

Adult male Dungeness crab (*Metacarcinus magister*) movements near Reedsport, Oregon from a fisheries collaborative mark-recapture study.

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February 15, 2011

**Prepared by
Oregon Sea Grant (OSG)**



**Prepared for
Oregon Wave Energy Trust (OWET) & Oregon Dungeness Crab Commission (ODCC)**



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Executive Summary

Motivation:

Oregon's fishing community is concerned about the potential effects that wave energy conversion devices could have on Dungeness crab movement, behavior and harvests. Though crabbing has been a mainstay of West Coast economies for decades, little information has been collected or analyzed on adult Dungeness crab movement, in general, and for the Oregon Coast, specifically.

To help begin addressing this critical information gap, The Oregon Wave Energy Trust (OWET), the Oregon Dungeness Crab Commission (ODCC) and Oregon Sea Grant added value to a planned baseline study conducted by H.T. Harvey and Associates. Crabs collected for the baseline study were tagged after they were measured and before they were returned to the ocean. Commercial crabbers later returned the tags, and were rewarded for collaborating in the project.

Methods:

Legal sized male crabs (6 ¼" carapace width) were tagged at three locations near Reedsport, Oregon, in October and November of 2009. A total of 2788 tags was deployed and crabs were recaptured in the commercial crab fishery. Tags were returned with recapture locations to Oregon Sea Grant and a \$20/tag reward was provided.

Results:

Out of 2788 tagged crabs released, 952 crabs were recaptured and the tags returned to Oregon Sea Grant. A total of 626 tags was returned with location data of sufficient detail for analysis. The overall return rate of 34.15% is notably high for a mark-recapture study; however, this is not unreasonable because a high percentage of male crabs is harvested during each season. Additionally, a historic Oregon crab tagging study found a similar return rate. Crabs travelled distances ranging from 0.27 km to 90.68 km (Table 1). 65% of crabs traveled less than 20 km, 77.7% of crabs traveled less than 30km, and 95.5% of crabs traveled less than 50km (Figure 1). Crabs moved primarily in the alongshore direction, with minimal across shelf movement (Figure 4). See enclosed maps of recapture locations.

Caveats:

Because commercial crabbers target their fishing effort based on past experience, it is likely that some locations had a higher chance of being sampled than others. This sampling bias might inflate the tag recovery rate in those areas and has the potential to skew our results. That said, the tag recapture locations should not be interpreted as reflecting the distribution of fishing effort in the Reedsport study area.

The distances reported here represent a minimum distance that the crab traveled. Additional tags were returned with general locations indicating that crabs may be moving as far north as Tillamook, Oregon (approximately 140 miles). It remains unknown to what degree Dungeness crab movements vary from year to year.

The findings of this study should be treated as preliminary rather than definitive. Additional studies are needed to fully characterize adult Dungeness crab movements in Oregon's coastal waters.

Introduction

Dungeness crab movements in other regions

Despite their commercial importance, there are few published studies on Dungeness crab (*Metacarcinus magister*, formerly *Cancer magister*) movements and no recent studies from the Oregon coast. Relevant studies have been conducted in fjords in Southeast Alaska, in protected waters on the west coast of Vancouver Island, British Columbia, on the open Northern California coast, and on the Oregon coast from 1947-1950 and are described below.

Southeast Alaska

Two studies from a fjord system in southeast Alaska concluded that adult Dungeness crabs only moved short distances, from a few hundred meters to a few kilometers (Stone and O'Clair 2001, Stone and O'Clair 2002). There are several important differences between the Stone and O'Clair studies and the Reedsport tracking effort. Stone and O'Clair's (2001) study design allowed for more detailed analysis of crab movements than our study. The crab movements were tracked using acoustic tags, with bi-weekly monitoring of crab locations. The fjord system habitat differs greatly from Oregon's coastal shelf habitat as well. In the southeastern Alaskan fjords habitat patches suitable for Dungeness crab are separated by large tracts of non-suitable habitat. The investigators postulated that each fjord operated as a separate population with little exchange of adults between fjords.

British Columbia

An analysis of male and female Dungeness crab movement conducted in protected coastal waters near Tofino, British Columbia, suggested fairly limited movement (Smith and Jamieson 1991). Male crabs showed limited movement, and stayed within the local archipelago where they were tagged and released. Movement was estimated to be approximately 300 meters per day, with a seasonal migration toward shallower waters in the summer and deeper waters in the fall. The authors of this study concluded that female crabs also showed limited movement, with no evidence of a seasonal cross shelf migration. Overall, the Smith and Jamieson (1991) analysis

suggested that the majority of male crabs remained within 10 km and female crabs within 14 km of release location.

