shellfish observers during the 1994 C. opilio and C. bairdi fisheries.

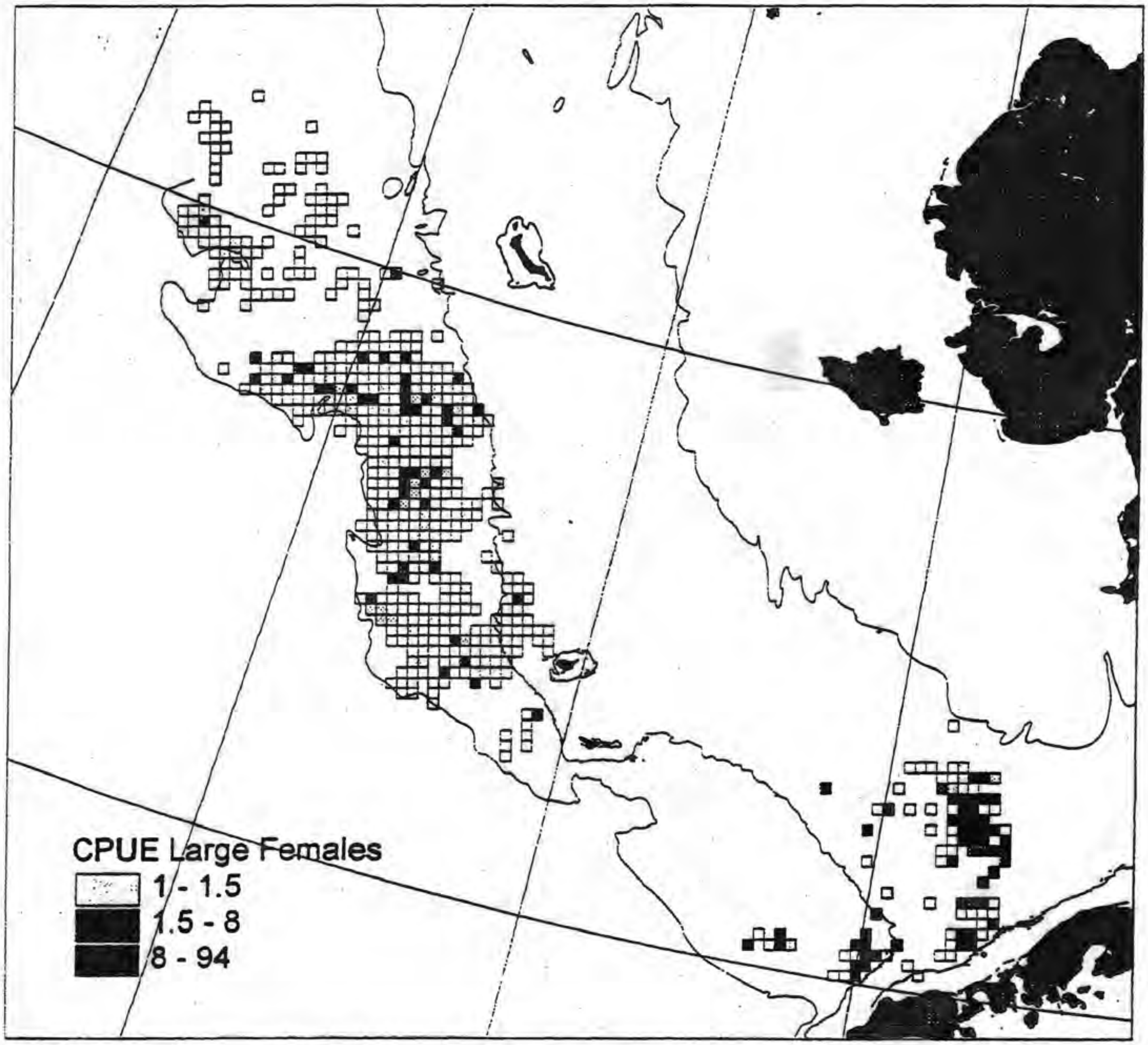


Figure 36. Distributiion of C. bairdi bycatch from data collected by shellfish observers during the 1994 C. opilio and C. bairdi fisheries.

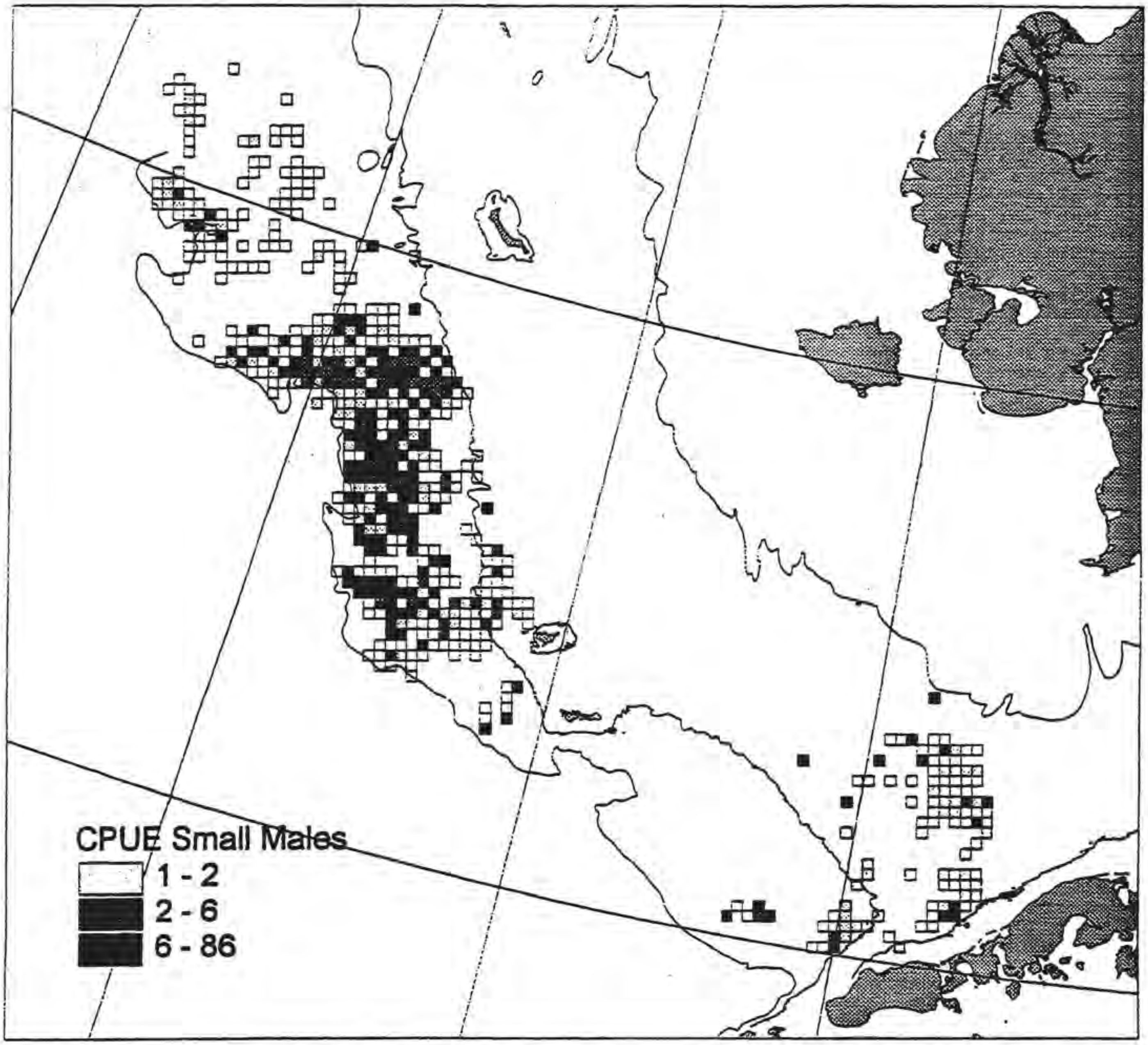


Figure 37. Distribution of C. bairdi bycatch from data collected by shellfish observers during the 1994 C. opilio and C. bairdi fisheries.

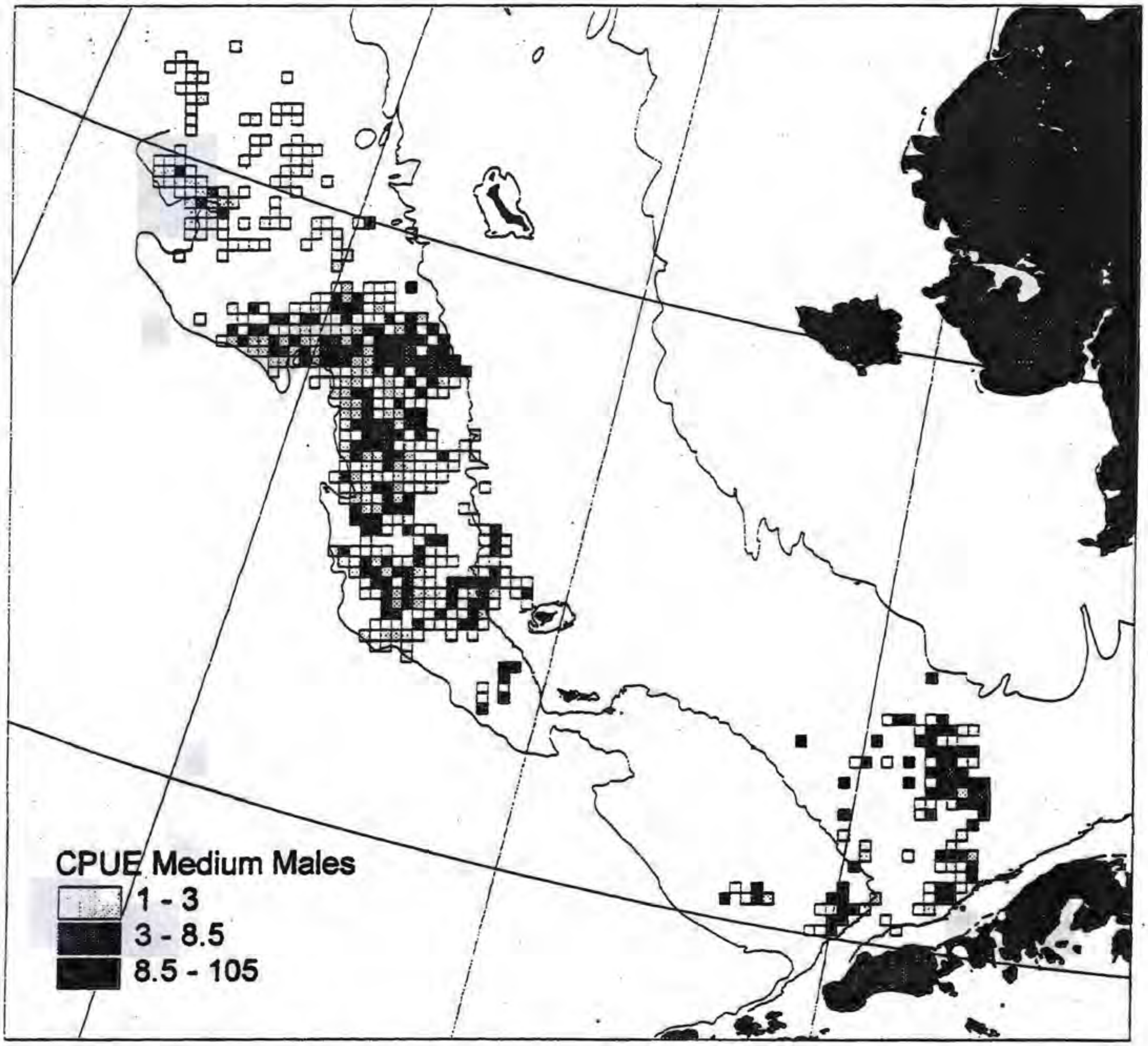


Figure 38. Distribution of C. bairdi byctach from data collected by shellfish observers during the 1994 C. opilio and C. bairdi fisheries.

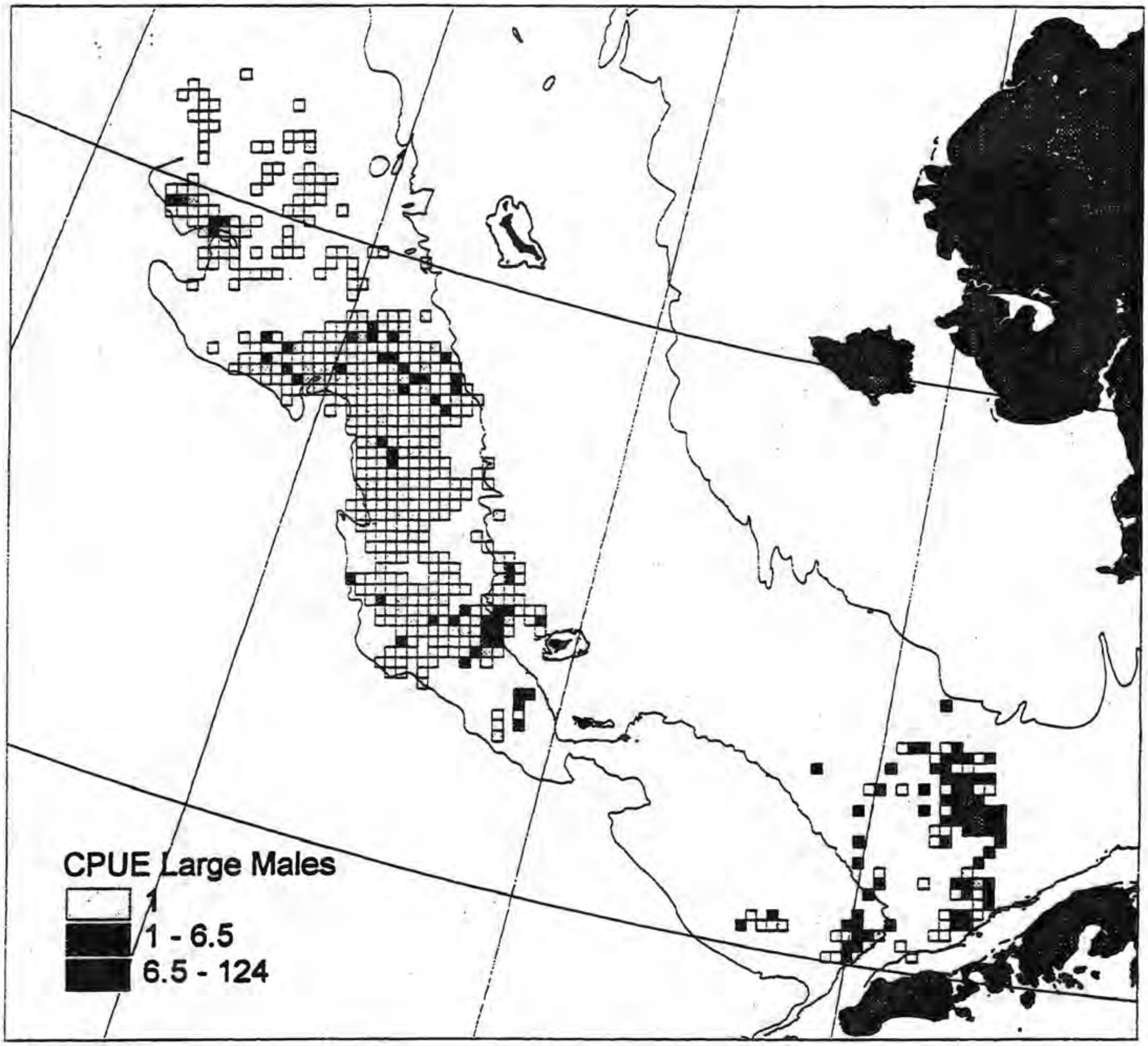


Figure 39. Distribution of C. bairdi from data collected by shellfish observers during the 1994 C. opilio and C. bairdi fisheries.

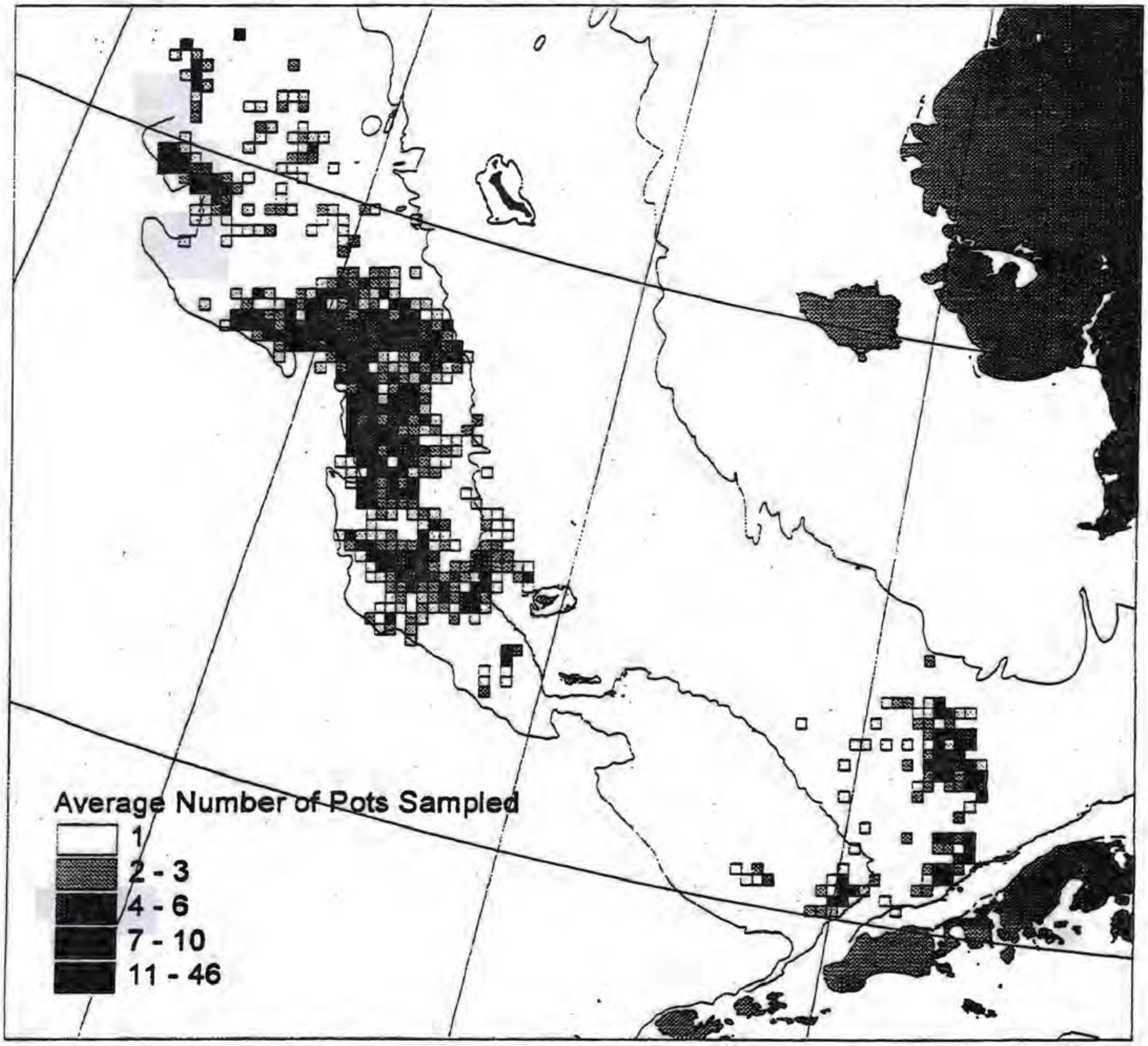


Figure 40. Distribution of C. bairdi bycatch from data collected by shellfish observers during the 1994 C. opilio and C. bairdi fisheries.

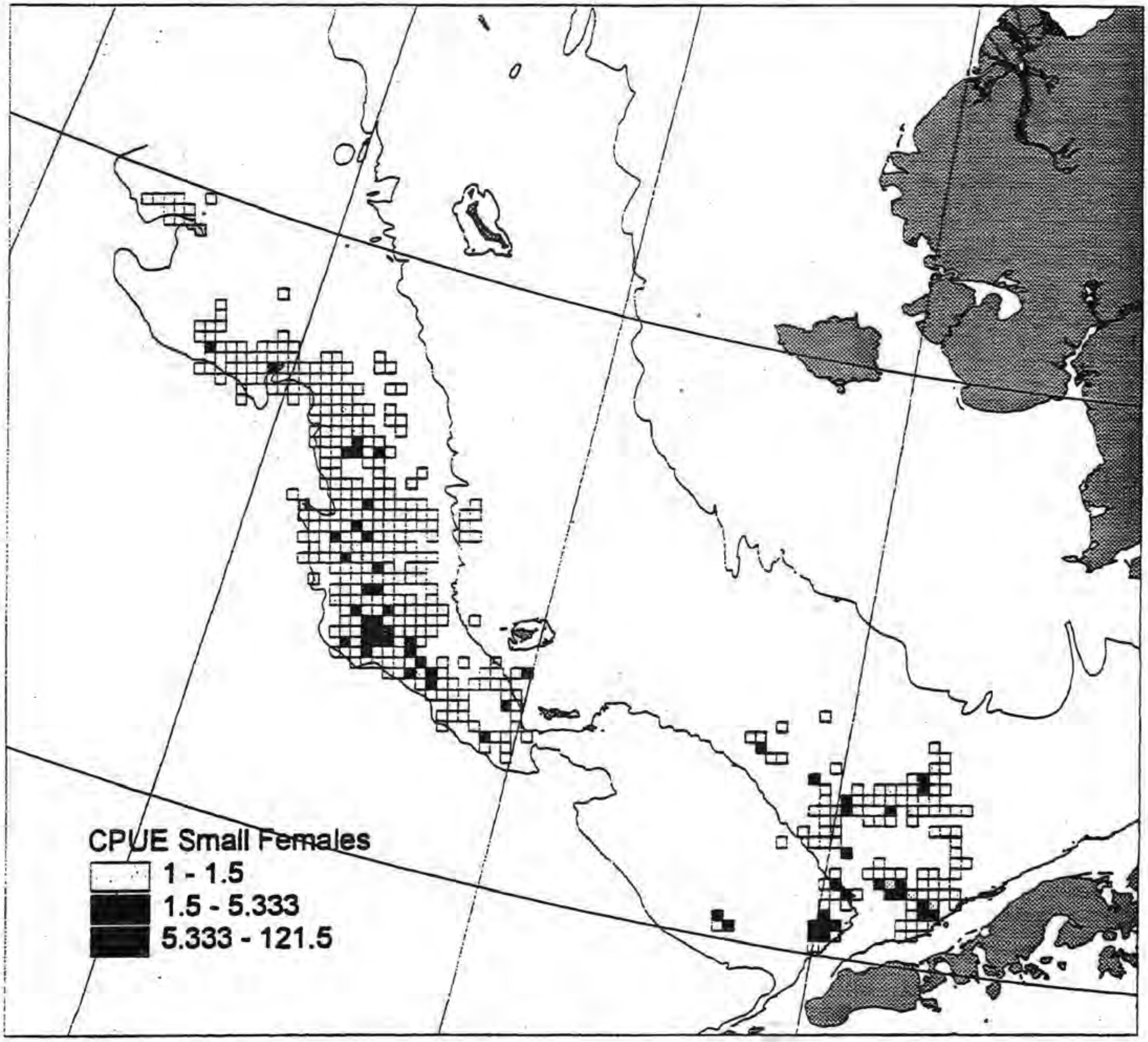


Figure 41. Distribution of C. bairdi bycatch from shellfish observer data collected during the 1995 C. opilio and C. bairdi fisheries.

