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California's Dungeness Crab: Conserving the Resource and Increasing the Net Economic Value of the Fishery

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INTRODUCTION

Along the Pacific coast (CA/OR/WA), the historical mainstays of the fishing industry have been the Pacific salmon, groundfish, and Dungeness crab fisheries. However, recent cuts in allowable landings of salmon and groundfish have shifted fishing effort toward crab. Diminishing opportunities in salmon and groundfish in California will further increase fishing effort on Dungeness crabs, resulting in the intensifying derby that now characterizes the fishery and imposing increased pressure on stocks at deeper depths. Projected increased fishing effort will also likely create new biological conservation concerns for Dungeness crab populations and diminish its net economic value of the fishery.

In this project, we examined the potential performance and industry participants' perceptions of alternative management regimes that could increase the fishery's net economic value and safety. We also investigated biological information potentially critical for effective management of this increasingly intense fishery. Some of the project results were used by Legislative staff and some fishermen's organizations in developing a bill (vetoed by the governor) establishing limits on the number of traps per vessel south of Point Arena.

This report is divided into the three major components of the project, (1) economics of the processing sector, (2) harvesting characteristics and fishermen's perceptions of management alternatives, (3) biological information related to movements, mortality, and mating.

I. An Economic Overview of Dungeness Crab (*Cancer magister*) Processing in California

We (Hackett *et al*. 2003) obtained baseline economic information on the industrial sector that processes Dungeness crab landed in California. This baseline information included the mix of product forms and prices, value added by processors, the value of their capital stock, and their total peak and non-peak employment.

METHODS

Hackett et al. (2003) focused their analysis on the firms that receive and process Dungeness crab landed in California and on the product forms they sell. Our interviews included six processing firms in California and southern Oregon that purchased 60% of the crab landed in California in 2000.

Value Added

At any given market-mediated stage of production, value added is measured as total revenue generated from sales of the product at that stage of production minus the value added at the previous stages of production (if any). Value added represents income that flows to those who supply the capital, labor, entrepreneurship, and intermediate good and service inputs that are assembled together in production. Value added also includes tax income provided to federal, state, and local government (Hackett 2002).

Data and Scenarios

The data used came from both primary and secondary sources. In all cases these data are confidential and/or proprietary in nature. Data on vessel landings were derived from existing fish ticket data gathered by the California Department of Fish and Game (CDFG) and archived by the Pacific States Marine Fisheries Commission (PSMFC) in their PacFIN database. Product form, price, and product mix information were collected from the processors through in depth on-site interviews and completion of a written questionnaire. The survey instrument also gathered information on capital investment and employment. Price per pound for various product forms can vary substantially over a given season, and so we asked processors to report average or typical price per pound for various product forms. The mix of various crab products made by processors was generally reported in two forms, either total pounds of each product form produced, or the percentage of purchased crab going into each product form.

In order to determine value added by processors we acquired authorization to access confidential data on purchases of crab by various processors in 2000 from fish ticket data archived by the PSMFC in the PacFIN database. New data protocols at the California Department of Fish and Game (CDFG) restricted access to some state-wide data. Due to the incomplete CDFG data set, a number of adjustments and estimates had to be made in our analysis. While the data we initially received from PacFIN was annual year data, we later learned that processors generally track their data based on fishing seasons (November/December through July). Because we could not go back and get processor purchase data from PacFIN based on fishing season, we were forced to assume that a processor's purchase share of statewide landings based on annual year data is equivalent to what it would be based on fishing season data. Consequently, the estimates reported as "2000" in this article refer to the 1999–2000 fishing season, while estimates reported as "2001" refer to the 2000–2001 season.

Moreover, since the PacFIN dataset only included purchases of crab landed at the four north coast ports, we had to estimate processor purchases of crab statewide based on the known proportion of north coast landings purchased by each processor. Specifically, we first computed the share of north coast landings purchased by each processor and then assumed that the same proportion applied to their statewide landings. Thus, if a processor received 20% of all north coast landings, we assumed that the processor had likewise received 20% of statewide landings. Since the four north coast ports included approximately 70% to 90% of statewide crab landings over the last ten years, our projection of central coast purchases covers less than 30% of statewide landings.