Northern California

Studies conducted in northern California, on an open coastal shelf similar to that of the Oregon coast, indicated that adult female crabs moved very little (Diamond and Hankin 1985). No research was conducted on male crab movement. Most crabs in the study moved only a few kilometers, with a maximum distance of 80 km. Most movement occurred in the alongshore direction. Although the data in Diamond and Hankin's (1985) study was complicated by non-random fisheries dependent sampling, there was some indication of a spring time migration toward the nearshore. Investigators hypothesized that the movement towards the nearshore in the spring could be associated with post-molt mating and spawning in shallow waters.

Oregon

A study conducted from 1947-1950 by Waldron (1958) was similar in many regards to the current study. As part of a comprehensive, coast-wide study of Dungeness crab biology, Waldron tagged over 4000 adult legal-sized male crabs during 1947-1948 at a series of offshore locations. A total of 1,485 tags was recovered and returned by the commercial crab fleet with the location of capture. The return rate for the study was 36.3%, and the majority of tags were recovered within 6 months of release. Commercial crabbers did not receive any reward for participating in the study, and Waldron (1958) cited the importance of personal contacts between researchers and the fleet in facilitating tag returns. The crabs travelled an average of 15.3 km in an average of 80 days from the time of release to the time of recapture. Waldron determined rates of travel for some crabs, which ranged from 7km per day for five days to 1.3 km per day for distances exceeding 92 km. A large proportion of crabs exhibited non-directional movement (57%), while 19% moved alongshore to the South and 24% moved North. The methods used in the study precluded the detection of across shelf movement for crabs both tagged and recovered at offshore locations. The study included tagging and recapture of crabs at locations within coastal bays, and found that there was substantial exchange of crabs between bays and offshore

locations. The return rate for crabs tagged within bays was 31.4%. Crabs tagged within bays tended to travel shorter distances than those tagged offshore, averaging only 7.8 km.

Crab movement summary

In summary, there is a historic study characterizing Dungeness crab movement on the Oregon coast, and several studies for crab movement in other regions (Waldron 1958, Diamond and Hankin 1985, Smith and Jamieson 1991, Stone and O'Clair 2002). It can be expected that the behavior and movement of crabs is a response to their physical environment, and could vary with changes in habitat. The habitat available to Dungeness crabs on the Oregon coast differs from that available on the British Columbia or Alaskan coasts. First, the Oregon coast has larger tracts of continuous soft-bottom habitat, particularly in the study region. Second, the studies from British Columbia and Alaska focused on sheltered, relatively low energy marine environments, while Oregon's coastal shelf is exposed to higher wave energy and stronger alongshore currents (Mann and Lazier 2006). The physical environment on the Oregon coastal shelf is quite different than the study sites where crab movement has been previously studied in Alaska and British Columbia but more closely resembles the study site in Northern California. At the outset of this study, it was unclear if Dungeness crabs would exhibit similar movement patterns on the Oregon coast as they did in 1947-50. Though the benthic habitat remains similar to conditions nearly a half century ago, the size of the commercial crabbing fleet has changed alongside other dynamic environmental factors. It is unlikely that the Dungeness crabs on the Oregon coast have movement patterns similar to those in Alaska or British Columbia, but may follow similar patterns to those observed by Diamond and Hankin (1985) on the Northern California coast and Waldron (1958) on the Oregon coast.

The Dungeness crab fishery

A recent recipient of Marine Stewardship Council certification, the Dungeness crab fishery is conducted as a limited entry, pot fishery. Fishermen deploy series of baited circular steel framed traps with a separate line and buoy marking the location of each pot. These series of pots, called strings, are deployed along a bathymetric contour and retrieved 1-7 days later. The pot

deployment period, or soak time, varies by vessel, weather conditions, location, and season. Commercial crabbers report that pot strings are generally deployed between the outer edge of the surf zone at approximately 5 fathoms to 80 fathoms, though crabs occur to 200 fathoms depth (Pauley et al 1986, ODFW 2010).