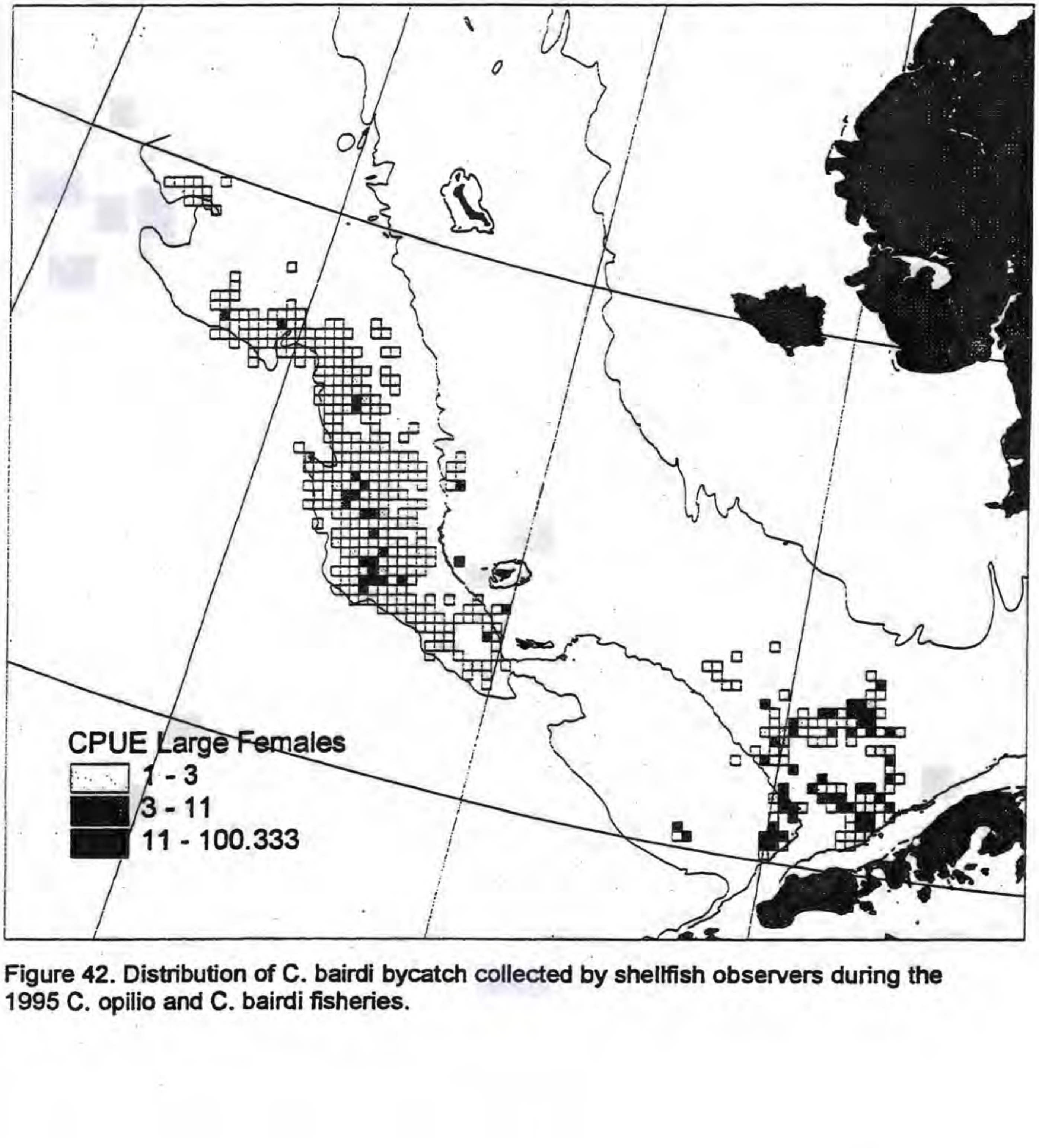


Figure 42. Distribution of C. bairdi bycatch collected by shellfish observers during the 1995 C. opilio and C. bairdi fisheries.

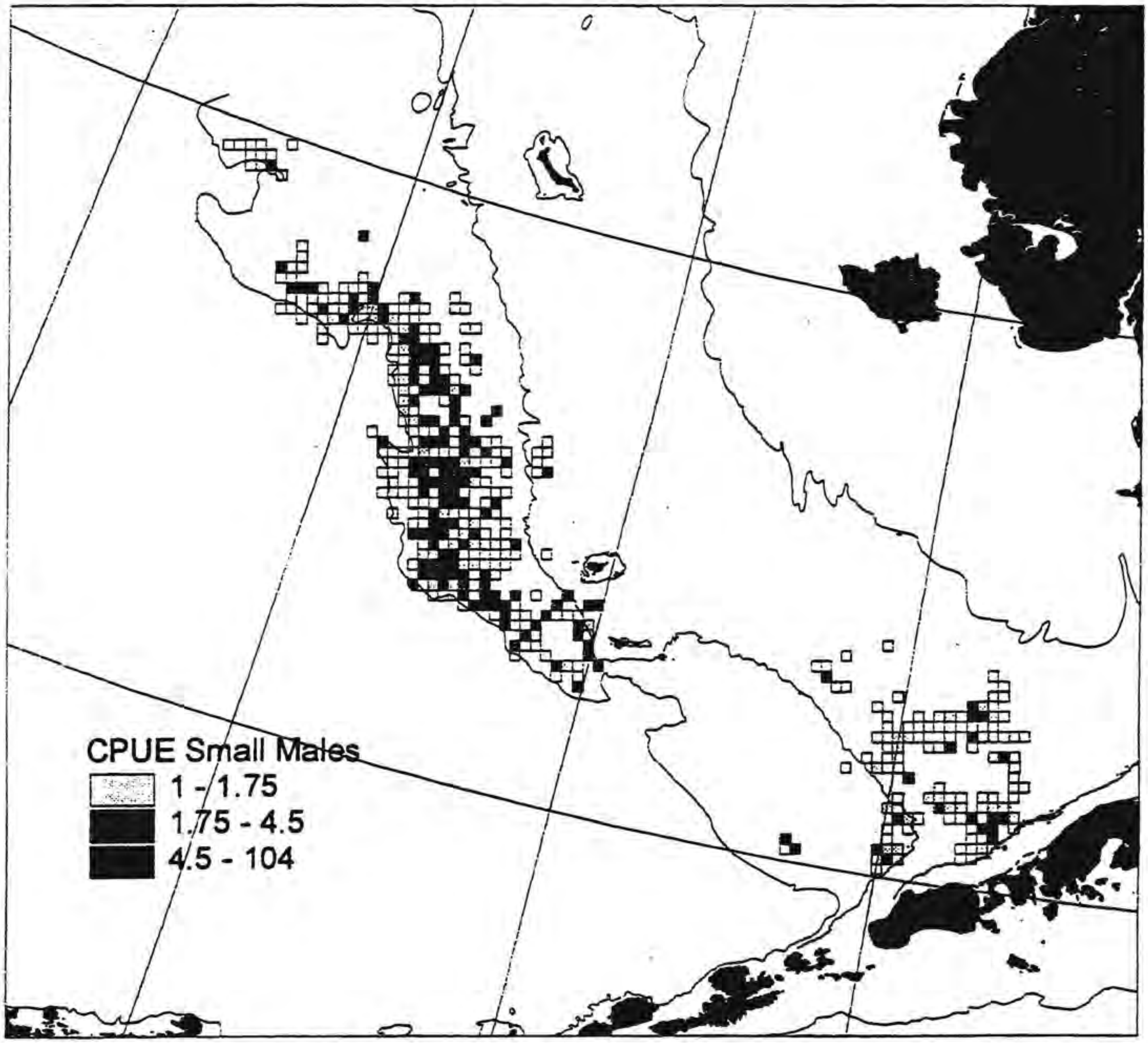


Figure 43. Distribution of C. bairdi bycatch from data collected by shellfish observers during the 1995 C. opilio and C. bairdi fisheries.

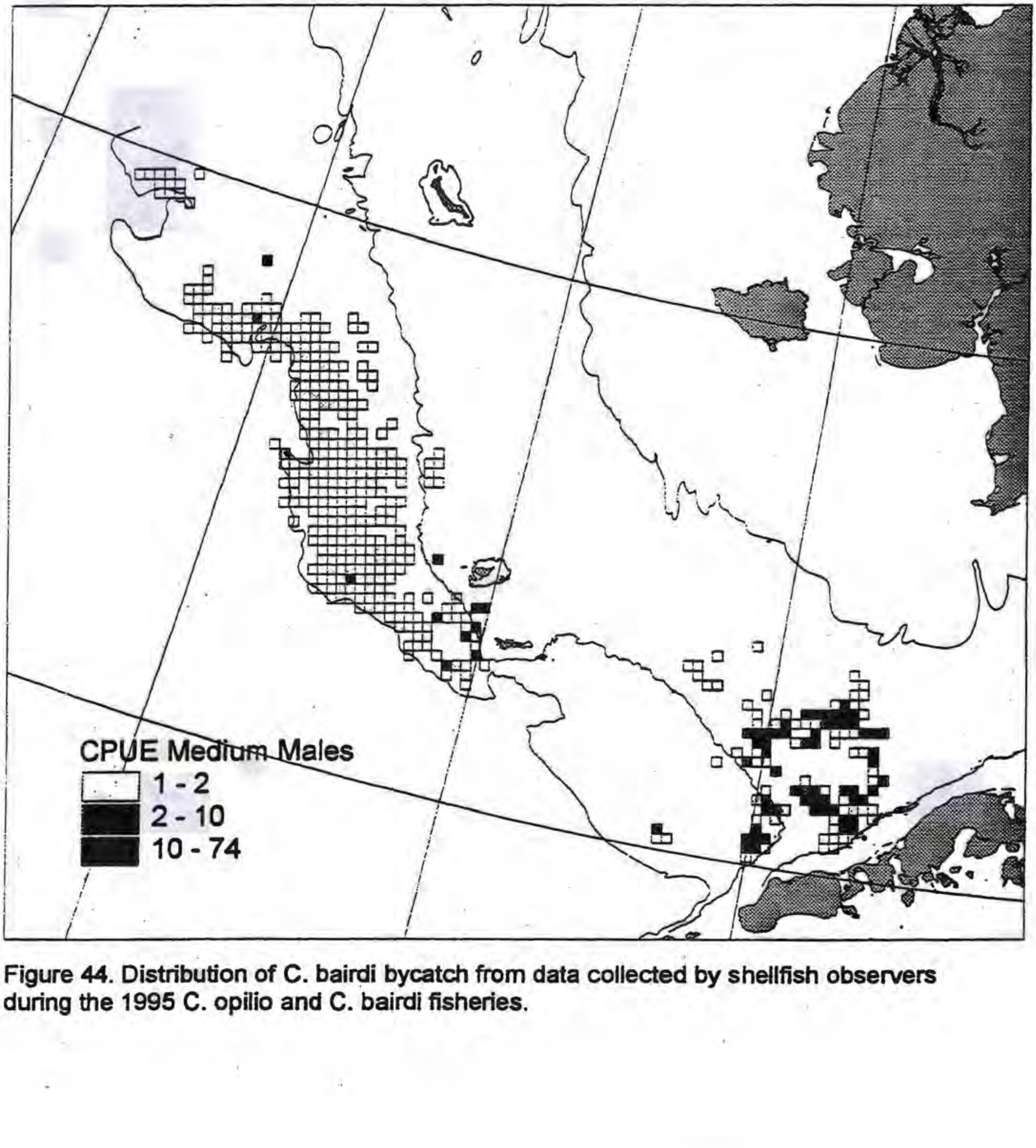


Figure 44. Distribution of C. bairdi bycatch from data collected by shellfish observers during the 1995 C. opilio and C. bairdi fisheries.

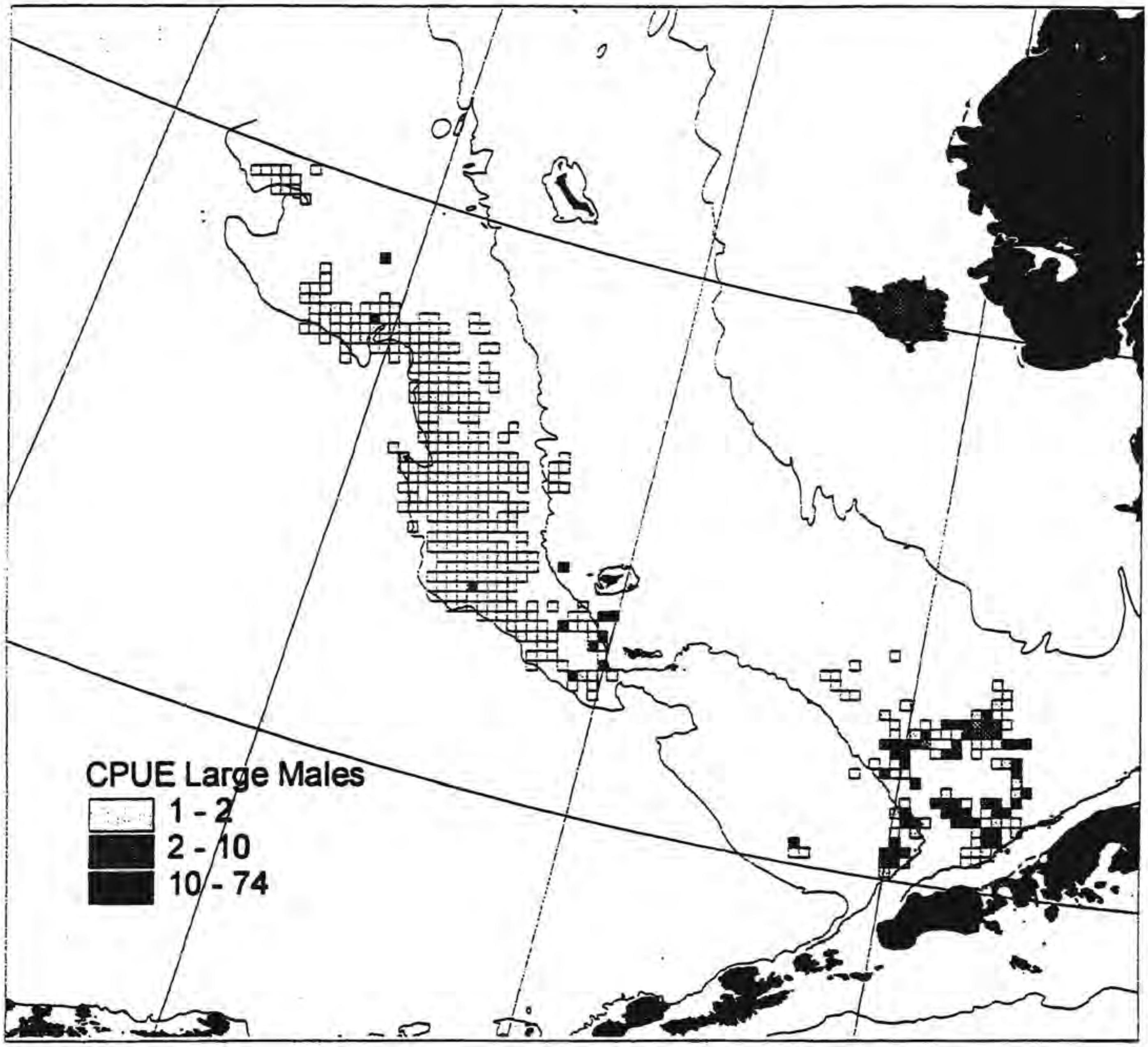


Figure 45. Distribution of C. bairdi bycatch from data collected by shellfish observers during the 1995 C. opilio and C. bairdi fisheries.

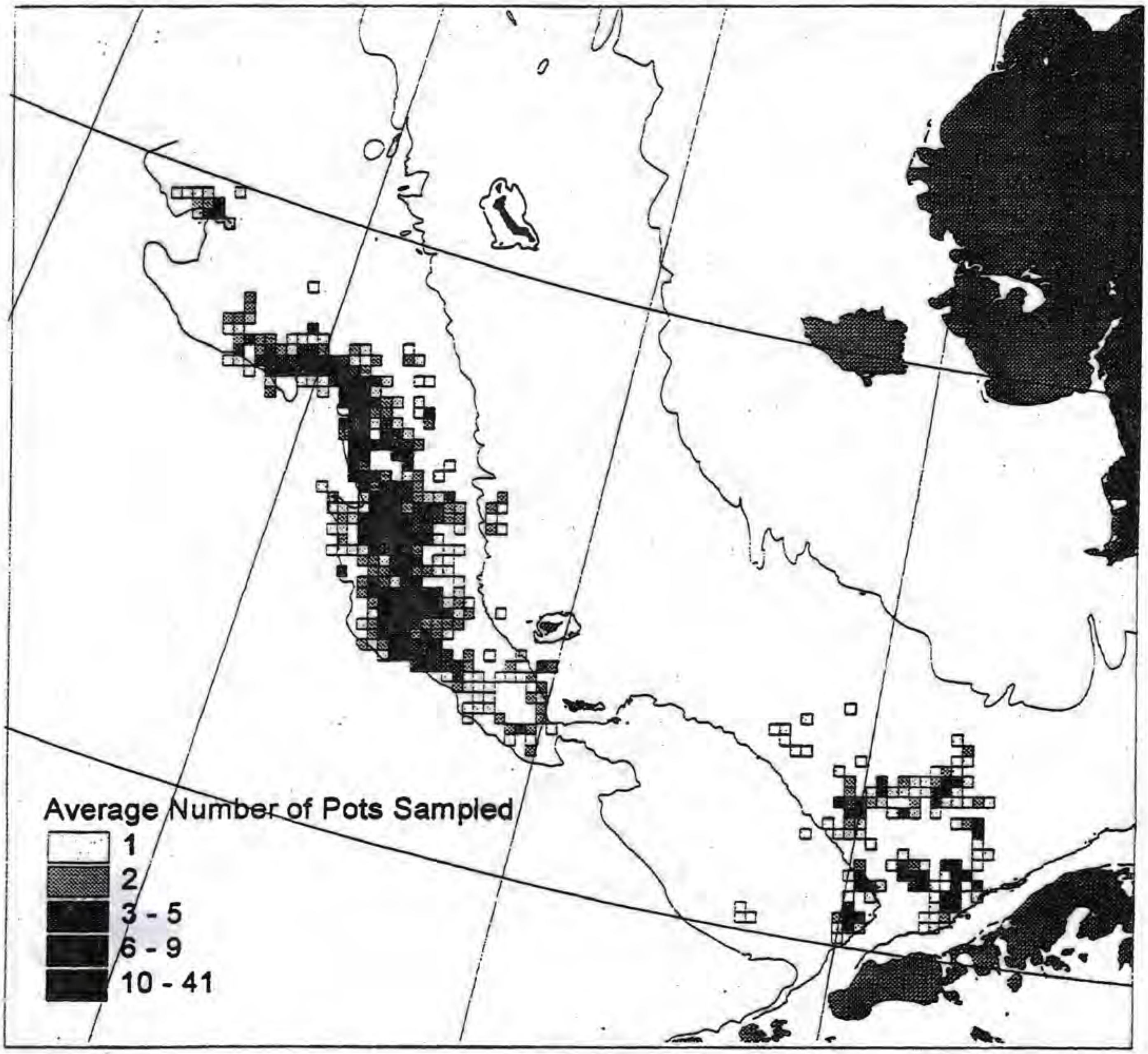


Figure 46. Average number of pots sampled by shellfish observers during the 1995 C. opilio and C. bairdi fisheries.

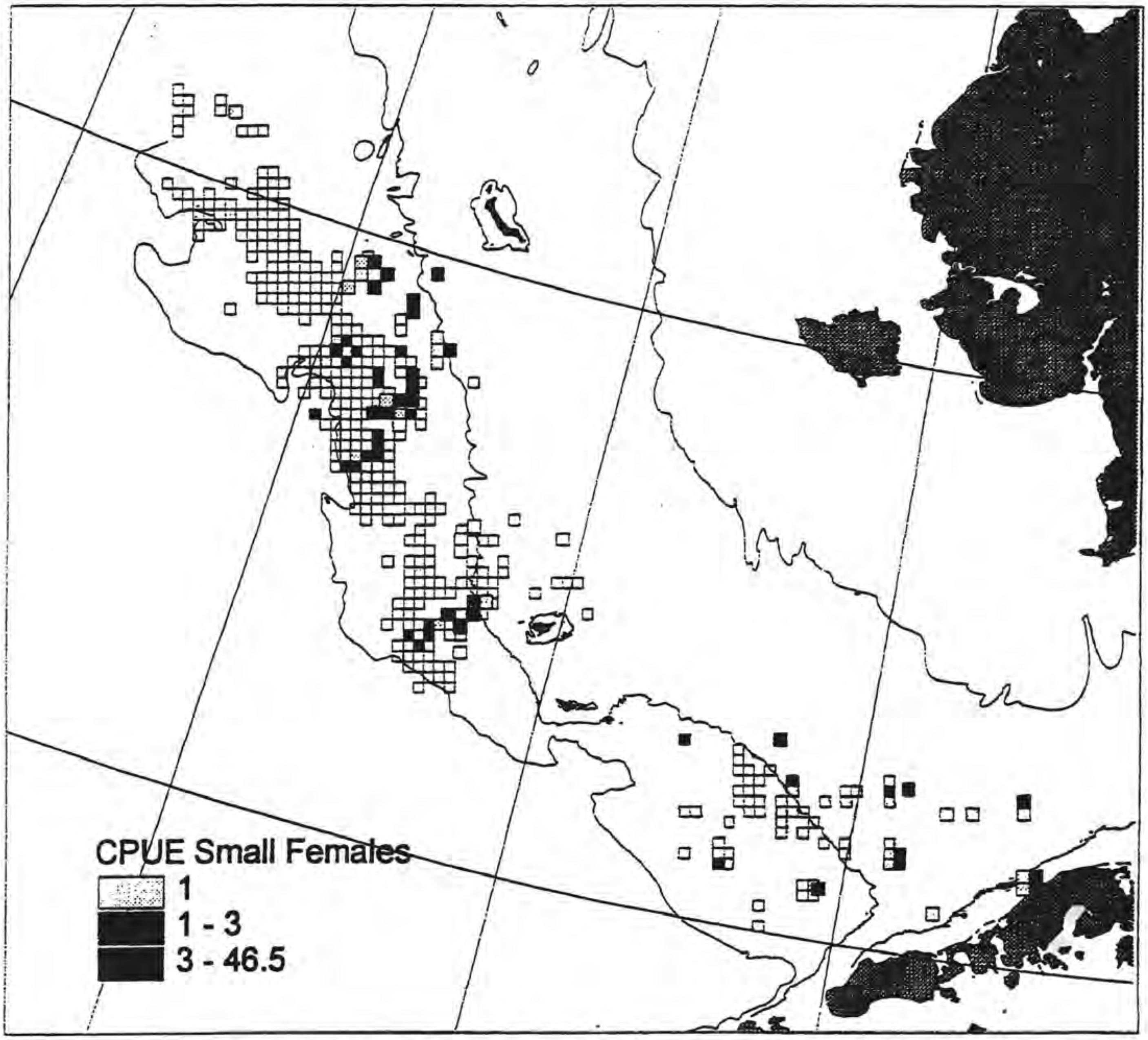


Figure 47. Distribution of C.bairdi bycatch from data collected by shellfish observers during the 1996 C. opilio and C. bairdi fisheries.