Motivation for study

In light of planned and proposed wave energy conversion (WEC) projects on the Oregon coast, the fishing community expressed concerns about the potential impacts of WEC devices on Dungeness crab harvests and behavior. There were no studies available regarding the potential impact of wave energy devices on the behavior and movement of adult Dungeness crabs. It was difficult to infer or anticipate crab responses to WEC devices because of the dearth of general information available on adult crab movements in Oregon.

To begin filling this gap in knowledge and begin cultivating collaborations between the wave energy industry, the commercial fishing fleet, and researchers, OWET, ODCC, and OSG commissioned a multi-faceted study to collect information on bottom-associated (benthic) marine life and Dungeness crab movement in the wave energy project area off the coast of Reedsport, Oregon, north of the Umpqua river. The primary goals of the benthic ecology study were to provide a point of comparison for future monitoring and evaluate the statistical rigor of the sampling program (Terrill *et al.* 2010). The crab movement study was carried out as a collaborative effort between H.T. Harvey and Associates, Oregon Sea Grant personnel, and over 100 commercial crabbers and crab processors. The primary goal of the study was to obtain baseline data on the distances and directions that Dungeness crabs tagged in the project area travelled during the 2009-2010 harvest season (December 1st, 2009-August 15th, 2010).

Ultimately, the information gathered in the both studies will enable Oregonians to evaluate the effects of the planned WEC project off Reedsport on the local benthic community, aid State management agencies in their management responsibilities, as well as inform crabbers, other stakeholders and project developers.

Methods: Tagging and Recapture

Legal sized male crabs (6 ¼" carapace width) were tagged at three locations (see Table 1 below). A fluorescent pink tag, imprinted with a four digit code and reward and contact information was attached to each crab on the rear appendage with a constrictor knot (Smith 1971 as cited by Terrill et al. 2010). The tags were not deployed sequentially, and some duplicate numbered tags were released at the South control site. These issues did not present problems for statistical analysis, because an accurate count of deployed tags was recorded at each location. The recapture effort was conducted entirely during normal operations of the commercial Dungeness crab fleet from December 1st 2009 until August 15th 2010. Tags were accepted from fleet members from December 1st 2009 until Sept 1st, 2010.

Table 1. Tag numbers and release locations at South control, Project Site, and North Control Site.

Tags 0000-0999
South Control Site

Long	Lat
124.25° W	43.70° N

Tags 1000-1999
Project Site

Long	Lat
124.24° W	43.76° N

Tags 2000-2999
North Control Site

Long	Lat
124.23° W	43.80° N

Methods: Coordination with Commercial Crabbers and Processors

Oregon Sea Grant representatives contacted Dungeness crab license holders and processors during late November 2009. All Dungeness crab license holders were sent an informational flier by mail (Appendix 1). All Dungeness crab processor facilities listed on the Oregon Dungeness Crab Commission website were contacted by phone and sent an identical informational flier. A telephone hotline was established, with information about the project in an outgoing message, and a voicemail box for participants to request additional information.

Researchers also fostered effective collaboration by providing compensation to participating fishermen. Compensation for all participants was provided in the form of a \$20 per tag reward, and was sent immediately upon receipt of the tag(s). At the end of the study, a summary of project findings and a map of recapture locations was returned to each individual participating crabber with that individual's tag returns highlighted. The purpose of returning these individual maps was two-fold; it was critical to ground-truth the location data with the crabber to ensure

accuracy, and it was important to provide preliminary results of the study directly to the crabbing fleet. Throughout the study period members of the crabbing fleet expressed interest in learning about the purposes, methods, and results of the study and questions were answered promptly and thoroughly. Finally, two drawings for \$1000 were conducted at the end of the study period. One drawing for all participants was conducted, and a second drawing was conducted for participants who provided usefully precise location data when they returned their tags. To conclude the study, a copy of this final report will be provided to each participating crabber and other relevant stakeholders.

Methods: Mapping and Summary Statistics

Locations were included in the analysis if the participant provided an exact location or the locations of the ends of the string of pots, with a few exceptions. General descriptions were accepted only for single tags when a landmark and a depth were provided (e.g., “Due west from Heceta Head at 17 fathoms”), such that a latitude and longitude of capture could be determined. Recapture locations were not included in the analysis if they overlapped with land when mapped. This occurred in four cases where only general coordinates were provided (e.g., degrees and whole minutes only). Locations were converted from degrees minutes and Loran-C coordinates to decimal degrees for mapping and analysis. The conversion to decimal minute coordinates was done using custom equations in Microsoft Excel software. Loran-C coordinates were converted to decimal degrees using an electronic navigational chart and a Garmin GPS unit.

Distances, initial bearing on a great circle line, and bearing on a rhumb line (line of constant bearing) for crab movements between release and recapture locations were calculated using the statistical software R (R Development Core Team 2010) with the packages Geosphere 1.2-13 (Hijmans et al. 2010) and Fields 6.3 (Furrer et al. 2010). The differences between initial bearings on a great circle line and bearings on a rhumb line were inconsequential, so initial bearings on a great circle line were used for statistical analysis. All mapping was conducted using ArcMap 9.3.1 Geographical Information Software (ESRI 2010) with nautical charts used as

a base layer. Raster nautical charts were downloaded from NOAA (<http://www.charts.noaa.gov/GraphicCatalog.htm>).

All statistical summaries and analysis were completed using R statistical software (R Development Core Team 2010) and circular statistics conducted on the bearings followed methods described by Batschelet (1981) using the statistical package 'circular' in R statistical software.

Results

Of the 2788 tags deployed, 952 tags were recovered by fishermen or crab processors and returned to us. It should be noted that this rate of return for a mark-recapture study is unusually high. The minimum reward for a single participant was \$20, and the maximum was \$1980. Of the 952 tags returned, 626 were returned with location information sufficient for analysis.

There was an increase in recovery rate with increasing latitude of the release locations but the reason or reasons for this disparity are unclear. The recovery rates were 28.3%, 32.5%, and 43.0% at the Southern, Project and Northern release locations, respectively (Table 2). Distances traveled between release and recapture ranged from 0.27 km to 90.68 km (Table 3), with 65% of crabs travelling less than 20 km, 77.7% of crabs travelling less than 30km, and 95.5% of crabs travelling less than 50km (Figure 1). Recapture locations were clustered around the release sites, as shown in map showing recapture locations and kernel density map of recapture locations (Figures 2 and 3). An inset map (Figure 4) shows detail of recapture locations in the area immediately surrounding the release sites. Crabs moved primarily in the alongshore direction, with minimal across shelf movement (see Figure 4).

We examined the data for differences in crab movement among release locations and found none. There was no significant difference in the distances that crabs travelled among the three release sites (ANOVA of log transformed data, $p=0.69$). We also found no significant differences in the bearings that crabs travelled among the three release sites (circular ANOVA using high concentration F-test and likelihood ratio tests, $p=0.447$ and $p=0.84$, respectively).

Table 2. Summary of number of tags released, recaptured, and recapture rates across release sites.

	Released	Recaptured	Proportion returned
North Control	823	354	43.01%
Project Site	951	309	32.49%
South Control	1014	287	28.30%
All sites	2788	952	34.15%

Table 3. Summary statistics for distances crabs travelled between release and recapture locations.

n	Mean (km)	Median (km)	Std Deviation (km)	Min (km)	Max (km)
626	18.56	13.59	16.12	0.27	90.68

Histogram of distances between mark and recapture locations
Dungeness crabs tagged near Reedsport, OR in Oct. and Nov., 2009