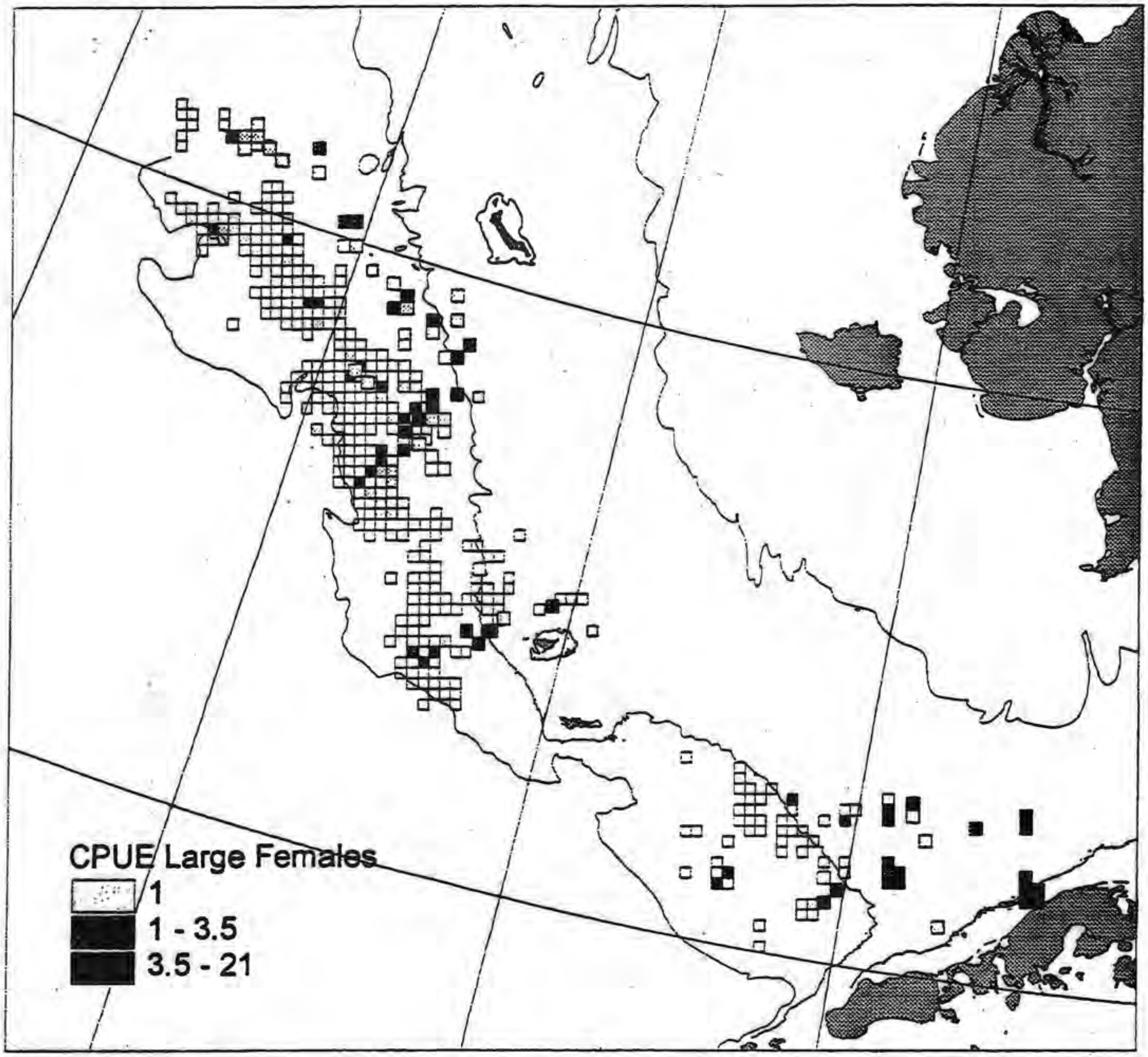


Figure 48. Distribution of C. bairdi bycatch from data collected by shellfish observers during the 1996 C. opilio and C. bairdi fisheries.

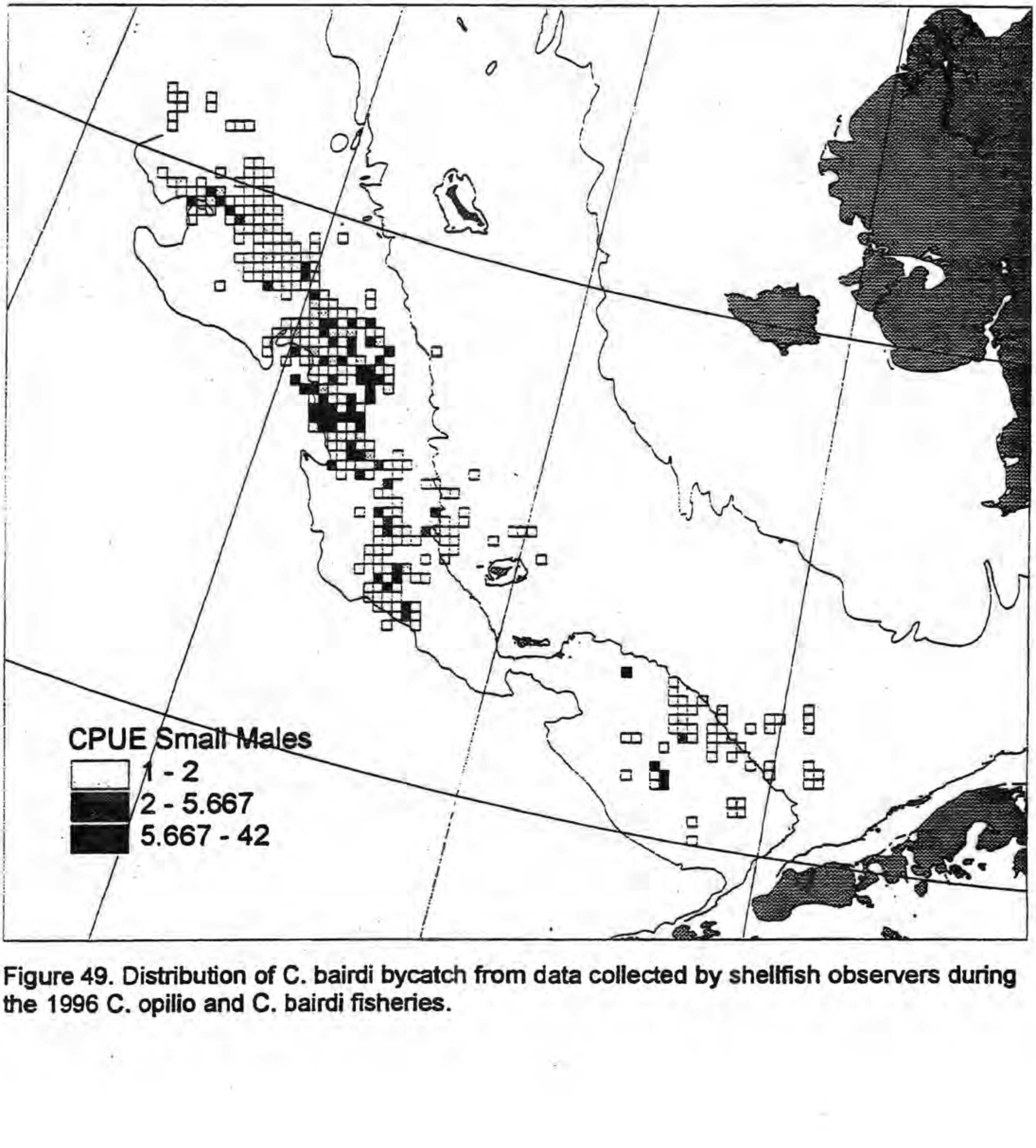


Figure 49. Distribution of C. bairdi bycatch from data collected by shellfish observers during the 1996 C. opilio and C. bairdi fisheries.

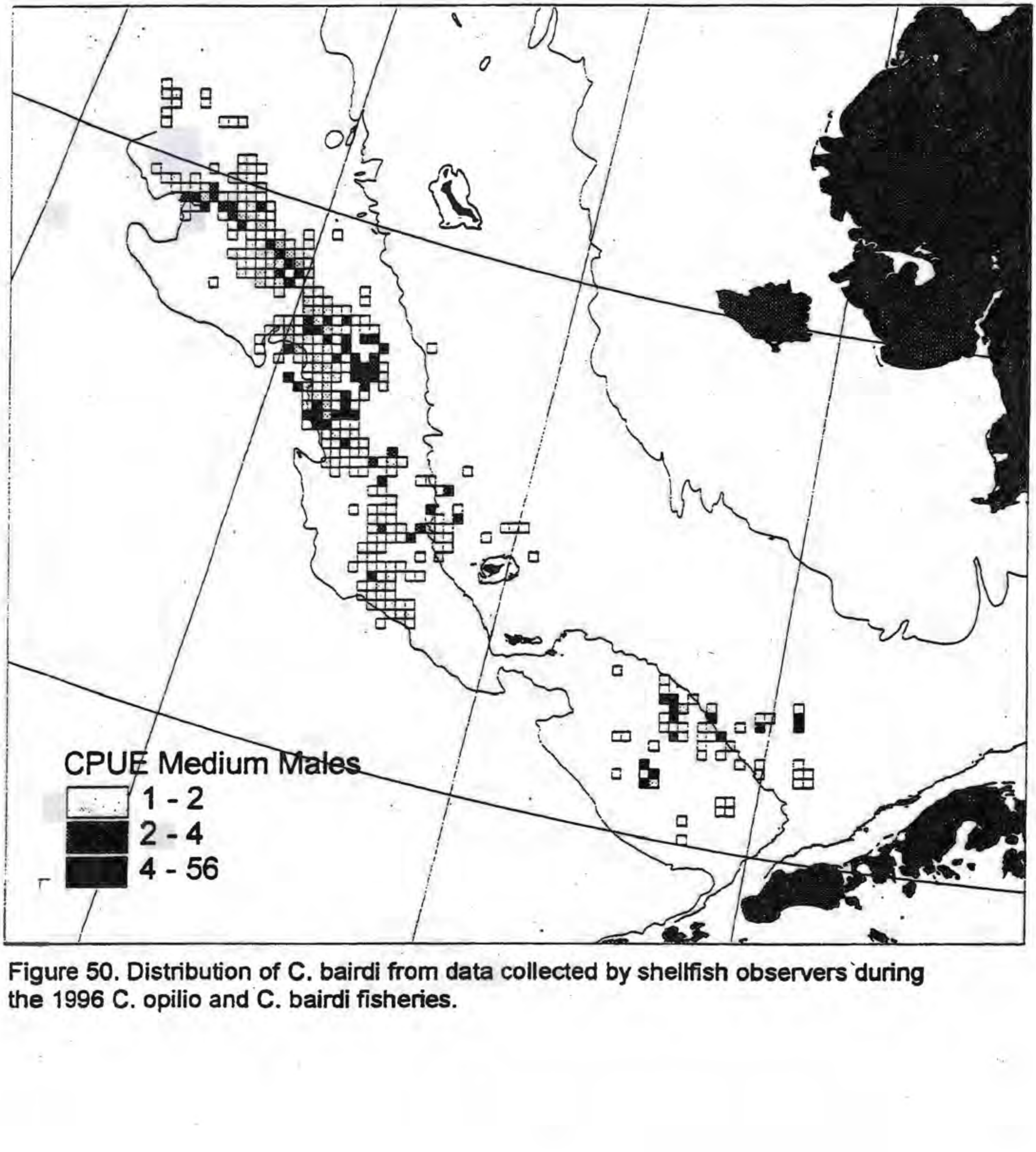


Figure 50. Distribution of C. bairdi from data collected by shellfish observers during the 1996 C. opilio and C. bairdi fisheries.

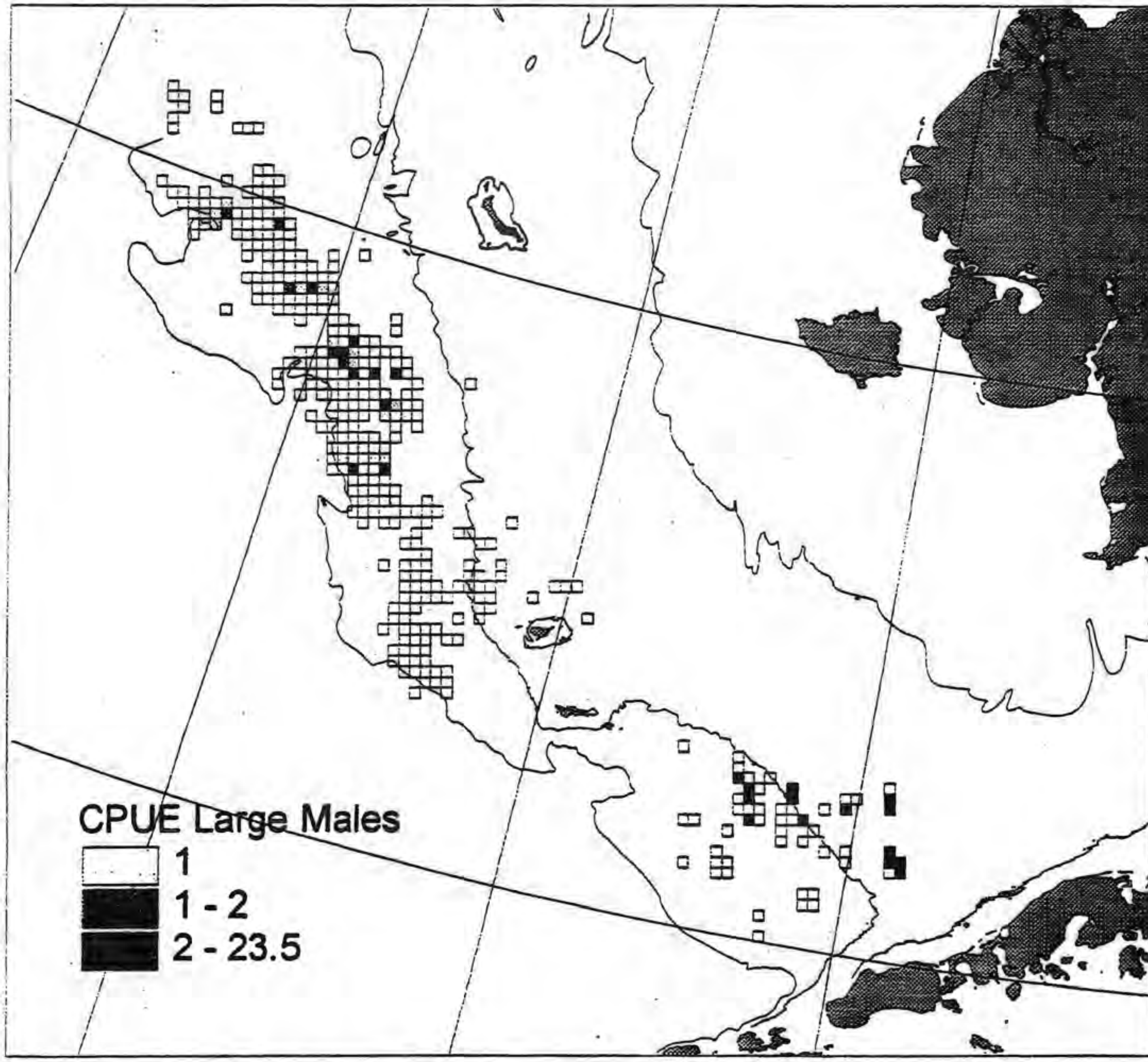


Figure 51. Distribution of C. bairdi from data collected by shellfish observers during the 1996 C. opilio and C. bairdi fisheries.

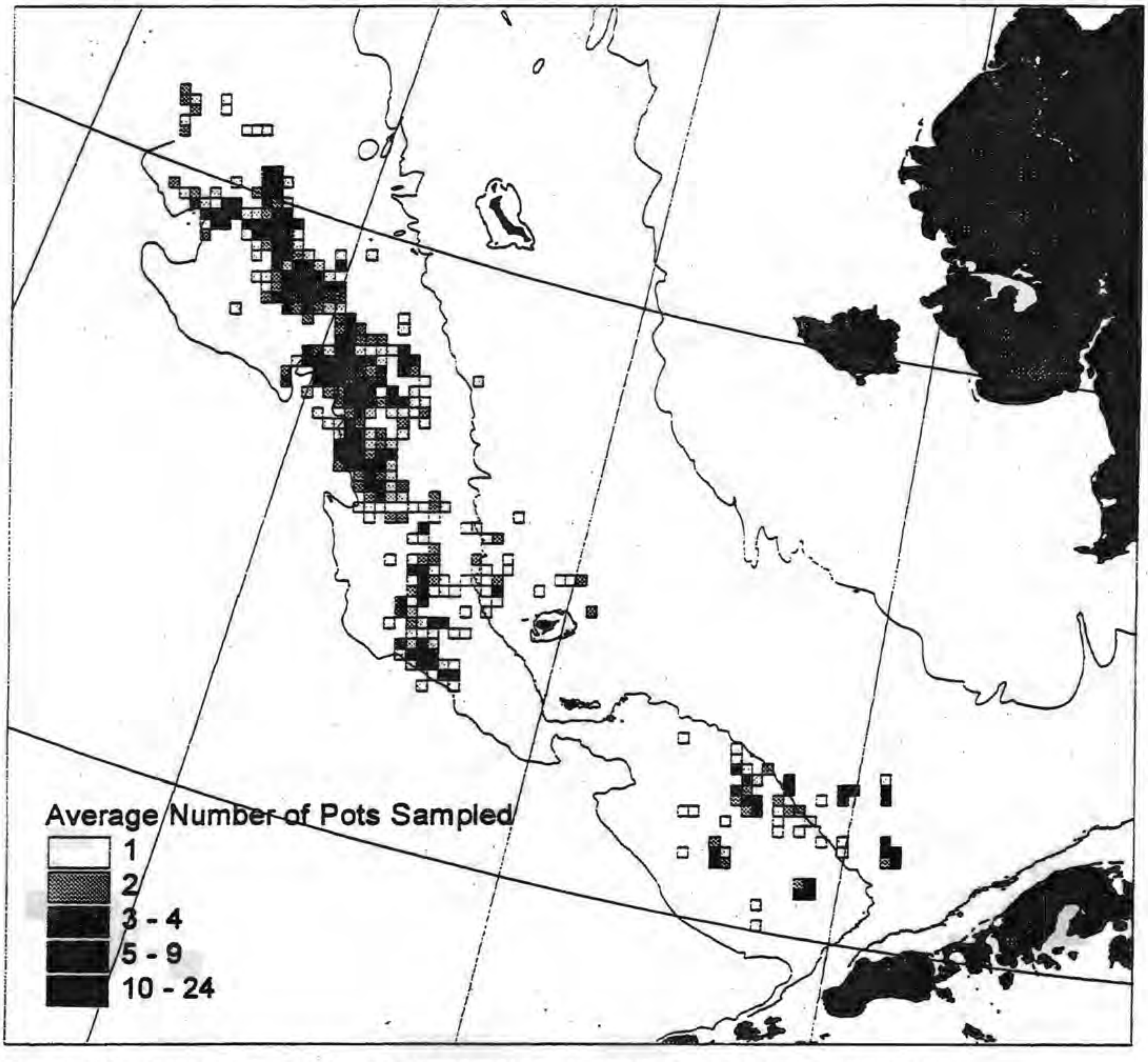


Figure 52. Average number of pots sampled by shellfish observers during the 1996 C. opilio and C. baidrdi fisheries.

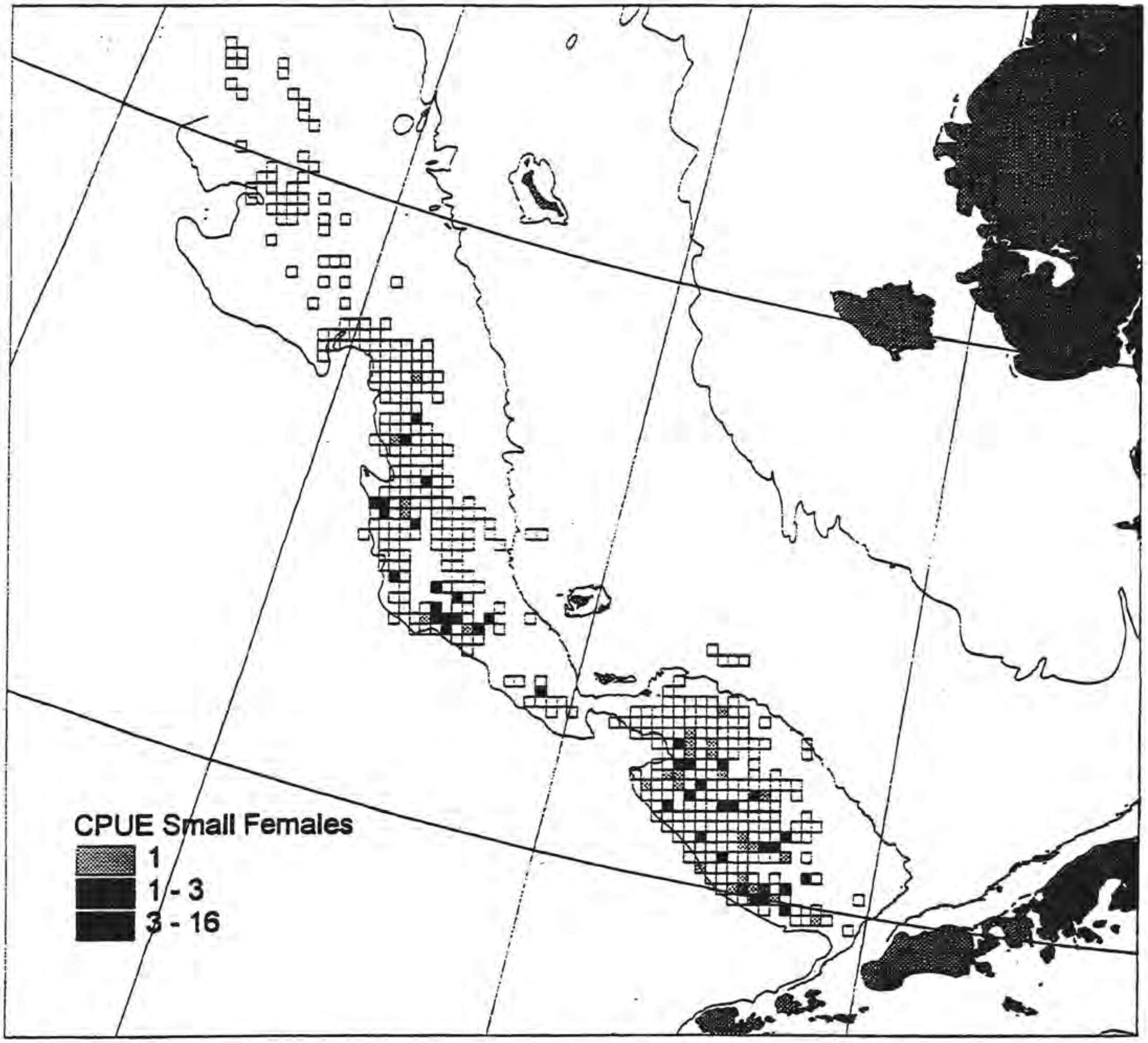


Figure 53. Distribution of C. bairdi bycatch from data collected by shellfish observers during the 1997 C. opilio fishery.