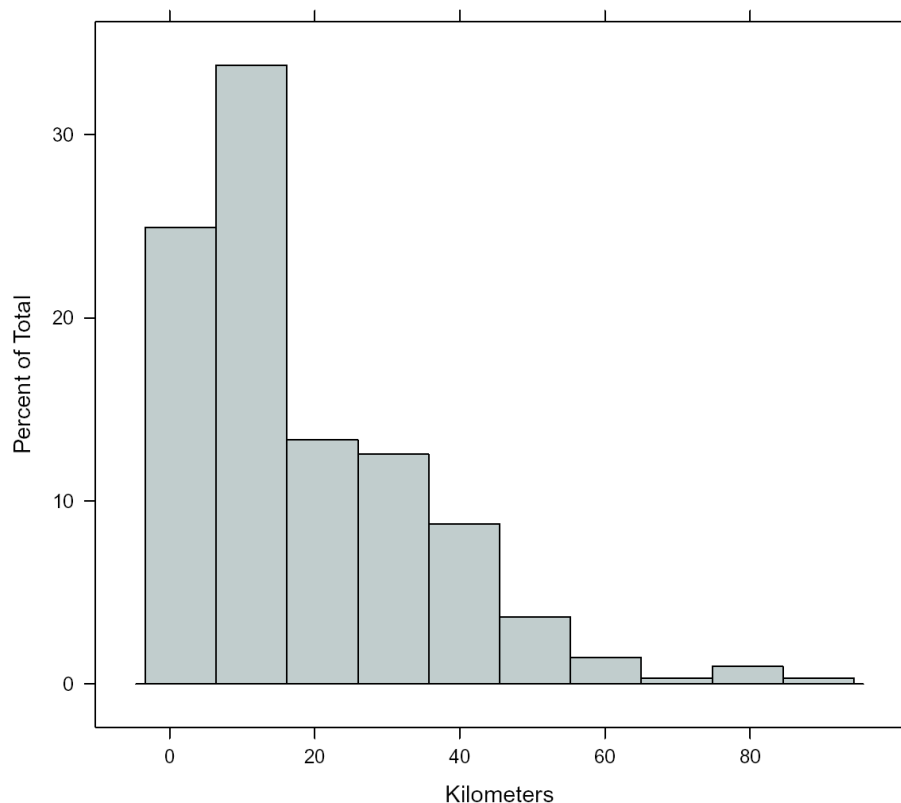
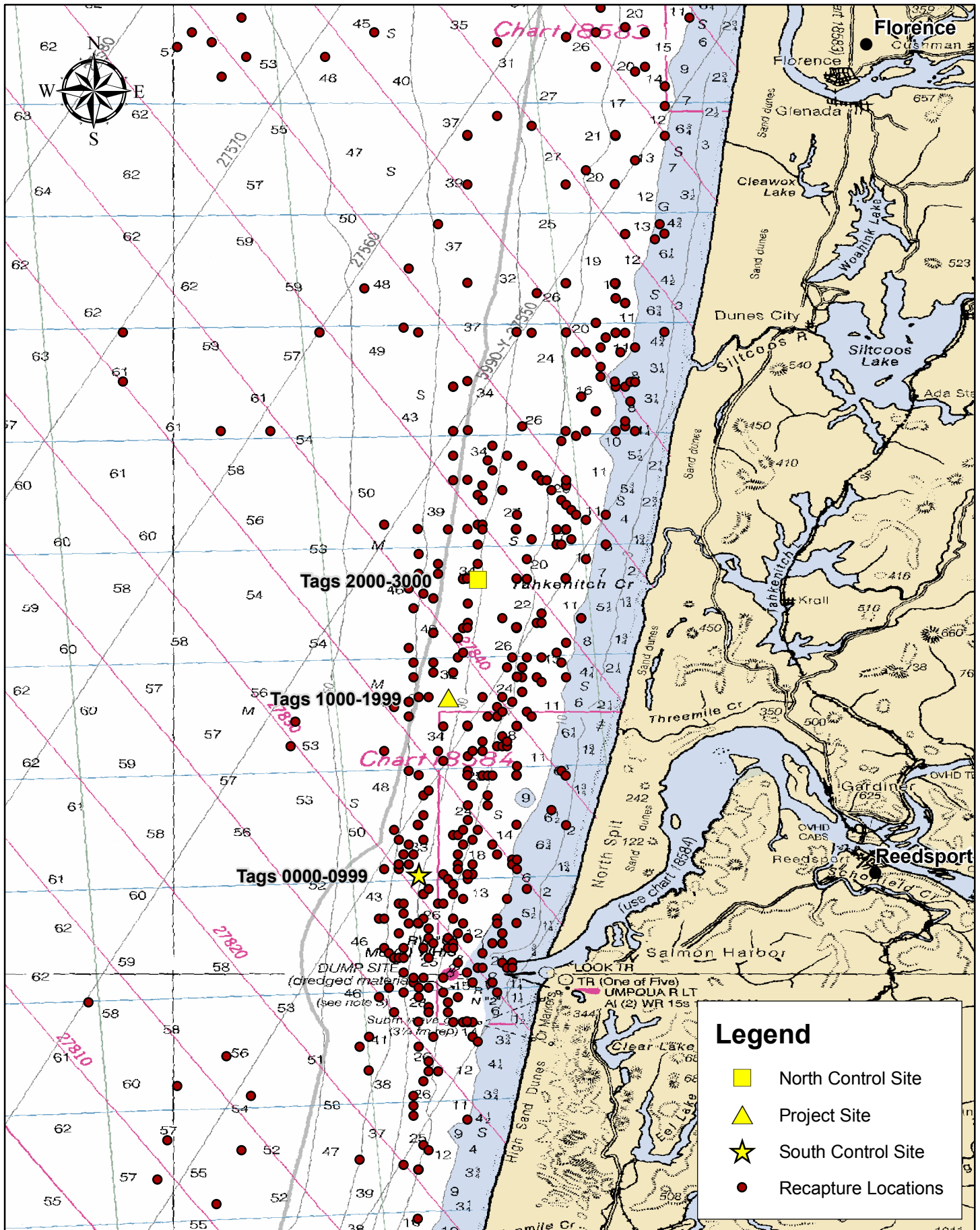


Figure 1. Histogram of distances traveled by Dungeness crabs released at three locations near Reedsport, Oregon. Bar height corresponds to the proportion of the total number of tagged crabs, with the majority of crabs moving less than 20 km.

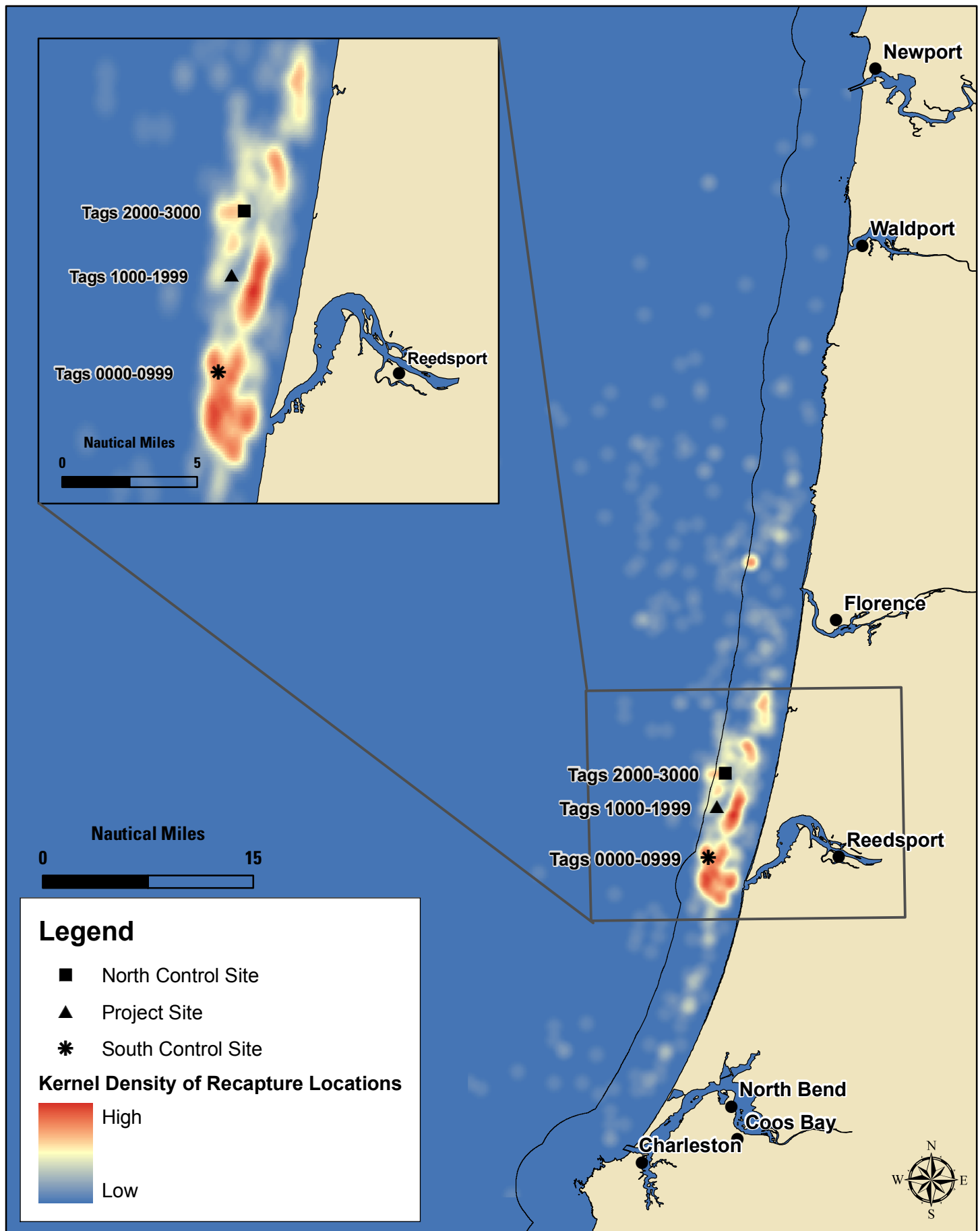
Map created by Amanda Gladics, October, 2010. Chart 18003: Cape Blanco to Cape Flattery.