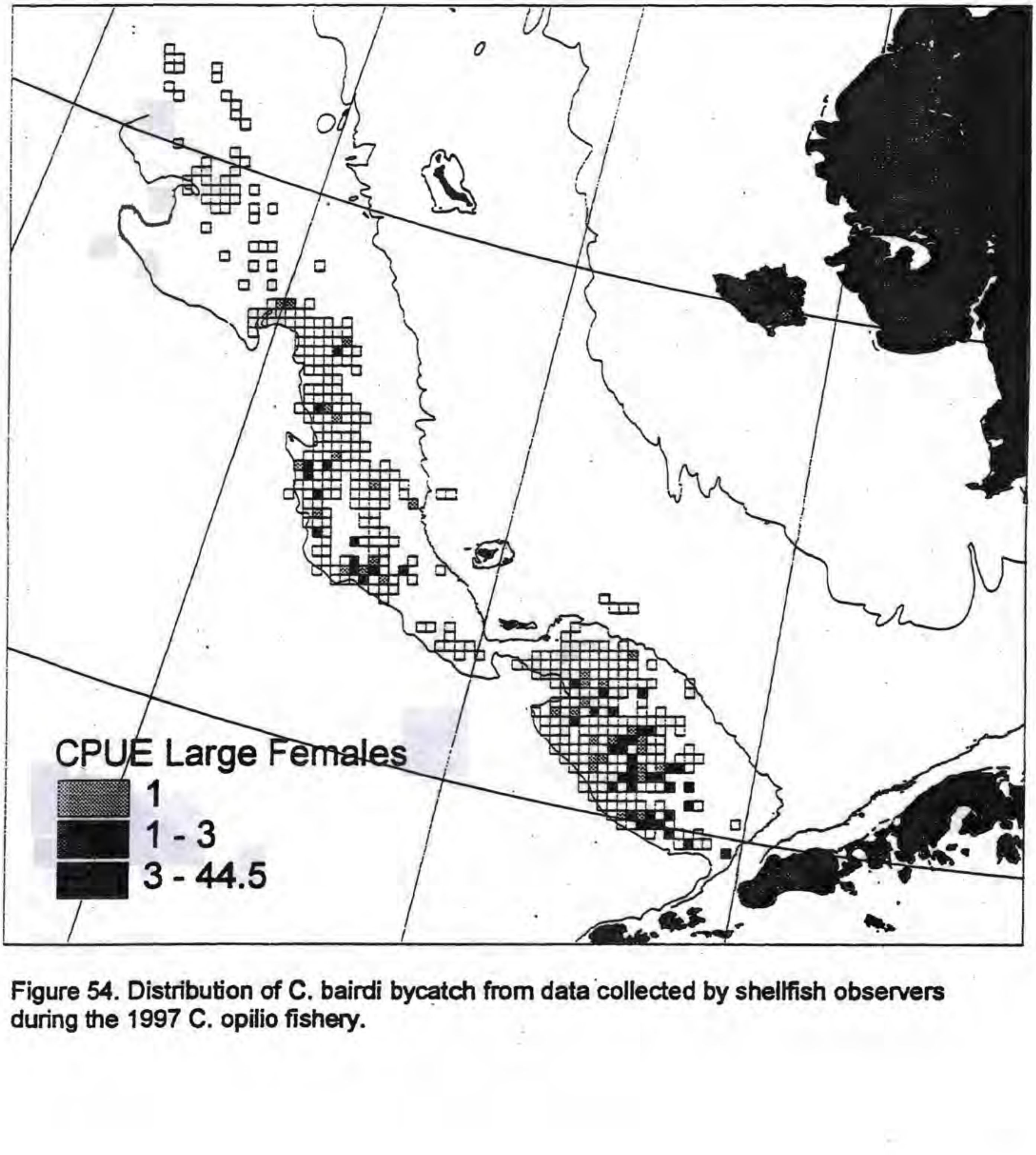


Figure 54. Distribution of C. bairdi bycatch from data collected by shellfish observers during the 1997 C. opilio fishery.

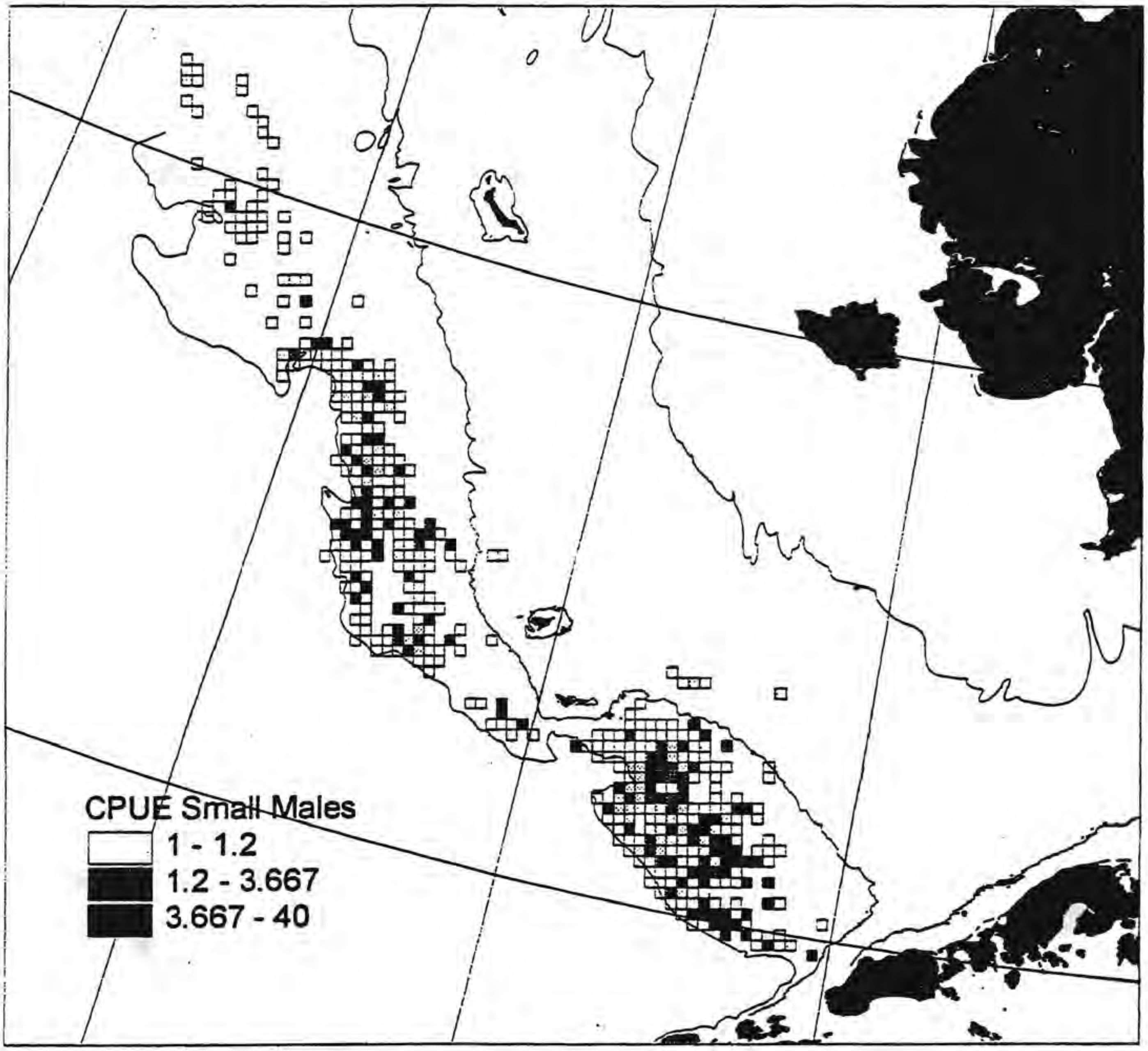


Figure 55. Distribution of C. bairdi bycatch from data collected by shellfish observers during the 1997 C. opilio fishery.

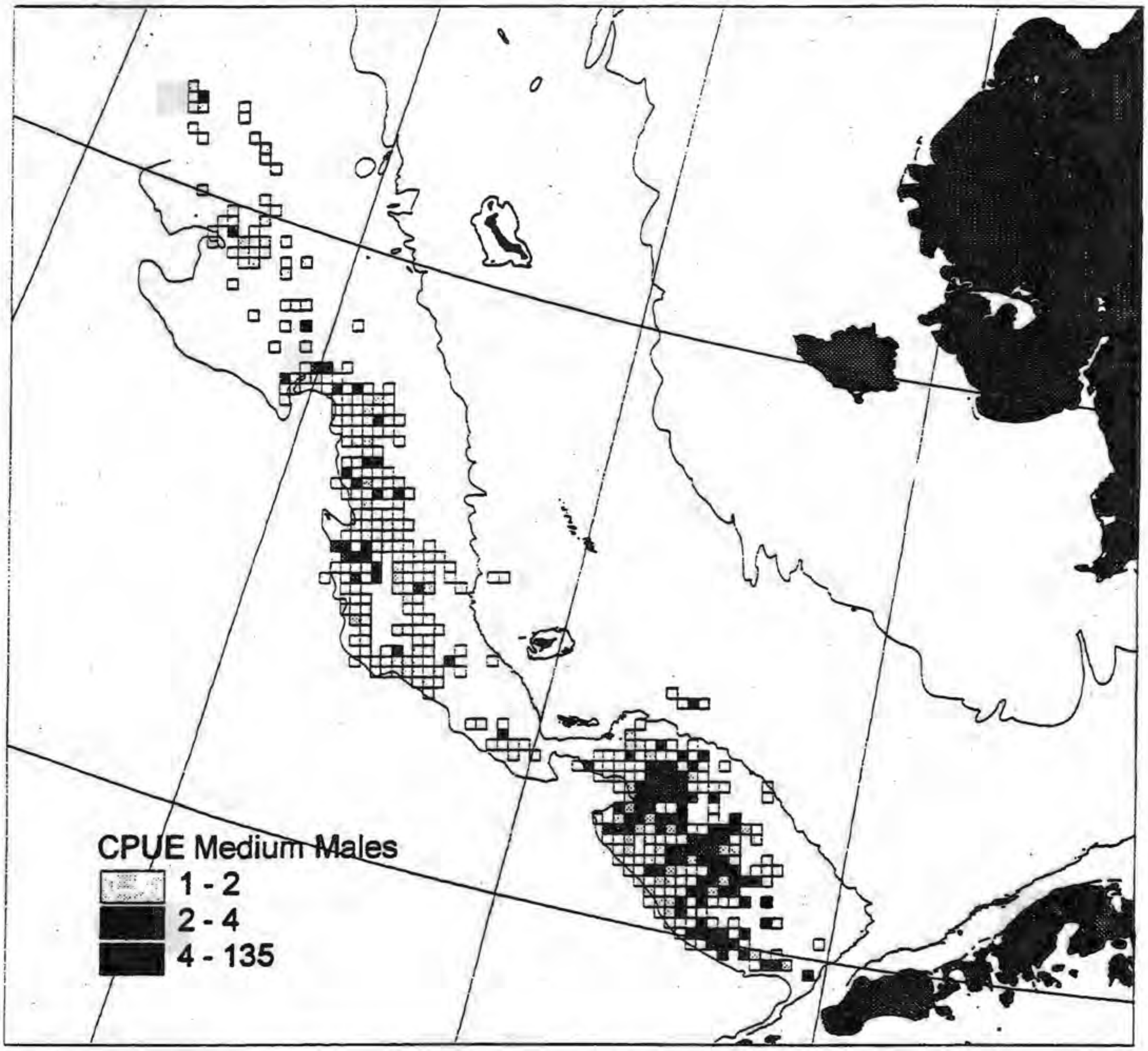


Figure 56. Distribution of C. bairdi bycatch from data collected by shellfish observers during the 1997 C. opilio fishery.

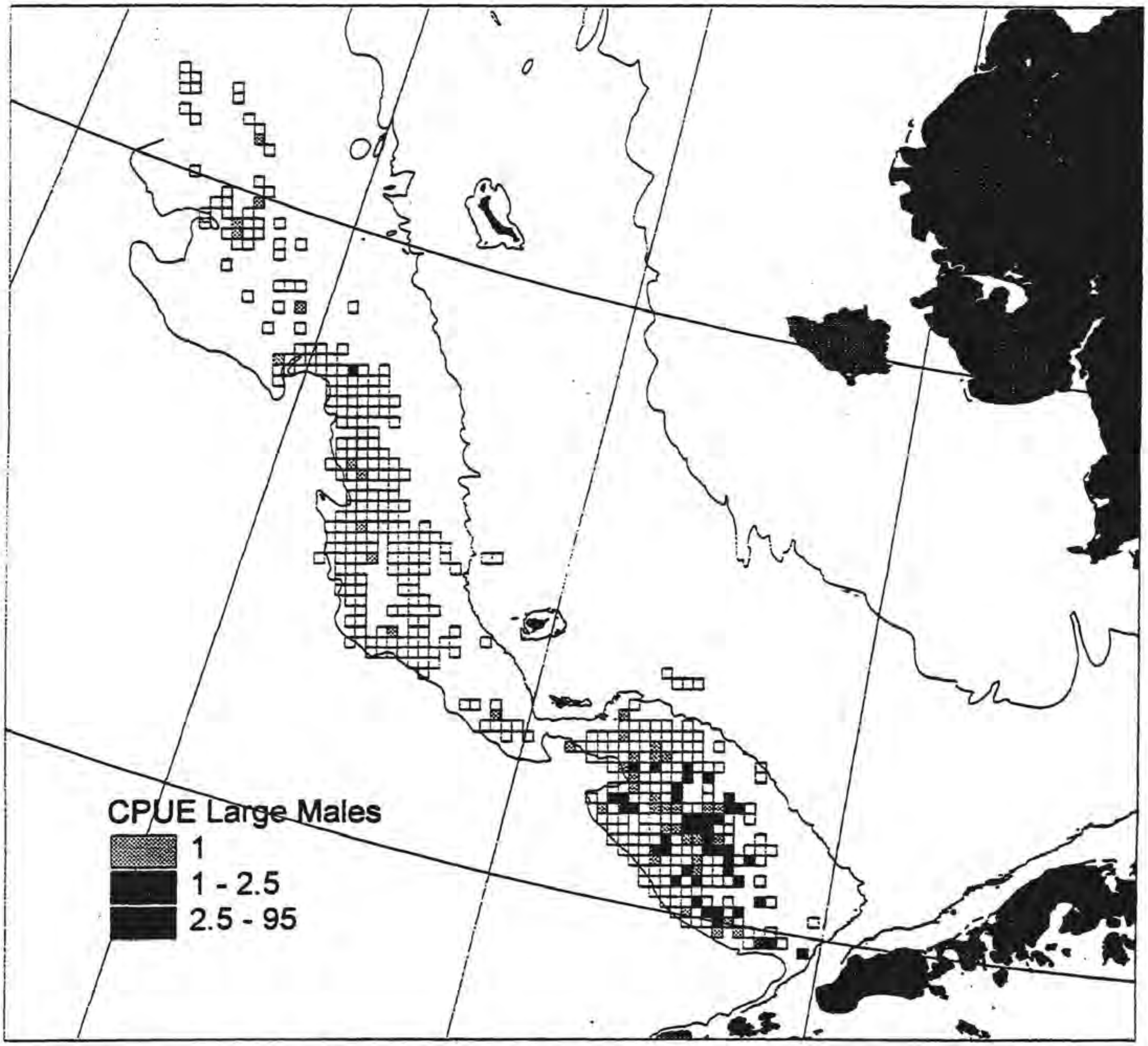


Figure 57. Distribution of C. bairdi bycatch from data collected by shellfish observers during the 1997 C. opilio fishery.

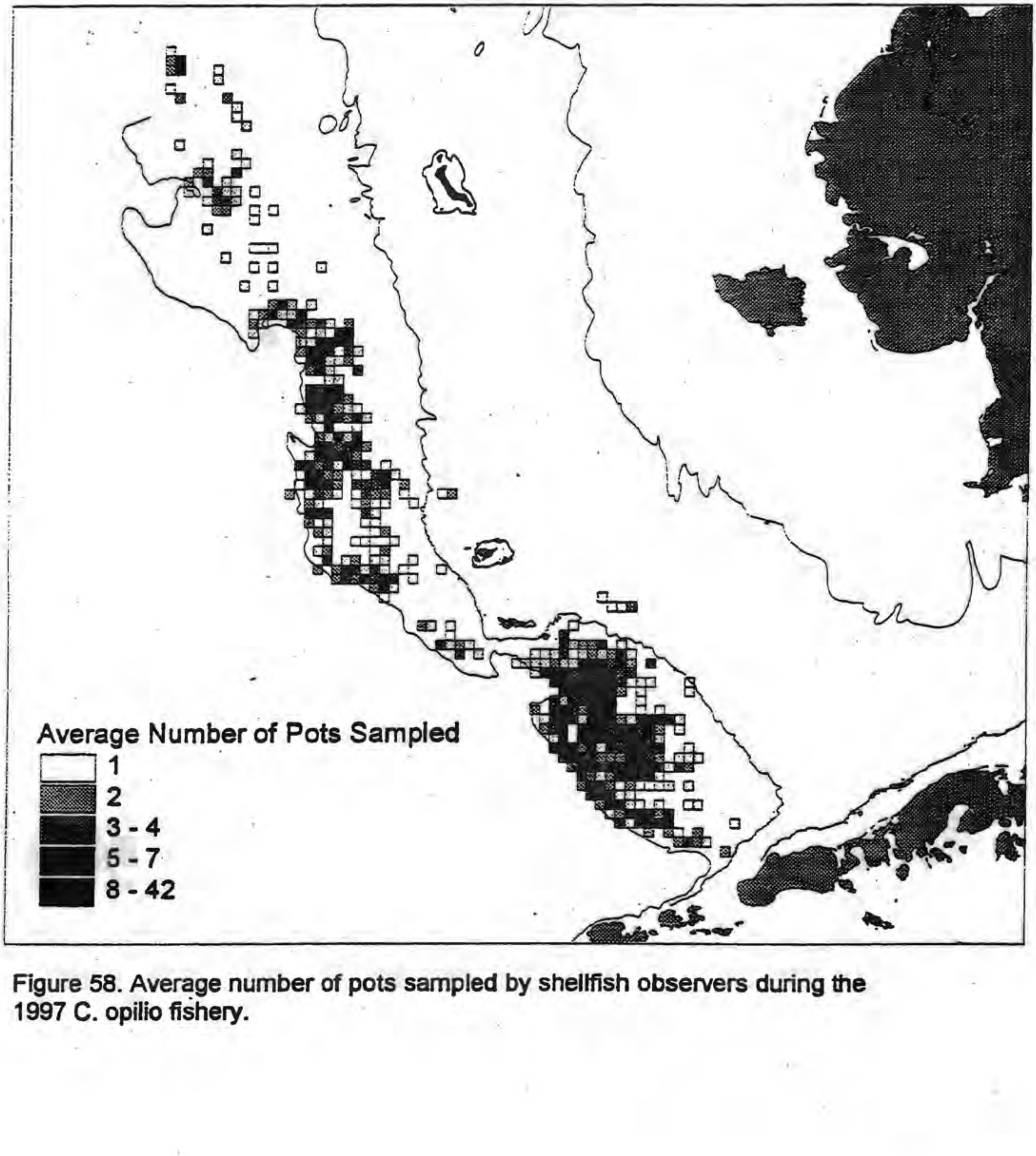


Figure 58. Average number of pots sampled by shellfish observers during the 1997 C. opilio fishery.

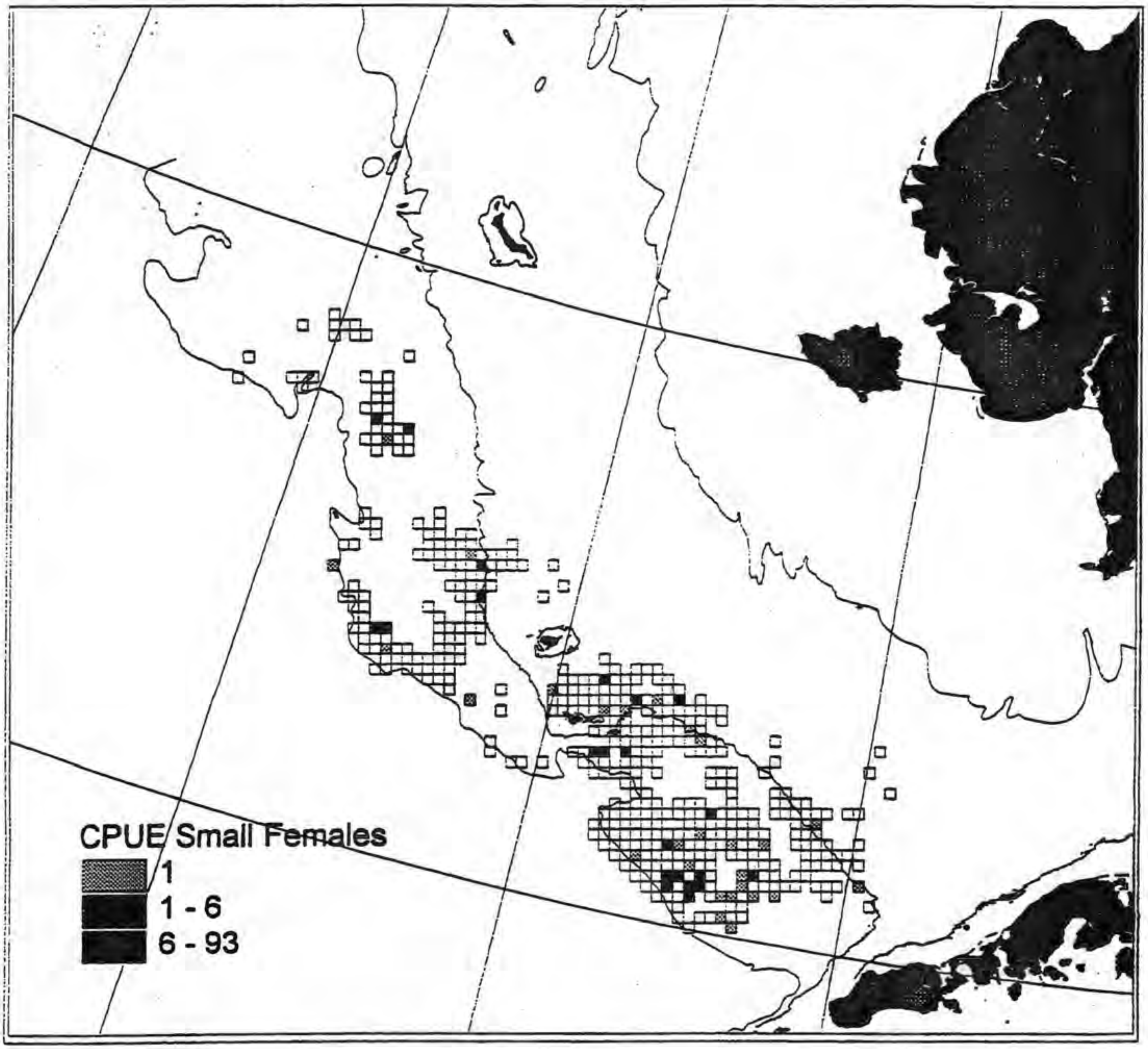


Figure 59. Distribution of C. bairdi bycatch from data collected by shellfish observers during the 1998 C. opilio fishery.