Recapture Locations

Inset of Release Sites



Density of Recapture Locations



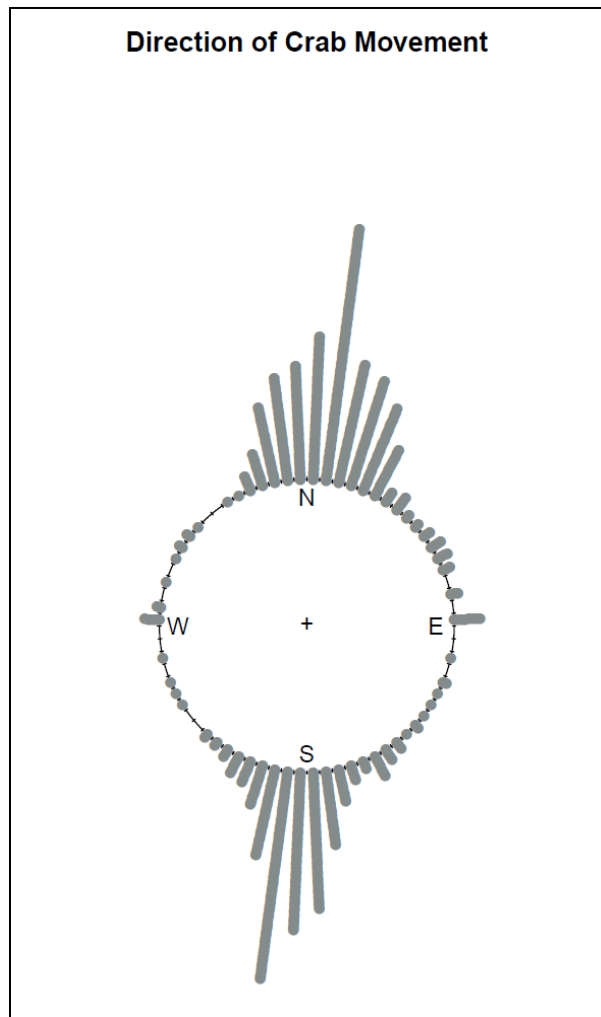


Figure 5. Direction of crab movements, displayed as stacked points in 10 degree bins on a compass circle. Analogous to a histogram, this figure shows that the majority of crabs moved in the along-shelf direction.

Discussion and Conclusions

Legal –sized male crabs tagged in our study moved much greater distances than those tracked in other regions, but movement in the alongshore direction was consistent with studies in northern California and on the Oregon coast (Waldron 1958, Diamond & Hankin 1985). It is important to consider the difference between alongshore movement and across shelf movement when interpreting these results. Water properties, such as temperature, salinity and oxygen levels, change dramatically at the sea floor between the inner shelf and outer shelf (Mann and Lazier 2002). Thus, across shelf movement can potentially require moving across stronger habitat gradients than alongshore movement.

There are few data on crab movement in Oregon, but the results in this study bear a striking resemblance to the findings of Waldon (1958). The two studies showed a very similar rate of tag return (approximately 35%), despite very different levels of fishing effort and being conducted more than 60 years apart. The two studies also found strikingly similar average distances between release and recapture locations (15.3 km from Waldron 1958, and 18.6 km from this study). Since the studies used similar fisheries collaborative methods and were conducted during the same season, we might infer that Dungeness crabs current movement behaviors are similar to behaviors exhibited in the late 1940's.

The differences between our findings and studies in other regions may be caused by differences in habitat (fjord versus open coast) and sex (male versus female). Strong alongshore currents that are present on both the Oregon and California coasts may account for the similarity in the direction of travel observed. An alternate explanation is that Dungeness crabs may be associated with a specific isobath or depth range during our study period. Another explanation may be that the bulk of our sampling effort occurred within a specific bathymetric range, as crabbers target depth contours when pursuing crab.