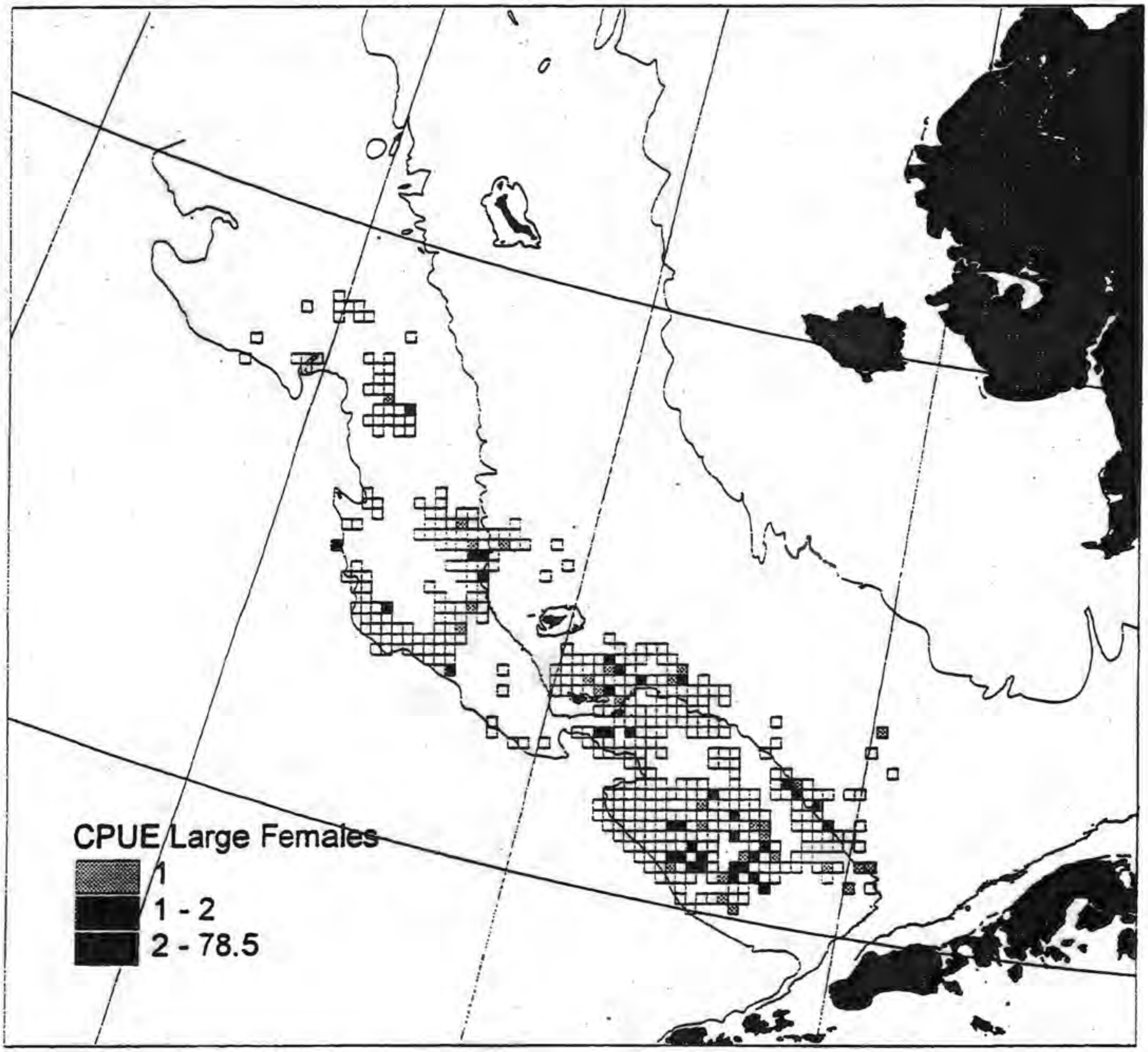


Figure 60. Distribution of C. bairdi bycatch from data collected by shellfish observers during the 1998 C. opilio fishery.

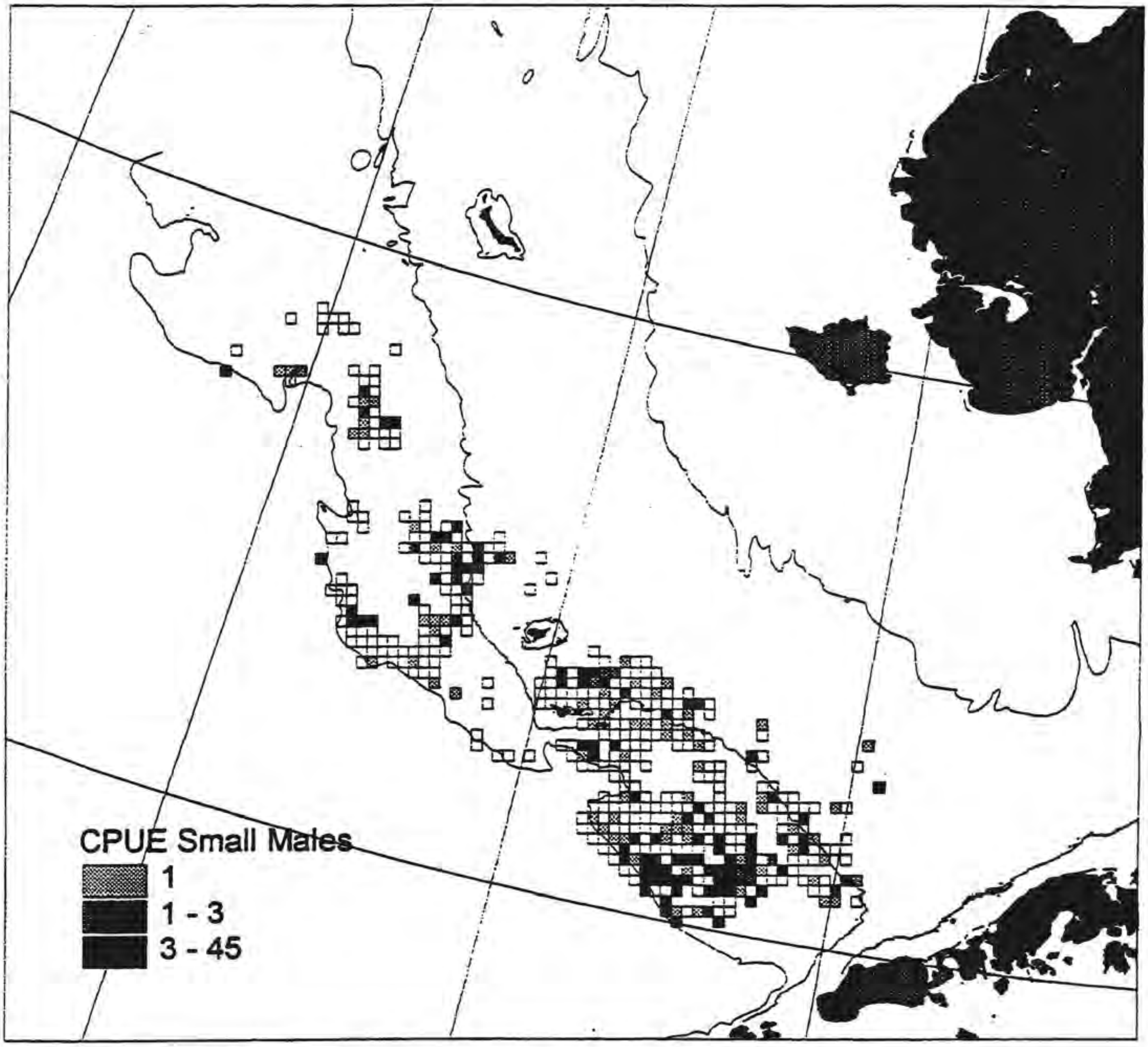


Figure 61. Distribution of C. bairdi bycatch from data collected by shellfish observers during the 1998 C. opilio fishery.

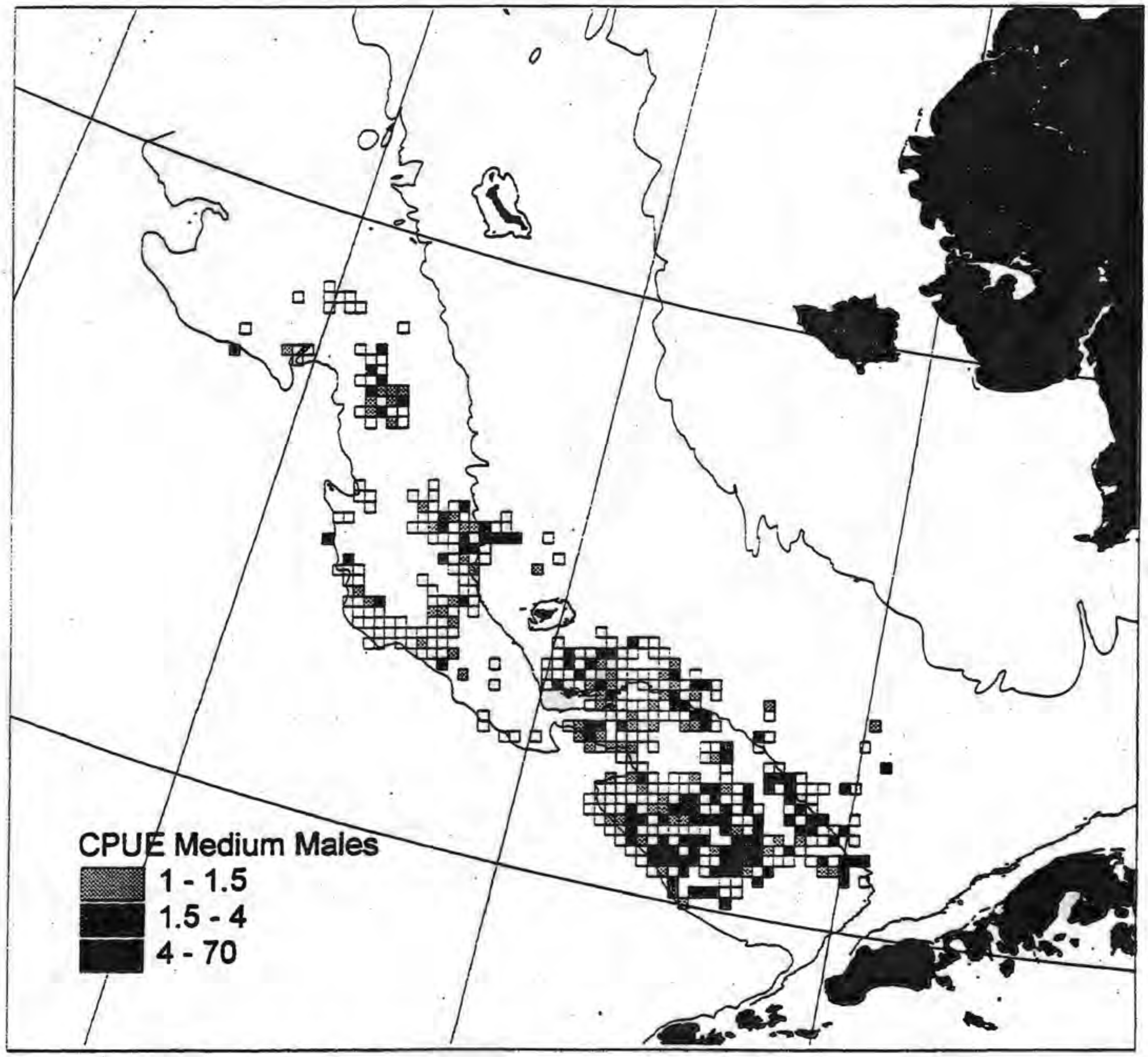


Figure 62. Distribution of C. bairdi bycatch from data collected by shellfish observers during the 1998 C. opilio fishery.

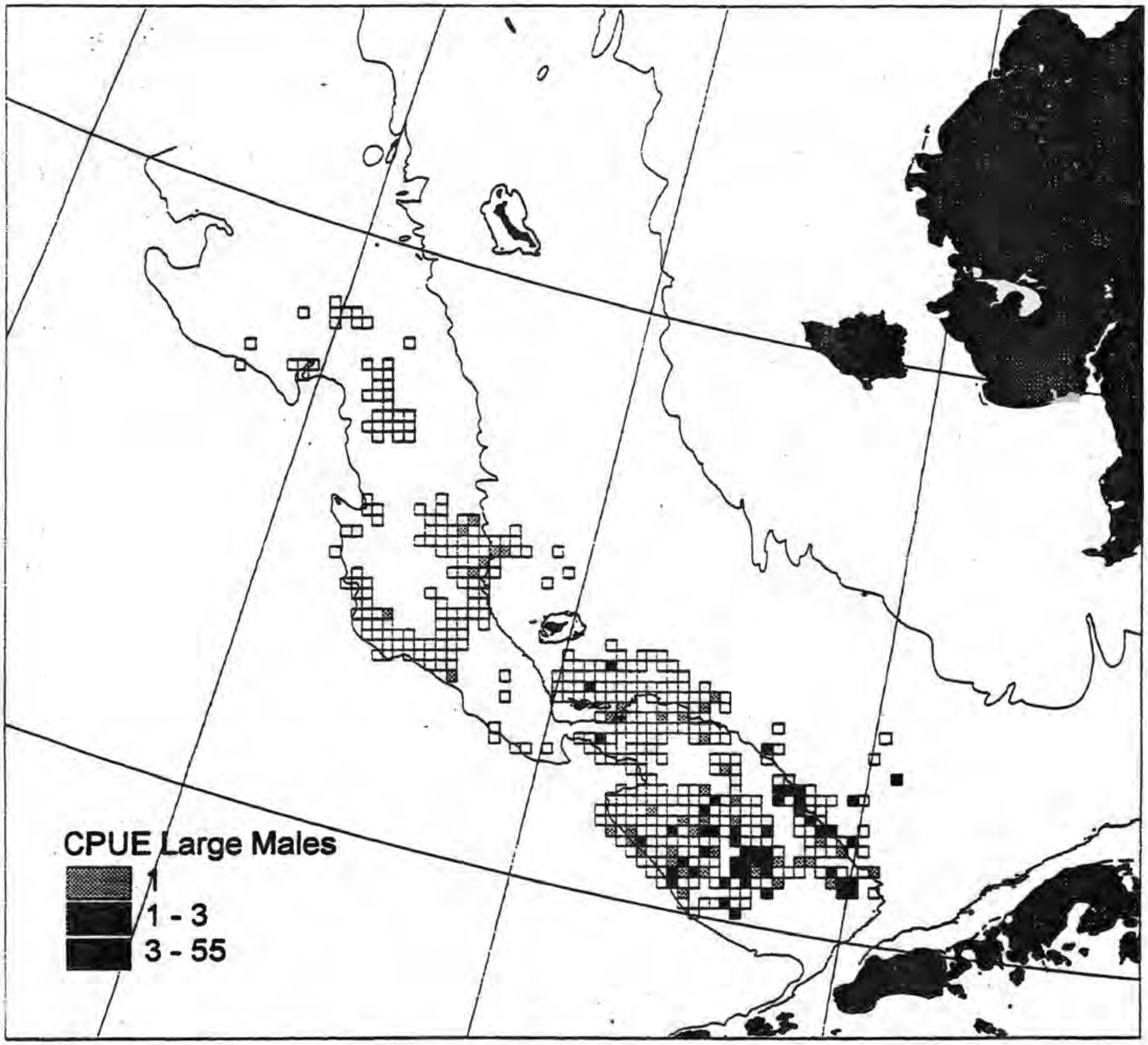


Figure 63. Distribution of C. bairdi bycatch from data collected by shellfish observers during the 1998 C. opilio fishery.

Appendix 1 The 1996 Industry Agreement on Tanner Crab PSC Limits

On August 30, 1996, the following agreement was reached by the negotiating committee on PSC caps for C. bairdi in the Bering Sea trawl fisheries. This agreement reflects revisions/clarifications made after the meeting.

PSC caps for bairdi:

The PSC limit for Tanner crab taken in Bering Sea trawl fisheries will be based on total abundance of C. bairdi as indicated by the NMFS annual bottom trawl survey as follows:

Area	Abundance*	PSC Limit
Zone 1	0 - 150 million crabs	0.5% of abundance
	150 - 270 million crabs	750,000 crabs
	270 - 400 million crabs	850,000 crabs
	over 400 million crabs	1,000,000 crabs
Zone 2	0 - 175 million crabs	1.2% of abundance
	175 - 290 million crabs	2,100,000 crabs
	290 - 400 million crabs	2,550,000 crabs
	over 400 million crabs	3,000,000 crabs

* Abundance is the total population index (sum of all size/sex groups) of the Eastern District (east of 173° W) from the NMFS trawl survey.

Caveats and Recommendations:

1. These PSC limits will be subject to a 3 year review.

2. In the interim, other approaches to PSC limits will be analyzed. These approaches include basing PSC limits on number of mature crabs, weight of crabs, and mortality of crabs taken in trawl fisheries.

Industry Support:

All parties here below signed will support this agreement at the North Pacific Fishery Management Council meeting through Secretarial review and approval. The Committee strongly recommends that the NPFMC approve this agreement without change. Any substantive change from this agreement releases the parties from supporting said agreement.

OVERVIEW OF POPULATION DYNAMICS AND RECOMMENDED HARVEST STRATEGY FOR TANNER CRABS IN THE EASTERN BERING SEA

By

Jie Zheng and Gordon H. Kruse

Regional Information Report[1] No. 5J99-04
Alaska Department of Fish & Game
Division of Commercial Fisheries
P.O. Box 25526
Juneau, Alaska 99802-5526

February 26, 1999

[1]The Regional Information Report Series was established in 1987 to provide an information access system for all unpublished divisional reports. These reports frequently serve diverse ad hoc informational purposes or archive basic uninterpreted data. To accommodate timely reporting of recently collected information, reports in this series undergo only limited internal review and may contain preliminary data; this information may be subsequently finalized and published in the formal literature. Consequently, these reports should not be cited without prior approval of the author or the Division of Commercial Fisheries. This report was funded in part by cooperative agreement NA67FM0212 from the National Oceanic and Atmospheric Administration. The views expressed herein are those of the authors and do not necessarily reflect the views of NOAA or any of its subagencies.

EXECUTIVE SUMMARY

Due to periodic recruitment, Tanner crab (*Chionoecetes bairdi*) abundance in Alaska fluctuates widely. Currently, most Tanner crab fisheries are closed due to low population levels. Managing Tanner crab fisheries to produce relatively high stable yield with a minimum chance of stock collapses presents a great challenge. In order to evaluate the current harvest strategy against alternative strategies for eastern Bering Sea (EBS) Tanner crabs, we need to understand their population dynamics. We constructed a size-based model to improve population estimates of Bristol Bay Tanner crabs. We also investigated the controversial hypothesis of terminal molt for male Tanner crabs, an issue having great implications for management. We rejected the terminal-molt hypothesis statistically as it failed to provide the most consistent interpretation of field-collected data on size, shell condition, and claw size of the Tanner crab population in Bristol Bay during 1990-1997. Molting probability of male Tanner crabs declines sharply once large claw is obtained, but a large majority of sublegal crabs can grow to legal size. Recruitment is periodic or cyclic for Bristol Bay Tanner crabs, resulting in a weak density-dependent stock-recruitment relationship in which recruitment is only loosely related to parental abundance levels. Computer simulations with a size-based model show that the yield curve is relatively insensitive to high harvest rates and that no harvest strategy can prevent stock collapse when recruitment fluctuates dramatically with long periodicity and high amplitude. A conservative strategy reduces the probability of stock collapse, however. We recommend a new harvest strategy for the EBS Tanner crab stock that is stair-stepped at 0, 10% or 20% of molting mature males (100% of newshell and 15% of oldshell males >112 mm (4.4 in) carapace width (CW)) depending on whether the biomass of females >79 mm CW is <21.0 million lbs, ≥21.0 and <45.0 million lbs, or ≥45.0 million lbs. The strategy also includes a 50% cap on harvest rate for exploitable legal crabs (100% of newshell and 32% of oldshell males >137 mm CW (5.5 in)). Guideline harvest levels (GHL) are determined separately for crabs in areas east of 168°W (Bristol Bay) and west of 168°W (Pribilof Islands) in the Eastern Subdistrict. Total GHL in the Eastern Subdistrict is equal to the sum of these two GHLs. The recommended strategy adjusts legal harvest rates according to changes in stock productivity indexed by recruitment strength: high legal harvest rates during the upward recruitment cycle and low rates that protect large-sized crabs and reproductive potential during the downward recruitment cycle. As compared to the current harvest strategy, the recommended new strategy is easily implemented, has similar trade-offs between high mean yield and relatively low variation in yield while increasing fishing opportunities (few years of closed fisheries) and reducing probabilities of being at overfished levels.

PURPOSE

The purpose of this report is to provide the basis for proposed new harvest strategies for Tanner crab fisheries in Alaska. We provide a brief history of the fisheries, an overview of the fishery management goal and management measures, and a summary of problems with the current management strategy. Then, we summarize four analyses of Tanner crabs in the Bristol Bay portion of the EBS: (1) a length (size)-based analysis (LBA) of population changes over time; (2) an analysis of terminal molt – that is, the hypothesis that male crabs stop molting once they reach maturity; (3) stock-recruit (S-R) relationships; and (4) an evaluation of alternative management strategies based on the Tanner crab population dynamics. Finally, our combined analyses led us to propose a new harvest strategy for Tanner crabs in Bristol Bay. We extended these results to Tanner crabs in the EBS and provided a framework to apply our findings and recommendations to Tanner crab stocks in the Gulf of Alaska.

HISTORY OF FISHERIES

Tanner crabs widely distribute in the waters off Alaska, extending as north as Norton Sound and as south as Southeast Alaska. The stocks used to support some of the most important fisheries in Alaska. The fisheries have followed a boom and bust cycle. In the EBS, Tanner crabs were first targeted by Japanese and Russian fleets in 1965. The EBS fishery expanded quickly in the late 1960s, and the catch reached 53 million lbs in 1968. Foreign fishing for Tanner crabs has been prohibited under the Magnuson Fisheries Conservation and Management Act since 1980. Directed fisheries for EBS Tanner crabs by the U.S. fleet began in 1974. Catch peaked in 1978 at 69 million lbs (Otto 1990). The EBS population collapsed in the mid-1980s, and no fishing was allowed in 1986 and 1987. During 1990-1993, catches averaged 33 million lbs and annual ex-vessel values averaged US$46 million. Catches dropped sharply after 1993, and the EBS fishery has been closed since 1997 due to the depressed stock condition.

MANAGEMENT GOAL AND MEASURES

An optimal harvest strategy for any fishery resource depends on fishery management goals. In March 1990 the Alaska Board of Fisheries (Board) adopted a fishery management policy for king and Tanner crabs (ADF&G 1998). The goal of the policy is to maintain and improve these crab resources for the greater overall benefit to Alaska and the nation. Achievement of this goal is constrained by a need to minimize: (1) risk of irreversible adverse effects on reproductive potential; (2) harvest during biologically sensitive periods; (3) adverse effects on non-targeted portions of the stock; and (4) adverse interactions with other stocks and fisheries. The policy endeavors to maintain a healthy stock, provide for a sustained and reliable supply of high quality product that leads to substantial and stable employment, and provide for subsistence and personal use of the resource. In brief, the Board specified a series of policies to protect the crab stock and provide for optimum utilization:

- Maintain stocks of multiple sizes and ages of mature crabs to sustain reproductive viability and to reduce industrial dependency on annual recruitment;

- Routinely monitor crab resources so that harvests can be adjusted according to stock productivity;
- Minimize handling mortality of non-legal crabs;
- Maintain adequate brood stock to rebuild the population when it is depressed;
- Establish management measures based on the best available information for each area; and
- Establish regulations for an orderly fishery.