All studies conducted using fisheries dependent data come with several important caveats, which must be considered when interpreting the results. Since we have no data on the spatial distribution of fishing effort during the study, we cannot determine if the movement data we have collected is a representative sample of the movements of individuals within the population. It is possible that our findings have been biased because the crabbers we depended upon for tag recovery sample the environment in a non-random manner. In other words, because crabbers target certain areas based on past experience some locations had a higher chance of being sampled than others. As pointed out above, the commercial fishery is also constrained by depth, and commercial pot strings are generally deployed between 5 and 80 fathoms. The deepest recaptures in this study were at about 80 fathoms, and crabs occur to 200 fathoms depth (Pauley et al 1986, ODFW 2010).

It is also important to remember that the recapture locations are not representative of fishing effort, and should in no way be interpreted to reflect the distribution of fishing effort near Reedsport, Oregon.

Unfortunately, we were unable to collect consistent recapture dates, and so rate of travel cannot be determined. We believe that nearly all of the tags we received were recovered by May, 2010 and likely represent wintering and pre-molt movements. Since we have only a start and end point, the distances reported here represent a minimum distance that each crab traveled. It is highly unlikely that crabs moved in a direct line between the release locations and recapture sites, consequently the actual distances traveled by crabs may be much higher. More detailed tracking studies would be required to calculate movement behavior on shorter timescales. We have no information on the rate of tag shedding, which could be substantial because of the tagging method used, and must assume that the distance and direction of crab movement did not have an effect on tag shedding.

Inter-annual variability is the norm in Oregon's coastal ecosystems, but we are only able report on one year of movements. It remains unknown to what degree Dungeness crab movements vary from year to year, and how representative these results are of movements over the long term.

It should be noted that there were additional tags returned with general location information that indicated that crabs may be moving as far north as Tillamook. Unfortunately, these locations were too general to include in the analysis for this report. It is unknown if the crab movements observed on the southern Oregon coast are representative of crab movements in coastal waters throughout the state. Verbal feedback from some crabbers indicated that additional tags were recovered but not returned to us. There are a variety of reasons why crabbers may have chosen not to submit recovered tags, including (but not limited to) hesitancy to release fishing location information, concerns regarding the influence study results might have on future wave energy development, time constraints, or lack of interest in the study.

There were no differences in the distances or directions traveled between release locations. Although this result was expected, it provides a baseline for future studies. A similar study should be conducted after any installation of wave energy conversion devices in this area. An important conclusion from this research experience is that cooperative research methods can leverage existing resources can be highly effective in gathering baseline data, despite the

inherent limitations of fisheries dependent data collection. The cooperative research approach fostered communication and understanding between stakeholder groups with differing goals and values. The meaningful involvement of commercial crabbers throughout the project greatly contributed to the success of the project from both a scientific standpoint as well as cultivating a better working relationship between the wave energy industry and the commercial crabbing industry. The data collected by fishermen during this research will be useful to wave energy industry members in assessing impacts from wave energy conversion devices to marine biological resources and serve to enhance the body of knowledge on basic Dungeness crab biology.

Future Research Recommendations

If WEC devices are installed at or near the project site, a similar tagging study should be conducted. It would be helpful to select control locations that are further from the project site. We recommend a similar co-operative fisheries research design, with particular emphasis on including fleet members in the development of specific hypotheses and project design. Specific instructions must be provided to fleet members on what data to record to ensure data consistency and accuracy, and consistent communication between researchers and fleet members should be maintained. Prompt payment of compensation to participating crabbers should continue to be a priority, and it may be helpful to provide a higher reward for tags returned with complete location data. A mark-recapture study in another location on the Oregon coast would provide additional information on whether the movements we observed are representative of crab movements throughout Oregon's coastal waters. Conducting a similar study in the same area prior to a wave energy device deployment would provide valuable insight on the degree of variability in the movement patterns we observed.

Acknowledgements:

We wish to gratefully acknowledge the financial support of Oregon Wave Energy Trust, the Oregon Dungeness Crab Commission and Oregon Sea Grant. We thank Scott Terrill and Pete Nelson at H.T. Harvey and Associates, who coordinated the deployment of the tags. We also thank Rick Lilienthal and the crews of the *FV Delma Ann* and the *FV Apache*, who were instrumental in the tagging effort. We thank Justin Huff, who assisted in producing individualized maps for all participating crabbers. This study could not have taken place without the advice, wisdom, support, and participation of Oregon's commercial crabbers. The comments and suggestions from Sarah Henkel and two anonymous reviewers from OWET greatly improved the clarity of this manuscript.

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