Current size-sex-season measures, i.e., harvest of only large males and no fishing during spring molting and mating periods, are consistent with these policies. The size-sex-season measures are based on economic consideration of market value, protection of females, and allowance of at least one mating season for males. A legal size of 138 mm (without spines, commercial measurement with spines is 140 mm, 5.5 in) CW is used for Tanner crab fisheries statewide with the exception of Prince William Sound where it is 135 mm (5.3 in) CW. A constant harvest rate strategy is also used to set GHL where abundance estimates are available. For example, for the EBS stock, a harvest rate of 40% is currently applied to the abundance of legal-sized male crabs. Optimal harvest rates have not formally been evaluated for any Tanner crab stocks in Alaska. The Board's policy on king and Tanner crab management provides specific criteria under which alternative harvest strategies can be evaluated. The Maguson-Stevens Fishery Conservation and Management Act provides additional criteria (NMFS 1996). In particular, National Standard 1 states that "conservation and management measures shall prevent overfishing while achieving, on a continuing basis, the optimal yield from each fishery."

PROBLEMS AND APPROACHES

Tanner crab fishery management is facing a great challenge, and some changes in strategies are needed for several reasons. First, with an exception of a small fishery in Southeast Alaska, all other Tanner crab fisheries in Alaska are currently closed due to depressed stocks. The EBS stock was recently classified as "overfished" by the North Pacific Fishery Management Council (NPFMC 1998). According to the Magnuson-Stevens Fishery Conservation and Management Act (NMFS 1996), a rebuilding plan is needed to rebuild an overfished stock. Second, low stocks aren't necessarily managed more conservatively because the current 40% rate is fixed regardless of stock size provided that the fishery is open. Alternative harvest rates, including reduced rates at low stock sizes, need to be evaluated. Third, GHLs on low stocks often exceed the actual catch because low abundance and the predominance of oldshell crabs lead to poor fishery performance. Finally, although the fishery has been closed from time to time, the current harvest policy does not formally specify fishery thresholds.

To address these problems, ADF&G proposes to revise the harvest strategy for the directed EBS Tanner crab fishery as part of a joint Board-Council effort to rebuild this depressed stock. The Council leads other parts of the rebuilding effort that may include redesign of trawl closure areas and bycatch cap revision on groundfish fisheries. ADF&G's proposed new harvest strategy is based on detailed analyses of Tanner crabs in the Bristol Bay portion of the EBS. The results of our analyses of Bristol Bay Tanner crabs can be extended to the whole EBS with implications to the Gulf of Alaska stocks.

We selected Bristol Bay for study because the longest and most complete data sets were available and because this area supported the most valuable Tanner crab fishery in Alaska. Also, a large majority of mature EBS Tanner crabs are in Bristol Bay. We distinguished Bristol Bay Tanner crabs from those around the Pribilof Islands because there are statistically significant genetic differences between Tanner crabs in the two areas (Merkouris et al. 1997) and survey abundance data are more reliable for Bristol Bay. In addition, Somerton (1981) found an east-west cline of decreasing size at maturity in EBS female Tanner crabs, with the largest mean size of mature females occurring in eastern Bristol Bay. Although Tanner crabs in these two areas are not distinguished as separate stocks for management purposes, modeling Tanner crabs in Bristol Bay alone gives us more reliable results because of these differences.

ADF&G's proposed new harvest strategy is based on several analyses of the stock and fishery. We developed a LBA to improve abundance estimates of Bristol Bay Tanner crabs. The LBA was then modified to investigate a so-called "terminal-molt hypothesis" of male crabs. We also estimated the S-R relationships based on the results of LBA and from a review of literature on Tanner crab reproductive biology to understand the recruitment dynamics. Then, based on the results of the LBA, terminal molt, and S-R analyses, we conducted computer simulations to evaluate alternative harvest strategies for Bristol Bay Tanner crabs. Finally, we extended the simulation results on Bristol Bay Tanner crabs to EBS Tanner crabs and recommended a new harvest strategy. The technical details of our approaches are described in four scientific papers: LBA (Zheng et al. 1998), terminal molt (Zheng and Kruse MSb), S-R relationships (Zheng and Kruse MSa), and harvest strategies (Zheng and Kruse MSc). Copies of these papers are available upon request. An overview of these studies follows.

LENGTH-BASED ANALYSIS

Rationale to Develop the LBA

The annual trawl survey conducted by the National Marine Fisheries Service (NMFS) gathers essential data on the status of crab stocks in the EBS (Stevens et al. 1998). Yet, year-to-year changes in oceanographic conditions lead to changes in crab distributions and availability to survey gear. These changes may cause measurement errors that lead to unexpected shifts in area-swept abundance estimates unrelated to true changes in population size. Data from previous years' surveys and commercial catches provide valuable auxiliary information to help decipher real population changes from survey measurement errors. We developed the LBA (Zheng et al. 1998) to utilize these multiple years of data and multiple data sources to more accurately estimate abundance than using current-year survey data alone. The exact same motivation led to similar age-structured analyses for most important fish stocks off Alaska and elsewhere around the world.

Overview of the LBA

The LBA is an analytical procedure to estimate annual abundance of crab stocks for which extensive high-quality data are available. The LBA makes use of detailed annual data on size, sex, and shell condition from trawl surveys, onboard and dockside catch samples, and annual commercial harvests. Males and females are modeled separately by 5 mm CW intervals as newshell (i.e., those that molted within the past year) and oldshell crabs (i.e., those that have not molted within the past year). The annual abundance of crabs in each width group is a combined result of recruitment, growth, natural mortality, and harvest. Note that this is a size-based analysis, not an age-based analysis that is commonly used for fish stocks.

Comparison of LBA and Area-swept Estimates

LBA estimates of abundance fitted well with NMFS survey area-swept estimates of abundance over the history of the survey in Bristol Bay (Figure 1). Mature female (>79 mm CW) and male (>112 mm CW) abundances generally declined from the mid-1970s to the mid-1980s, increased sharply during the late 1980s, and decreased again in the early 1990s (Figure 1). Currently, Tanner crab abundance is at an extremely low level.

Benefits of the LBA are that it provides relatively precise abundance estimates for male and female crabs for fishery management, yields information needed to estimate S-R relationships, and provides a means to analyze alternative harvest strategies. Another benefit of the LBA is that it smoothes out measurement errors in the survey. Survey measurement errors were very high in some years; for example, the survey appeared to greatly overestimate mature female abundances in 1977, 1991, 1995, and 1996, and mature male abundance in 1975 and to greatly underestimate mature female abundances in 1979 and 1993 (Figure 1). Often, high measurement errors were caused by an extremely high catch in one or two survey stations. By smoothing out survey measurement errors, the LBA provides a more consistent interpretation of stock changes over time than do survey area-swept estimates.

TERMINAL MOLT OF MATURE MALE TANNER CRABS

What Is Terminal Molt and Why Do We Need to Understand It?

In many majid (true) crabs, it has been hypothesized that the maturity molt is the last or terminal molt (Hartnoll 1963). Maturity is often assessed with morphometric data. For males, morphometrically mature crabs are distinguished from morphometrically immature crabs by an increase in chela height for a given CW (Somerton 1980; Conan and

Comeau 1986). In this report, the term "morphometric maturity" was objectively described as large-clawed as opposed to small-clawed males and does not necessarily coincide with physiological or functional maturity. For females, a prominent increase in the width of the abdomen indicates sexual maturity (Somerton 1981). It is commonly accepted that female Tanner and snow crabs (*Chionoecetes opilio*) undergo a terminal molt at maturity. Based on their snow crab work in the Gulf of St. Lawrence in Atlantic Canada, Conan and Comeau (1986) and Conan et al. (1990) suggested that all males of the genus *Chionoecetes* have a terminal molt at the time they reach morphometric maturity. This assertion led to a considerable debate (Conan and Comeau 1988; Donaldson and Johnson 1988; Jamieson et al. 1988; Conan et al. 1990; Dawe et al. 1991). Scientists around the world as well as within Alaska have not reached a consensus on this issue.

Whether male Tanner crabs undergo a terminal molt at maturity has important implications on the assessment and management of crab fisheries. Terminal molt has implications on legal size limit and yield optimization. If terminal molt occurs before reaching legal size, crabs will never become available for harvest. Conversely, if terminal molt occurs after reaching legal size, crabs may be harvested before having an opportunity to mate, thus reducing reproductive potential and perhaps future recruitment. In terms of yield per recruit, a size limit is not an efficient management measure to optimize harvest of a cohort of crabs that stop growing over a wide range of sizes. Consequently, a conflict exists between management objectives for maximizing physical or economic yield per recruit and adequately protecting a stock's reproductive potential. Additionally, over the long term, use of a size limit on an exploited stock exhibiting terminal molt will result in harvesting the fastest growth segment of the stock with potential adverse genetic consequences (Kruse 1993; Sainte-Marie et al. 1995). The existence of terminal molt also affects the choice of suitable methods to estimate growth and natural mortality parameters, which are important to assess stock size and to evaluate optimal harvest strategy.

Literature Review

Evidence for the terminal-molt hypothesis in *Chionoecetes* species mainly comes from snow crabs in the Gulf of St. Lawrence. Conan and Comeau (1986) observed that large-clawed male snow crabs failed to molt in the laboratory, and in their field studies they did not find large-clawed males with mouth parts indicating imminent molting. Sainte-Marie et al. (1995) also observed in the field that molting of large-clawed male snow crabs was virtually nil over several consecutive years. Nine scientists (Dawe et al. 1991) challenged the idea of terminal molt by critically questioning the methods used by Conan and Comeau (1986) and presenting new data. Among the new data were observations of molting of large-clawed males both in the field and laboratory (Dawe et al. 1991). Sainte-Marie et al. (1995) argued that the observations reported by Dawe et al. (1991) might be caused by exceptions and classification errors and that large claw might not be a strict condition for terminal-molt status. In Alaska, Otto (1998) assessed EBS snow crabs under the assumption of terminal molt.

In their critique of Conan and Comeau's (1986) paper, Donaldson and Johnson (1988) provided evidence contrary to the terminal-molt hypothesis for Gulf of Alaska Tanner crabs. All of the 318 males collected from Women's and Chiniak Bays, Kodiak Island, including several classified as "morphometrically mature," molted in holding pens. Donaldson and Johnson also cited Paul and Paul's (1986) study of encrusting barnacles on Tanner crabs from Cook Inlet. Thirty-nine percent of male crabs 120-180 mm in CW carried barnacles that lived 1-2 growing seasons; no males had barnacles >3 growing seasons. In contrast, 87% of terminal-molt females had barnacles, and 42% of those had lived 3-4 growing seasons. Paul and Paul (1986) cited these results as consistent with Donaldson et al.'s (1981) estimate of an 18-month male intermolt period, and Donaldson and Johnson (1988) expected similar barnacle age distributions on males and females if terminal molt occurred in both sexes.

Conan and Comeau (1988) questioned the conclusiveness of these data and argued that the low proportion (5 of 318) of morphometrically mature males in the sample was consistent with expected misclassification error rates of crabs that might have been morphometrically immature. Regarding the shell-age data from Cook Inlet, Conan and Comeau proposed that a low proportion of oldshell large males was not surprising given (1) large size overlap of morphometrically immature and mature males, and (2) higher mortality rates of males than females due to the large male-only fishery. Conan and Comeau acknowledged that it was not possible to rule out the possibility that terminal molt may not occur in all *Chionoecetes* species, but they suggested that no evidence exists that molting of morphometrically mature males occurs to any significant degree.

Direct evidence now exists that, at least under some conditions for *Chionoecetes bairdi*, the proportion of morphometrically mature males that molt may be very significant, contrary to the terminal-molt hypothesis. Paul and Paul (1995) studied 23 sublegal-sized (110-139 mm CW), functionally mature male Tanner crabs that mated with multiparous females; 74% of these males initiated molting after 26-27 months in the laboratory. According to the criteria of Stevens et al. (1993), 76% of these functionally mature males were morphometrically mature (Paul and Paul 1995). Thus, the generality of the terminal-molt hypothesis remains questionable.

Our Approach

The purpose of our terminal-molt study was to explore the consistency of the terminal-molt hypothesis with field data collected during the annual stock assessments of Tanner crabs in the EBS. We fitted a LBA (Zheng et al. 1998) to trawl survey estimates of male Tanner crab abundance in Bristol Bay from 1990 to 1997 by shell condition (newshell and oldshell) and maturity status (morphometrically mature and immature). We used a non-linear least squares approach to estimate abundance, recruitment, and molting probability and compared model fits with and without an assumption of a terminal molt to evaluate consistency of this hypothesis with field observations. Although comparable data on morphometric maturity status are unavailable for other Tanner crab stocks in Alaska, changes in molting probability can be revealed by the shell conditions of sublegal male crabs which are approximately one molt away from reaching legal size. So, we also examined proportions of sublegal oldshell male Tanner crabs from five stocks in the EBS and the northern Gulf of Alaska to seek evidence that molting probabilities varied over time by region.

Summary of Results

The model fitted observed abundances well, and the fit was best made without assuming a terminal molt at morphometric maturity (large claw size). We rejected the terminal-molt hypothesis statistically as it failed to provide the most consistent interpretation of field-collected data on size, shell condition, and claw size of the Tanner crab population in Bristol Bay during 1990-1997. However, we found that molting probability of male Tanner crabs declines sharply once morphometric maturity is achieved: from 93% to 15% during 1990-1993 and from 61% to 0% during 1995-1996. Although the terminal-molt hypothesis appears valid for 1995 and 1996, a significant percentage of morphometrically mature males appear to have molted in 1990-1993, contrary to the hypothesis. The percentage may have been much higher in previous years. Proportions of oldshell sublegal male crabs during 1990-1997 were about 2.5 times as high as those during 1975-1989, suggesting much higher molting probabilities prior to 1990. However, data were not collected on claw size that would have allowed us to confirm that morphometrically mature crabs molted at higher rates during the 1970s and 1980s than during the 1990s.

An examination of the proportions of oldshell sublegal male Tanner crabs from five major Alaska stocks implies that molting probabilities vary widely by time and area. It appears that the terminal-molt controversy is somewhat a matter of degree. We speculate that the occurrence of terminal molt at morphometric maturity for male Tanner crabs may be stock specific and influenced by recruitment strength and prevailing environmental conditions. We suggest that growth to maximum body size is genetically controlled but modified by environmental conditions.

Implications to Fishery Management

Our results have implications for Bristol Bay Tanner crab fishery management. The current size limit is about 138 mm CW (140 mm CW for commercial fisheries in which the measurements include spines). Many crabs are morphometrically mature prior to attaining legal size, and only a small proportion of legal crabs are immature. The median size at morphometric maturity is 115 mm CW for Bristol Bay Tanner crabs (Somerton 1980), about one molt increment smaller than the size limit. Therefore, almost all males have a chance to mate at least once before they reach the legal size, and the current size limit should adequately conserve male reproductive potential, especially given the sperm retention capabilities of females (Paul 1984). Paul and Paul (1996) reached the same conclusion based on estimates of size of maturity and legal size limit for Kodiak Tanner crabs. That only 22% of all sublegal crabs were oldshell from 1975 to 1989 implies that the large majority of sublegal crabs can grow to legal size during this period. However, the low molting probability since 1990 suggests that a substantial proportion of sublegal crabs may no longer be able to attain legal size. If the current low molting probability continues, management options, such as lowering the current legal size limit or perhaps using a limit based on the ratio of chela height against CW, may need to be considered and evaluated to reduce the loss of harvest opportunity for small-size, large-clawed crabs. Alternatively, the reduced molting probability may provide added reproductive safeguards at low stock sizes. Finally, in our analysis of terminal molt, we found a large difference between the shell conditions of legal crabs from assessment surveys and the commercial fishery in the recent years. This suggested to us that an effective harvest strategy should include both abundance and shell-age composition in setting GHLs.

STOCK-RECRUITMENT RELATIONSHIPS

Overview

An S-R relationship predicts likely recruitment of progeny from a given spawning stock size. Such a relationship can be created by density-dependent predation, cannibalism, and food or space limitation. Inability or difficulty to find mates at low densities can also result in a strong relationship at low spawning stock levels. The commonly used S-R models are dome-shaped curves developed by Ricker (1954) and asymptotic curves by Beverton and Holt (1957).

The S-R relationship has important implications for harvest strategies. If no such relationship exists, i.e., recruitment is not related to the corresponding spawning stock size, then the optimal harvest strategy may be to harvest all crabs that have reached their maximum economic value. But many experiences around the world show that if stocks are heavily exploited, then recruitment will eventually be reduced and fisheries will collapse. Because recruits are survivors from eggs that are spawned by the parent stock, it follows that with a depressed spawning stock, there will be few eggs and few recruits in a closed population. Even if the S-R relationship has not been clearly demonstrated for each stock and species, it is prudent to assume an effect of stock size on recruitment at least at low spawning stock levels to avoid risk of commercial extinction. Due to lack of data, S-R relationships have not been estimated for most crab stocks in Alaska. Our study is the first attempt to estimate S-R relationships for a Tanner crab stock.

Our Approach

In this study, we used updated results from the LBA (Zheng et al. 1998) to develop an S-R relationship for Bristol Bay Tanner crabs. First, we developed a method to compute male reproductive potential, based on a literature review of Tanner crab reproductive biology and data on size at maturity and clutch condition from summer trawl surveys conducted by NMFS. Second, we estimated effective spawning biomass from mature female abundance and male reproductive potential. Finally, we fitted effective spawning biomass and recruitment data to both an ordinary and an autocorrelated Ricker model and examined patterns of residuals from the fits.

In this study, we assumed that female Tanner crabs mature at ≥80 mm CW. Although sizes at 50% maturity are smaller than 80 mm CW during most years from 1975 to 1997, 80 mm CW is the mid-point between the largest and smallest sizes at 50% maturity (Figure 2). Mean size of mature females may be routinely overestimated because it is difficult for the trawl gear to catch small crabs. Although our assumed maturity size of 80 mm CW is much smaller than about 93 mm CW estimated by Somerton (1981) using mean size of mature females, it more accurately represents observed sizes at 50% maturity during the time period we modeled, namely 1975-1997. Use of mean size of mature females as a cutoff size for maturity apparently greatly underestimates female mature abundances during most years.

Results

Recruits are not strongly associated with effective spawning biomass; both weak and strong recruitment occurred with both low and high effective spawning biomass (Figure 3). The strongest recruitment is almost 100 times as large as the weakest recruitment, and the largest effective spawning biomass is more than 10 times as large as the lowest one (Figure 3). Variation of recruitment caused great fluctuation of population abundance over time. Strong year classes occurred in the late 1960s and early 1980s, and weak year classes occurred in the mid and late 1970s and mid and late 1980s. Thus, recruitment is highly autocorrelated; that is, weak years follow weak years and strong years follow strong years. The exponential S-R curve was fit for effective spawning biomass of 14.1 million lbs or less (Figure 3), but the results are highly uncertain because only three pairs of such data are available.

Much variation of recruitment can be explained by autocorrelation or cycle; thus, environmental factors are likely to play a very important role in recruitment success. Some environmental conditions may trigger a switch between weak and strong recruitment from period to period. Rosenkranz et al. (1998) suggested that winds from the northeast are favorable to larval retention and recruitment, but the patterns of winds from the northeast are not consistent with periods of weak and strong recruitment all the time. Alternative explanations include adverse effects of cold bottom temperature on gonad development, beneficial effects of warm surface temperature on larval food (copepod production), groundfish predation and competition, and the possibility that the stock affects recruitment in some ways different than we modeled. Spawning geography, the spatial distribution of spawners, is one possible effect that may confound attempts to estimate S-R relationships.

Autocorrelated, periodic or quasi-periodic recruitment is common in crab stocks and some fish stocks (McKelvey et al. 1980; Koslow et al.1987; Koslow 1989; Zheng et al. 1995; Sainte-Marie et al. 1996; Zheng 1996; Zheng and Kruse in press). Although year classes for Bristol Bay Tanner crabs from 1968 to 1989 showed a strong cyclic behavior with a period of 13 or 14 years (Figure 3), catch data (Otto 1990) indicate that the cycle was weaker or shorter for year classes from late 1950s to late 1960s than from 1968 to 1989. Because of the brevity of available time series, the period length and even the existence of repeatable cycles are not well established. The strong recruitment cycles may also be caused in part by age-class overlap in recruitment estimated by a size-based model. Nevertheless, despite uncertainty about the details, recruitment of Bristol Bay Tanner crabs appears to be at least quasi-periodic.

A strong density-dependent relationship did not emerge after accounting for mates per male, effects of shell condition and size, and sperm retention by females. Based on our current understanding of Tanner crab growth and reproductive biology, we made assumptions about time lag from spawning to recruitment, cutoff size for maturity, average numbers of mates per male, lack of mating by some newshell males, and lack of mating of very large males with newshell females. However, our current understanding of Tanner crab reproductive biology remains quite limited. New knowledge on spawning geography, the proportions of oldshell and newshell males that participate in spawning migrations, and effects of senescence on male and female reproductive capability will be helpful. Additional studies on environmental effects on growth and recruitment would also be valuable. As our understanding of Tanner crab biology increases in the future, we will be able to refine these S-R relationships. .

EVALUATION OF ALTERNATIVE HARVEST STRATEGIES

Our Approach

The LBA and S-R relationships described earlier in this report were combined in a computer simulation model to evaluate alternative harvest strategies for Bristol Bay Tanner crabs. The primary features of the simulations are as follow:

- The model was initialized with data on population status for 1997.
- For each harvest strategy, we simulated the population and fishery for 100 years with 1000 replicates. The average population status and yield (i.e., catch in million lbs) from the simulations were summarized to compare the alternative strategies.
- The Ricker S-R curve with cyclic residuals was used, and the recruitment cycle was varied randomly between 10-18 years.
- Annual natural mortality rate was set at 33% (M=0.4) for males and 35% (M=0.43) for females. Handling mortality from the directed Tanner crab fishery and bycatch mortality from all non-pot fisheries were simulated separately from natural mortality. Therefore, natural mortalities for both males and females were lower than those estimated by the LBA (Zheng et al. 1998).
- Handling mortality rate of captured but discarded females and sublegal males was assumed to be 20% for the crab fishery.

- Bycatch from groundfish and scallop fisheries was set according to current prohibited species cap regulations, and handling mortality rate was assumed as 80% for the groundfish fisheries and 40% for the scallop fishery (NPFMC 1996).

We examined three kinds of alternative harvest strategies to set GHLs. These approaches ranged from a simple approach to a more complex approach incorporating gear selectivity and shell condition. Under the first harvest strategy, the status quo, GHL was set by legal harvest rate times legal male crab abundance. The current legal harvest rate is 40%, but we also evaluated nine other rates ranging from 10% to 60%. Under the second alternative, GHL was set by legal harvest rate times "exploitable" legal male crab abundance. Because the fishery disproportionately harvests newshell crabs over oldshell crabs, we defined exploitable legal males based on fishery selectivity parameters. We estimated 100% selectivity for newshell crabs and 32% selectivity for oldshell crabs based on comparison of catch and survey data from 1975 to 1997. Ten alternative harvest rates for exploitable legal males ranging from 15% to 65% were evaluated. Under the third approach, GHL was set by mature harvest rate times "molting mature males", but only legal males were allowed to be harvested with a catch cap of 50% of exploitable legal male abundance. In other words, the legal harvest rate is equal to the mature harvest rate times "molting mature male" abundance divided by legal male abundance. "Molting mature males" were defined as 100% of newshell males and 15% of oldshell males >112 mm (4.4 in) CW. These mature males have a high probability of molting within a year. Ten alternative mature harvest rates ranging from 10% to 35% were evaluated. This third approach most closely parallels the mature male harvest rate strategy currently used to manage the red king crab (*Paralithodes camtschaticus*) fishery in Bristol Bay. In the case of red king crabs, all mature males are used in the GHL calculation because they continue to molt with a high probability up to legal size, unlike Tanner crabs.

The Board's policy on king and Tanner crab management specifies the use of a threshold below which the fishery must be closed to maintain adequate brood stock. Because the S-R relationship is weakly density dependent, we did not attempt to estimate an optimal threshold in our simulations. Rather, we set a threshold based partly on past fishery management practice and partly on the S-R relationship. In the past, the effective spawning biomass was always below 15.5 million lbs in the years when the fishery was closed. This level of effective spawning biomass is slightly above the smallest effective spawning biomass with an above average recruitment level (Figure 3).

The Magnuson-Stevens Fishery Conservation and Management Act specifies that stocks below the size that would produce MSY should be harvested at a lower rate than when they are above the level that would produce MSY. To accommodate this, we evaluated each approach with a stair-step harvest rate schedule similar to that employed for the Bristol Bay red king crab fishery (Zheng et al. 1997a). We used 48.5 million lbs of effective spawning biomass as a base level, which is the average of simulated effective spawning biomass under the current 40% legal harvest rate. When effective spawning biomass was at or below 50%, 60%, or 70% of this base level, harvest rates would decrease 50% or 40%. A combination of three levels of effective spawning biomass and two levels of reduced harvest rates resulted in six alternative stair-step harvest rate schedules. We evaluated each stair-step schedule in combination with each of the three harvest strategy approaches.

To evaluate the strategies, statistics were collected on effective spawning biomass, probabilities of fishery closure, probabilities that the stock is below the overfished reference point as defined in the fishery management plan (NPFMC 1998), and yield. The probability of fishery closure was estimated as the proportion of replicates with estimated effective spawning biomass below threshold such that the fishery is prohibited for a given year. The overfished level is defined for Tanner crabs in the entire EBS, not just Bristol Bay. Based on the survey data from 1983 to 1997, we approximated the equivalent overfished level for Bristol Bay Tanner crabs as 58.6 million lbs of total mature male and female biomass. Results were averaged over the simulated time horizon and over all replicates. With respect to the Board's policy on king and Tanner crab management, two important considerations are the ability of a particular strategy to produce relatively large catches and its ability to produce some fishery stability by avoiding recruits-only fisheries. Therefore, to assess optimality, an equal trade-off value between increase in mean yield (a measure of size of catches) and decrease in standard deviation of yield (a measure of fishery variability) was computed as 0.5*yield-0.5*standard deviation (Zheng et al. 1997a) for each alternative strategy.

Results

Constant harvest rate. The trade-off between mean yield and standard deviation of yield as a function of constant harvest rate (i.e., without the stair-step) was similar among the three approaches (Figure 4). Mean yield, standard deviation of yield, and proportion of years that mature population abundance was below the overfished reference point increased as a function of harvest rate, but the standard deviation of yield increased at a faster rate than mean yield. The increase in mean yield generally slowed down as harvest rate increased, especially with legal harvest rate >40%, exploitable legal harvest rate >45%, and mature harvest rate >20%. Variations in yield, indexed by standard deviations of yield, were very high for all three approaches. This is a direct result of the periodic recruitment feature of Tanner crab population dynamics. Even without a fishery, mature spawning biomass fell below the overfished reference level in 9.4% of years. The legal harvest rate of 40% (status quo) is equivalent to an exploitable legal harvest rate of 45% and a mature harvest rate of 20%. Under equivalent harvest rates, both legal harvest rate and exploitable legal harvest rate approaches had similar mean yield and standard deviation of yield, but the proportion of years at overfished levels was lower for the exploitable harvest rate approach than the harvest rate approach. Mean yield, standard deviation of yield, and proportion of years at overfished levels with the 20% mature harvest rate approach were the lowest among the three equivalent approaches. The 50% cap on exploitable harvest rate for the mature harvest rate approach resulted in relatively flat curves of mean yield, standard deviation, and proportions of years at overfished levels when mature harvest rates were high (Figure 4).

Stair-step harvest rate. Alternative stair-step functions of harvest rate generally did not change the results very much (Table 1). Because standard deviation of yield increased much faster than mean yield at legal harvest rates >40%, exploitable legal harvest rates >45%, and mature harvest rates >20% (Figure 4), we used these harvest rates as the high harvest rate levels in the stair-step functions. The legal harvest rate of 40% also happens to be the status quo harvest rate. For each approach, a decrease from 70% to 60% to 50% in cut-off levels of effective spawning biomass or an increase in low harvest rates from 50% to 60% resulted in slightly higher trade-off values between increase in mean yield and decrease in standard deviation of yield but caused slightly higher percentages of years with fishery closure and with mature biomass being below the overfished reference point (Table 1). Overall, the mature harvest rate approach had slightly higher trade-off values between increase in mean yield and decrease in standard deviation of yield than the other two approaches. It also had slightly lower percentages of years with fishery closure and fewer years being overfished. The harvest strategy with a high mature harvest rate of 20% and a low rate of 10% with a cut-off of 34.0 million lbs of effective spawning biomass had the lowest percentages of years with fishery closure and being overfished among all the alternatives (Table 1). The trade-off value between increase in mean yield and decrease in standard deviation of yield was intermediate among the range in values among all harvest strategies (Table 1). In the context of National Standard 1 of the Magnuson-Stevens Fishery Conservation and Management Act, we considered this strategy as the most attractive alternative to the status quo strategy.

Sensitivity of the Results

We examined sensitivity of each strategy to changes in natural mortality, handling mortality, and S-R curve. The standard set of population parameters was used in each sensitivity analysis, except that both a normal Ricker S-R curve and a depensatory Ricker S-R curve were used and that the parameter under consideration was assigned one of two opposite and extreme values. For sensitivity studies on recruitment cycles, we used 200 replicates, each for 1000 years. A longer simulated time horizon was needed to examine cycle period.

As expected, higher natural or handling mortality rates resulted in much lower catch and higher percentages of years with fishery closure and at overfished levels for all alternative strategies, and vice versa for lower natural mortality or handling mortality rate. The depensatory S-R curve had a minor effect on the results of simulations except when depensation was combined with high natural mortality, which resulted in extremely low population abundances and few fishing opportunities. Effective spawning biomass rarely fell into the depensatory range under other circumstances.

Under the same test conditions, the status quo harvest strategy had slightly higher mean yield, lower standard deviation of yield, higher percentages of years with fishery closure and at overfished levels than when the status quo harvest strategy included stair-step harvest rates. The status quo harvest strategy also had higher mean yields than those for the proposed new strategy under the same conditions, but its standard deviations of yield and its percentages of years at overfished levels were much higher.

With the normal S-R curve, the status quo and proposed harvest strategies were very sensitive to period length (number of years between the mid-points of two periods of strong year classes) and amplitude (difference between highs and lows) of recruitment cycle, especially for a long period length and high amplitude. Coefficient of variation of yield and proportions of years of fishery closure and at overfished levels increased substantially as period length and amplitude of recruitment cycle increased. For a given combination of period length and amplitude of recruitment cycle, the proposed harvest strategy resulted in only a minor improvement on coefficient of variation of yield and proportion of years of fishery closure over the status quo strategy. The proposed harvest strategy reduced proportions of years at overfished levels considerably when the period length of recruitment cycle was 18 years or less.

In our analysis of alternative harvest rate strategies, we attempted to consider total fishing mortality as the aggregate of landed catch, handling mortality of discards in the directed fishery, and bycatch mortality in groundfish and scallop fisheries. Landings are documented on transaction receipts between processors and fishers called "fish tickets." At-sea observers monitor bycatch aboard vessels fishing for other species. Typically, total bycatch of Tanner crabs by groundfish and scallop fisheries is a small percentage of total crab abundance in the EBS. Whether a significant proportion of the Tanner crab population is adversely impacted by dredges and trawls, but not caught and observed, remains a matter of speculation. Large numbers of Tanner crabs are handled and discarded during crab fisheries due to restrictions on size, sex, season, and target species. In our study of the red king crab fishery in Bristol Bay, increased handling mortality in our model resulted in lower optimal harvest rates and higher optimal threshold levels (Zheng et al. 1997b). For the Bristol Bay Tanner crab fishery, we found that handling mortality had similar, but less pronounced, effects. Female Tanner crabs have much lower catchability during the fishery than legal-sized males. Thus, the impact of handling mortality on female Tanner crabs is smaller than on sublegal male Tanner crabs or female red king crabs. In our sensitivity analysis we bracketed handling mortality rate at 0 and 50% to span low rates from a study that attempted to emulate the fishing process (MacIntosh et al. 1996) and high rates from a laboratory study (Carls and O'Clair 1995) that considered extremely cold air temperatures during winter fisheries. An extensive bibliography of capture and handling effects was compiled by Murphy and Kruse (1995), and reviewed in some detail by Zheng et al. (1997b). Additional research is needed to accurately assess handling mortality rates experienced by Tanner crabs during commercial fisheries in the Bering Sea. Results from ongoing studies of cold windchill effects (Kruse 1998) may significantly affect our estimates of handling mortality rate during winter fisheries. As this research is completed, the implications on crab fishery management need to be analyzed.

In our simulations for the Bristol Bay stock, we set recruitment periodicity randomly from 10 to 18 years. We also examined the sensitivity of harvest strategies to recruitment cycles ranging from 4 to 30 years. We reached the same conclusion for the Bristol Bay Tanner crab stock as Koslow (1989) did for fish stocks: no harvest strategies can protect a stock from collapse if the recruitment cycle is long. This is intuitive from crab biology. Because Tanner crabs mature at about age 6 and few live longer than 12 years (Donaldson et al. 1981), significant numbers of mature Tanner crabs cannot be "banked" for more than 6 years for future spawning. However, reducing harvest rates and saving some mature crabs for future spawning when recruitment is in the downward cycle will reduce the chance of prolonged stock collapse.

EXTENDING THE RESULTS FROM BRISTOL BAY TO THE EASTERN BERING SEA

Legal-sized Tanner crabs in the EBS primarily occur in two areas: in Bristol Bay and near the Pribilof Islands. As stated in the Problems and Approaches Section, size at maturity in some years, genetics, and survey measurement errors are different between Bristol Bay and Pribilof Islands Tanner crabs. Legal-sized crabs are well separated between these two areas. However, there is no clear geographic separation of small Tanner crabs between these two areas. In addition, mean size of mature females decreases gradually from eastern Bristol Bay to the west rather than a sudden drop at the Bristol Bay regulatory border (168°W) (Bob Otto, NMFS, personal communication). Because Tanner crabs are not separated into Bristol Bay and Pribilof Islands stocks for management purposes and our modeling effort focused on Bristol Bay Tanner crabs, we need to extend the simulation results to Tanner crabs in the EBS.

A large majority of EBS Tanner crabs exist in Bristol Bay (Figure 5). From 1976 to 1998, more than 70% of EBS legal Tanner crabs were from Bristol Bay each year, and more than 90% of legal crabs occurred in Bristol Bay for 9 out of 23 years. Approximately 75% of mature males and female biomass >79 mm CW and 82% of legal males have historically occurred in Bristol Bay. Threshold (15.5 million lbs) and cut-off point (34.0 million lbs) for Bristol Bay crabs can be expanded to the EBS by dividing by 0.75. Because no effective spawning biomass was computed for Pribilof Islands Tanner crabs, we suggest using female biomass >79 mm CW as threshold and cut-off point for simplicity in applying our modeling work to fishery management. Although many females mature at a smaller size, survey abundance of females <79 mm CW is much less reliable than those for larger-sized females. The expanded threshold and cut-off point for EBS Tanner crabs are 21.0 and 45.0 million lbs of female biomass >79 mm CW, respectively. Applying this threshold to survey abundances of EBS Tanner crabs since the complete surveys started (1973) results in only five years of fishery closure: 1985/86, 1986/87, and 1996-1998; in practice, the fishery was closed only during four of these five years with the exception of 1996.

Proportions of EBS Tanner crabs in Bristol Bay were higher for legal crabs than those for mature males and females >79 mm CW, especially during recent years (Figure 5); this suggests that size structures of Tanner crabs in Bristol Bay may be different from the areas to the east. There were hardly any legal crabs in the Pribilof Islands area during the last five years. If molting mature males from Bristol Bay and Pribilof Islands are combined to set GHL for the EBS fishery, the GHL for the Bristol Bay area will be artificially inflated by molting mature males in the Pribilof Islands area. To avoid this problem, we suggest setting separate GHLs for Bristol Bay and Pribilof Islands based on their respective abundances of molting mature males. The 50% cap of exploitable legal males will take effect for either GHL if its relative legal crab abundance is too low. If the GHL in Bristol Bay or Pribilof Islands is too low to manage effectively, the fishery will be closed for that area. The GHL for the EBS fishery will be equal to the sum of GHLs in these two areas.

RECOMMENDED HARVEST STRATEGY

Our analyses on population dynamics and harvest strategies of Tanner crabs lead us to recommend changes in our current harvest strategy for EBS Tanner crabs. These changes will result in low harvest rates for stock rebuilding when the population is depressed and high harvest rates during high productivity periods. GHLs set by the recommend harvest strategy will also be closer to actual catches than the current strategy, especially when the population abundance is low.

There are five components for the recommended strategy as applied to EBS Tanner crabs:

- **Threshold:** 21.0 million lbs of female biomass >79 mm CW. The fishery will be closed when the stock is below threshold.
- **Mature harvest rates:** 20% of molting mature males when biomass of females >79 mm CW is ≥ 45.0 million lbs and 10% of molting mature males when biomass of females >79 mm CW is ≥ 21.0 million lbs and < 45.0 million lbs. Molting mature males are 100% of newshell and 15% of oldshell males >112 mm CW.
- **Legal harvest rate cap:** a 50% cap of exploitable legal males, which are 100% of newshell and 32% of oldshell legal males.
- **GHLs for Bristol Bay and Pribilof Islands:** GHLs are determined separately for crabs east of 168°W (Bristol Bay) and west of 168°W (Pribilof Islands) in the Eastern Subdistrict of the Bering Sea. If the GHL in Bristol Bay or Pribilof Islands is too low to manage effectively, the fishery can be closed for that area. Total GHL in the Eastern Subdistrict is equal to the sum of these two GHLs if the fisheries in both areas are open. If any portion of the Eastern Subdistrict is closed to fishing, the crab abundance in that portion will be excluded from the GHL computation.
- **A precautionary measure:** when the stock is reopened to fishing after having been closed to all commercial fishing in the preceding season due to the depressed stock

condition, the GHL in that season will be reduced to one-half of the value as computed in the above GHL determination. When a stock is reopened to fishing, it is very likely that the ratio of legal crabs to mature male crabs is low, which will result in a high legal harvest rate. This measure will prevent such a high rate. It also serves a protection against survey measurement errors.

Our results and recommended harvest strategy may have implications for the management of the Gulf of Alaska Tanner crab stocks. The framework of the recommended harvest strategy may be applied to these stocks (i.e., threshold and stair-step harvest rate), and detailed components of a harvest strategy may depend on data availability. If mature female biomass is available with an acceptable precision, it can be used to establish a threshold and cut-off point for low harvest rates. Otherwise, mature male biomass or abundance can be used. Molting mature males may need to be defined for each stock because of different molting probabilities.

CONCLUDING REMARKS

Although the current harvest strategy is a constant legal harvest rate of 40%, legal harvest rates actually implemented during the last 24 years were quite different from this level and varied greatly over time (Figure 6). Realized legal harvest rates were higher than 40% from 1977 to 1981 and from 1989 to 1992 and much lower from 1983 to 1988 and from 1994 to 1998. It appears that it is difficult to implement a constant legal harvest rate strategy. Preseason GHLs were generally slightly higher than actual yields for most years but much higher than actual yields when the GHLs were low (Figure 6). The recommended harvest strategy leads to higher legal harvest rates than the historical rates of the current strategy when population abundance is increasing and lower rates when population abundance is decreasing. Historical harvest rates more closely match the recommended new harvest strategy than the current "constant" harvest rate strategy (Figure 6).

The recommended harvest strategy takes into account the relationship between shell condition and productivity levels of Tanner crab stocks. Strong year classes are dominated by newshell crabs. Simulation results show that the recommended new strategy adjusts legal harvest rates according to recruitment strength which is indexed by changes in shell condition. Contrary to the current harvest strategy based on legal male abundance only, use of mature crab abundance and shell condition gives the recommended new strategy a forward-looking feature. When an increase in future legal crab abundance is expected due to increased recruitment to the mature segment of the stock, legal harvest rates are increased. Conversely, during a downward recruitment cycle, reduced legal harvest rates will forestall the decline of large, oldshell males that are most virile (Stevens et al. 1993; Paul et al. 1995).

As a comparison to the current harvest strategy, the recommended strategy has similar trade-off values between mean yield and variation in yield, but it leads to fewer shortages of mates for mature females and reduced probability that population abundance falls below the overfished reference point over a long term. If reproduction can be limited due to a shortage of mature males, it is most likely to occur during periods of low population abundance. As abundance declines, spatial distribution becomes more patchy, thereby potentially reducing mating encounters. By incorporating a fishery threshold and stair-step harvest rates, the recommended new harvest strategy has features more consistent with the Board policy than the current strategy and it embodies a precautionary approach to fishery management (Restrepo et al. 1998). These features reduce mature harvest rates to protect reproductive potential during periods of low abundance when risks of overfishing or falling below the overfished reference point are high due to uncertainties in abundance estimates and population dynamics (i.e., depensation vs. compensation). Due to periodic recruitment, it appears that no harvest strategy can completely prevent stock collapse, but a precautionary approach will reduce the chance of prolonged stock collapse.

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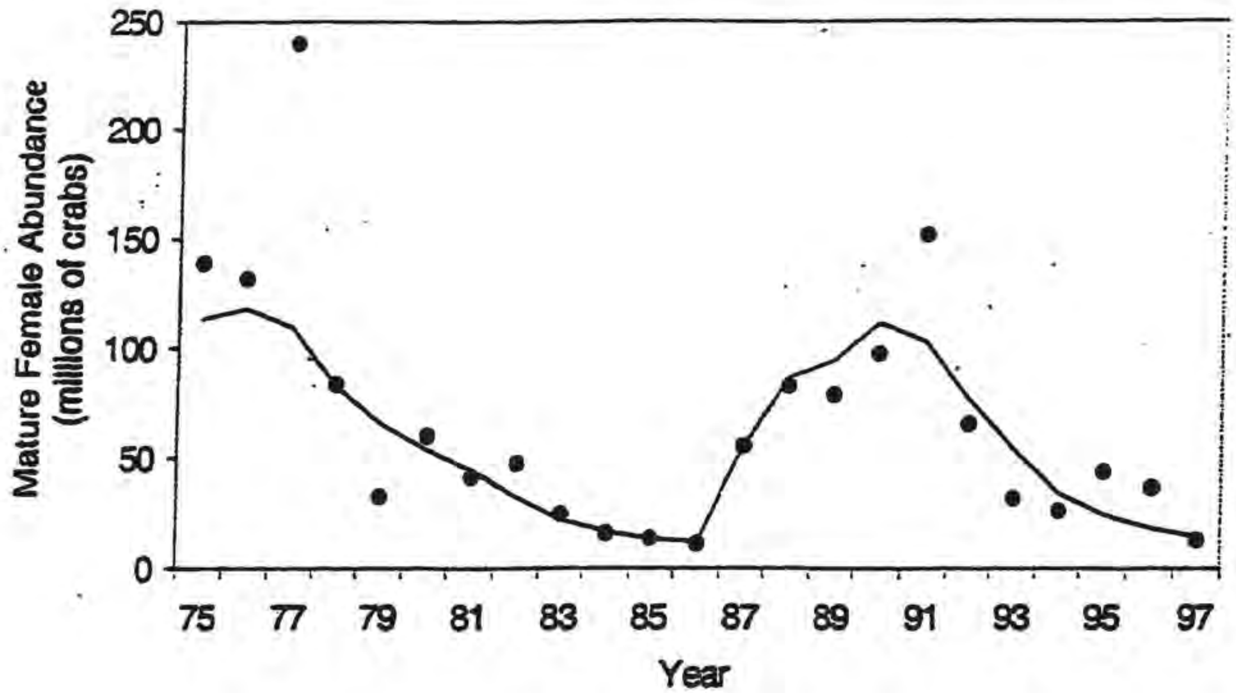
Table 1. Comparisons of mean yield, standard deviation of yield (SD), equal trade-off between increase in mean yield and decrease in standard deviation of yield, mean effective spawning biomass (SP), mean total mature biomass (TMB), percentage of years without fishing (Closure), and percentage of years below the overfished reference point (Overfished) for alternative harvest strategies. "Cut-off" is a level of SP below which the low harvest rate (HR) is used and at or above which the high harvest rate is used. The status quo strategy is underlined and the proposed new strategy is shown in bold. Historical data were included for comparison.

Cut-off (SP)	High HR	Low HR	Yield (million lbs)	SD	Trade-off	SP (million lbs)	TMB	Closure (%)	Overfished (%)
			Harvest Rates Applied to Total Legal Crabs						
15.5	0.4	0.0	16.264	17.635	-0.686	47.752	136.980	14.521	31.847
24.3	0.4	0.2	16.122	17.846	-0.862	48.087	138.177	14.034	30.917
29.1	0.4	0.2	16.021	17.941	-0.960	48.220	138.796	13.848	30.162
34.0	0.4	0.2	15.898	18.012	-1.057	48.332	139.431	13.721	29.385
24.3	0.4	0.24	16.155	17.794	-0.819	48.012	137.904	14.150	31.146
29.1	0.4	0.24	16.081	17.860	-0.890	48.114	138.369	14.018	30.579
34.0	0.4	0.24	15.990	17.906	-0.958	48.197	138.843	13.919	30.004
			Harvest Rates Applied to Exploitable Legal Crabs						
15.5	0.45	0.00	15.406	16.980	-0.787	48.438	140.972	13.598	28.480
24.3	0.45	0.225	15.238	17.198	-0.980	48.696	142.057	13.291	27.483
29.1	0.45	0.225	15.128	17.308	-1.090	48.808	142.641	13.167	26.772
34.0	0.45	0.225	14.991	17.405	-1.207	48.910	143.276	13.059	26.019
24.3	0.45	0.27	15.274	17.152	-0.939	48.645	141.834	13.351	27.706
29.1	0.45	0.27	15.188	17.236	-1.024	48.735	142.297	13.251	27.122
34.0	0.45	0.27	15.082	17.306	-1.112	48.817	142.798	13.158	26.524
			Mature Harvest Rates Applied to Molting Mature Male Crabs						
15.5	0.2	0.0	15.088	16.001	-0.456	48.422	141.268	13.366	27.333
24.3	0.2	0.1	14.943	16.180	-0.618	48.610	142.114	13.121	26.464
29.1	0.2	0.1	14.842	16.272	-0.715	48.698	142.599	13.000	25.754
34.0	**0.2**	**0.1**	**14.718**	**16.354**	**-0.818**	**48.777**	**143.129**	**12.875**	**24.986**
24.3	0.2	0.12	14.983	16.129	-0.573	48.557	141.878	13.188	26.714
29.1	0.2	0.12	14.905	16.195	-0.645	48.621	142.242	13.087	26.192
34.0	0.2	0.12	14.811	16.252	-0.721	48.682	142.646	12.994	25.620
			Estimated Historical Averages from 1975 to 1997						
			15.020	15.093	-0.036	51.998	143.752	13.043	26.087



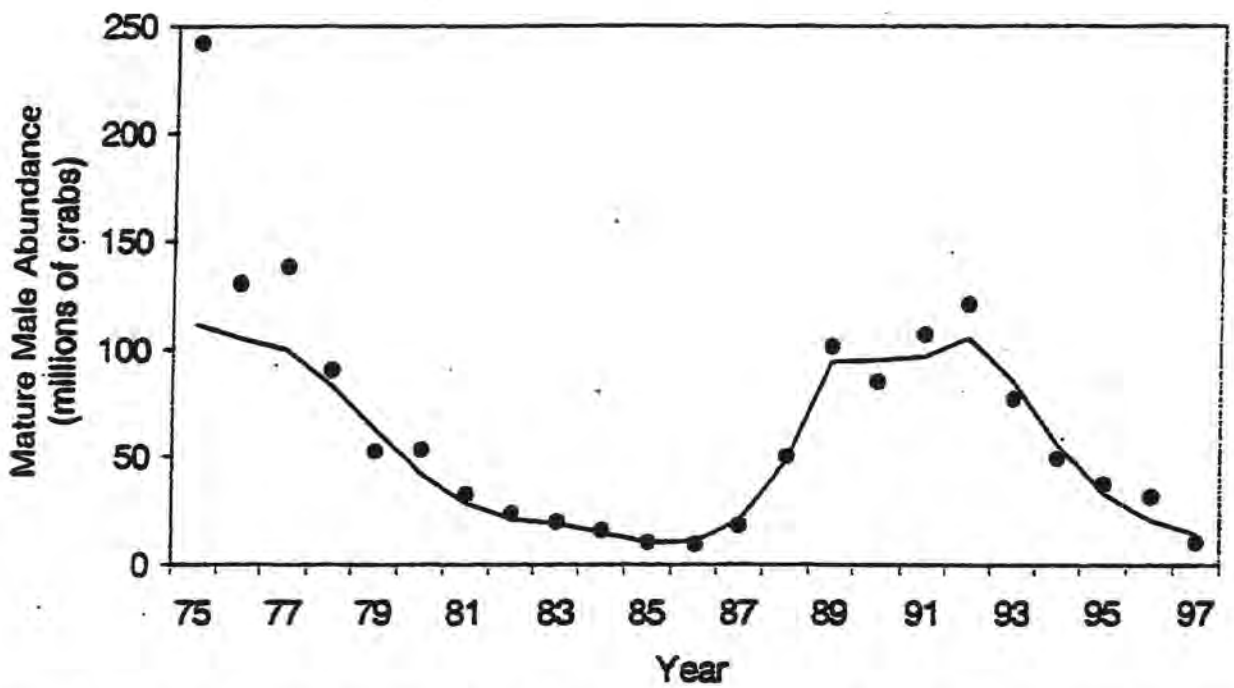


Figure 1. Comparison of area-swept (dots) and LBA (solid line) estimates of mature female (>79 mm CW, top panel) and male (>112 mm CW, lower panel) Tanner crab abundances in Bristol Bay.

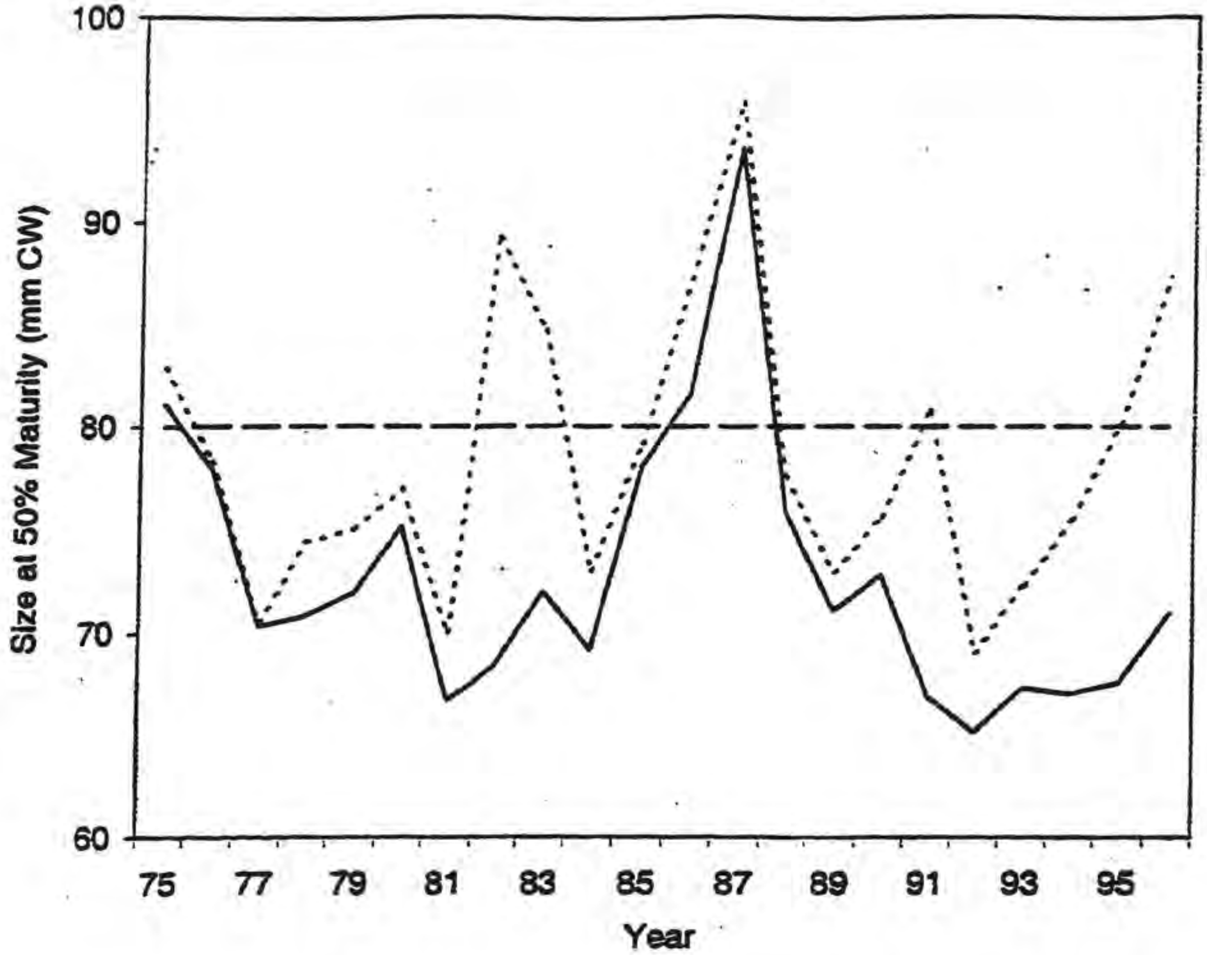


Figure 2. Size at which 50% of females are mature as estimated from clutch data from NMFS surveys for Bristol Bay Tanner crabs.

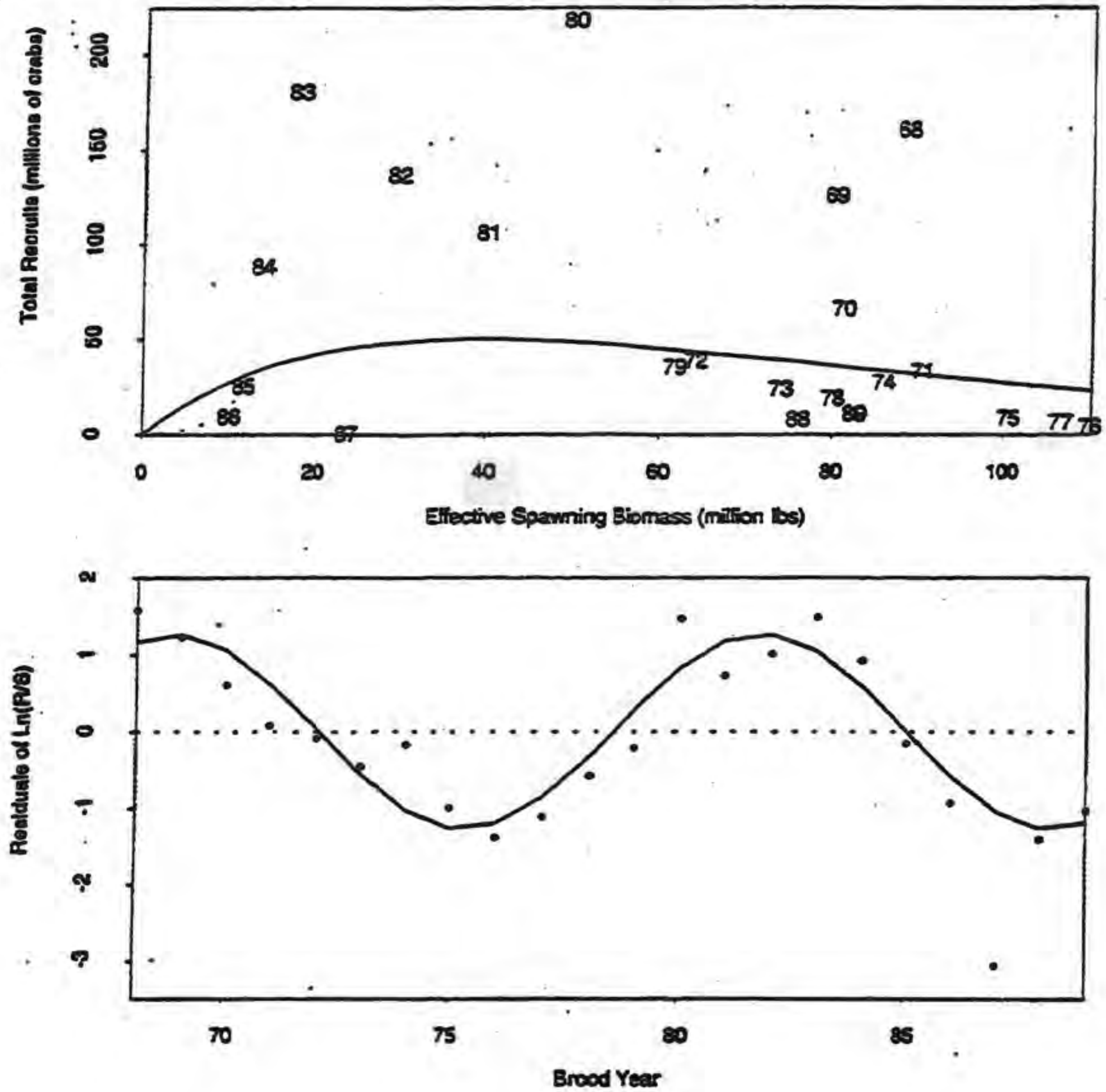


Figure 3. Relationships between effective spawning biomass (S) and total recruits (R) at age 7 (i.e., 8-year time lag, upper plot) and residuals of logarithm of recruits per S from a normal Ricker curve (lower plot) for Bristol Bay Tanner crabs. In the upper plot, numerical labels are brood year (year of spawning), solid line is a normal Ricker curve, and dotted line at low biomass is an exponential S-R curve (depensatory curve). In the lower plot, dots are residuals, and solid line is a sine function estimated from residuals.

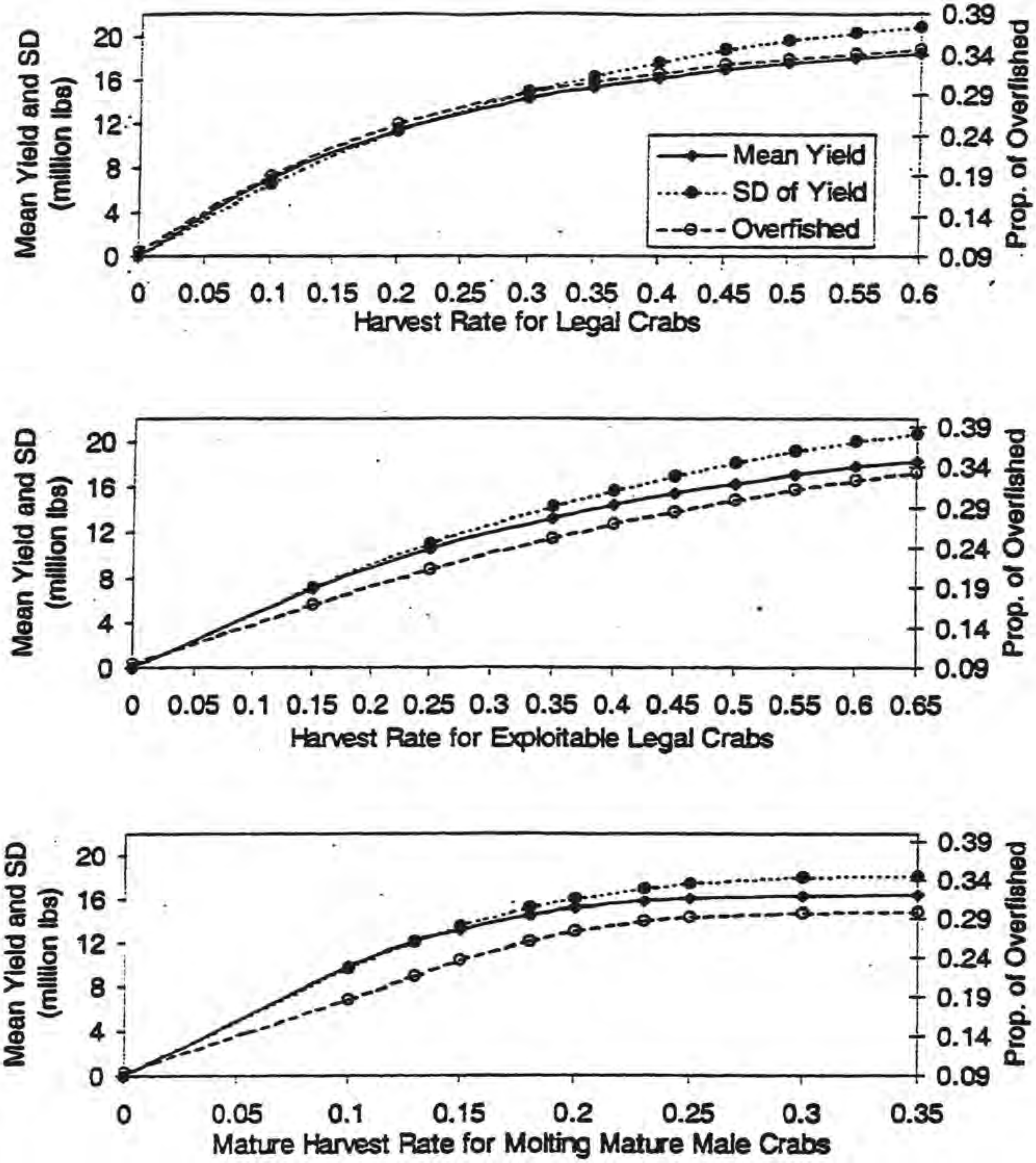


Figure 4. Mean yield (solid lines), standard deviation of yield (dotted lines), and probability of being at overfished levels (dashed lines) as a function of constant harvest rate for Bristol Bay Tanner crabs under the normal S-R curve assuming a 20% handling mortality rate for three harvest approaches.

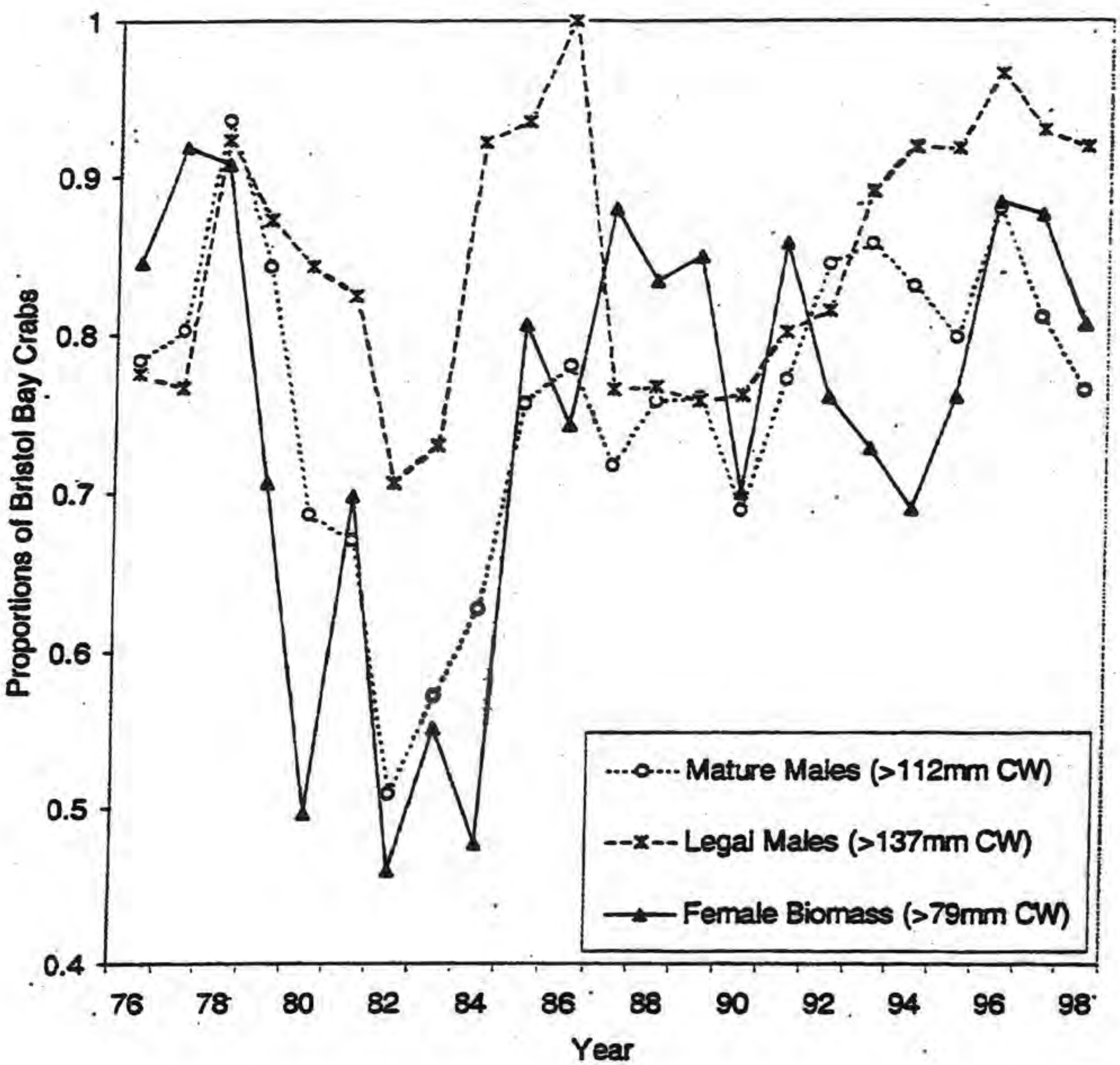


Figure 5. Proportions of Bristol Bay mature female, mature male, and legal Tanner crabs in the Eastern Subdistrict (east of 173° W in the eastern Bering Sea), estimated by the area-swept approach from NMFS survey trawl survey data.

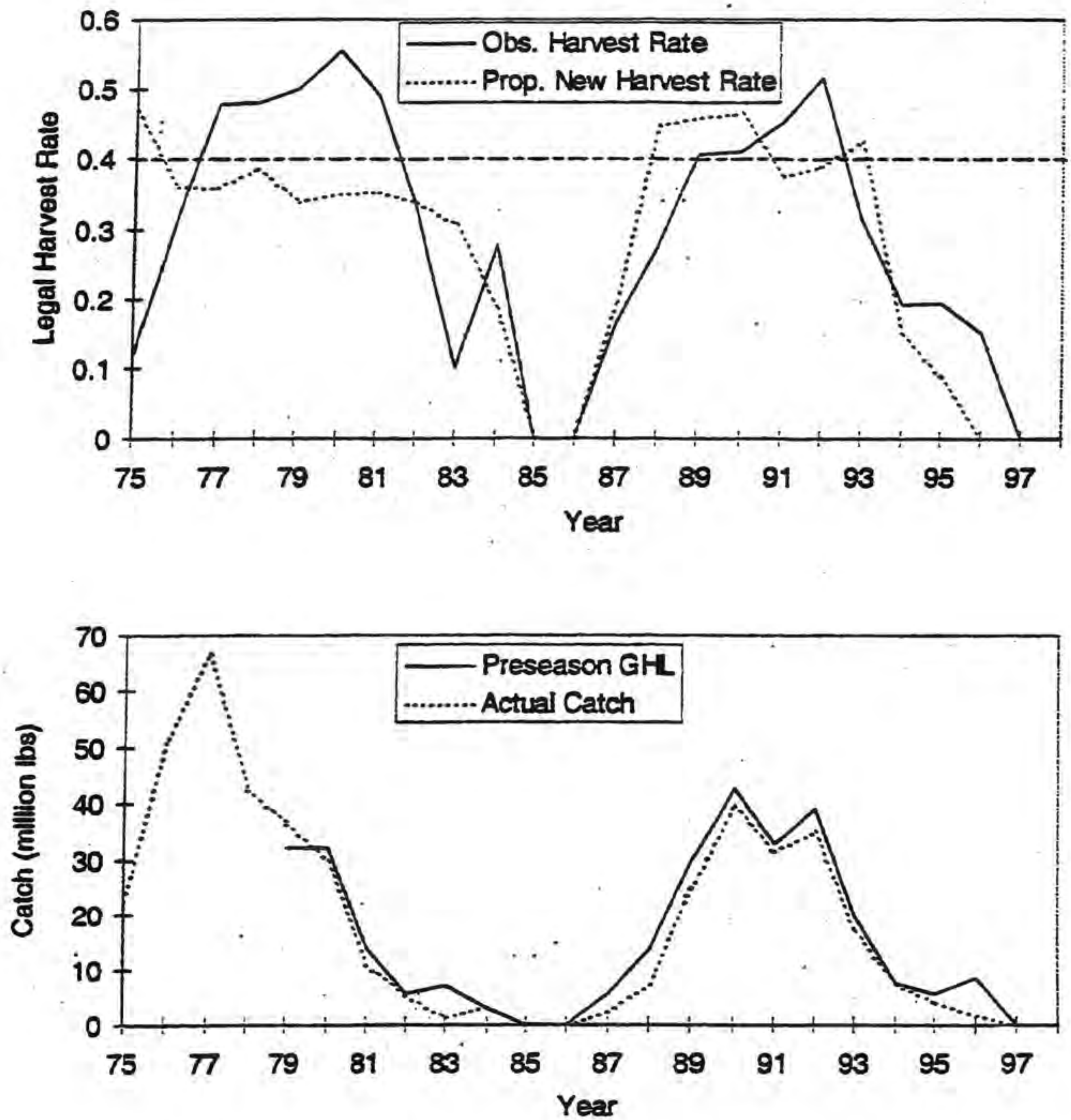


Figure 6. Comparison of the estimated harvest rates (solid line) and the harvest rates derived from the proposed new strategy (dotted line) as a proportion of total legal crab abundance (upper plot) and comparison of preseason guideline harvest levels and actual catches for eastern Bering Sea Tanner crabs (lower plot) from 1975 to 1998. Tanner crab abundances were estimated by the LBA for the Bristol Bay area and by the area-swept method for the Pribilof Islands area.