Due to the natural fluctuation in Dungeness crab landings it is desirable to generate analysis for more than one year, and consequently we sought out data for 2000 and 2001. Unfortunately, the change in data-management policy at CDFG prevented us from acquiring 2001 fish ticket data indicating the quantity and price of crab received by individual processors, a situation that resulted in our having to estimate those purchases. We used the statewide weighted average ex-vessel price per pound for 2001 to reflect the cost per pound of purchased crab for each processor. We developed two scenarios for estimating 2001 processor purchases to indicate the sensitivity of our results to different estimation approaches.

Scenarios with the suffix "00" in Table 1 involved estimating 2001 processor purchases by assuming that a processor's share of total statewide landings in 2001 was the same as its known share of total statewide purchases in 2000. Since year-to-year landings and processor volumes fluctuate, a second scenario was developed (designated by the suffix "9800" in Table 1) by assuming that a processor's known share of total statewide landings in 2001 is equal to the average share of its known total statewide landings purchased over 1998–2000.

A final data issue concerns the extent to which the sample of processors interviewed for this study is representative of all processors that purchase Dungeness crab landed in California. We succeeded in surveying six processors in California and southern Oregon who together purchased 60% of all crab landed in California in 2000. We use these data to develop estimates for all processors that purchased Dungeness crab landed in California. The processors we surveyed tended (with one exception) to be the larger operators; this resulted in a sample bias in our processor data. The bias exists because small processors frequently lack fixed facilities and may only operate for part of each year, making them difficult to locate and interview. For example, some small processors purchase crab at the dock and drive the live crab to urban seafood markets. Small processors tend to specialize in live and fresh crab and lack the facilities to process frozen product forms. Thus the "in-sample" data are biased toward frozen product forms.

Consequently, we created two additional scenarios based on different methods for extrapolating industry-wide product forms, prices, and value added from our survey data. One of these, designated with the letters "EX" in Table 1, is based on a simple extrapolation of the data from our overall survey data to processors outside of our sample. The other, designated with the letters "SM" in Table 1, is based on an extrapolation of the data from the small processor in our sample to processors outside of our sample. Thus, we have four scenarios for estimating product mix, product form prices, and value added for processors purchasing all California Dungeness crab landings in 2001 and two scenarios for estimating landings for 2000, as shown in Table 1.

In order to perform value added analysis we also had to yield-adjust product form quantities and prices to place them on a common basis with the original whole purchased crab ("round"). Yield adjustment is used to determine the percentage of the original whole crab by weight that remains in the product form after processing (Table 2).

Yield adjusted price per pound for each product form was calculated by multiplying the product form price per pound by the yield figures in Table 2. We then calculated the percentage of total yield-adjusted production going to each product form for each processor in our survey.

The next step involved calculating each processor's weighted average price (WAP), which is the weighted average yield-adjusted price charged for final product forms sold by each processor. Industry-wide weighted average price was estimated by multiplying each processor's WAP in our sample by their estimated share of statewide crab landings purchased. We then extrapolated the sample WAP (scenarios denoted by "EX"), or extrapolated the WAP for our small firm (scenarios denoted by "SM"), to get an industry-wide WAP. Once the industry-wide WAP was estimated, value added for the crab-processing industry could then be estimated. The percent value added was calculated as (WAP—weighted average ex-vessel purchase price) divided by average ex-vessel purchase price provided in Didier (2002). The percent value added simply expresses processor value added per dollar of purchased crab.

Industry-wide value added was then calculated by multiplying percent value added by the total cost of purchased crab landed in California (ex-vessel revenue). The scenarios were also used in an equivalent manner to estimate the industry-wide mix of Dungeness crab product forms, their weighted average prices, and their percent value added for 2000 and 2001.

RESULTS

Ex-vessel landings, revenue (value added), and price per pound is provided in Table 3. Crab fishers added nearly $18 million in value in the 1999–2000 season. In contrast, higher prices in

2000–2001 were not enough to compensate for reduced landings, and value added by crab fishers declined to a bit more than $12 million. Estimates for WAP, value added, and percent value added for processors that purchased Dungeness crab landed in California in 2000 and 2001 are provided in Table 4.

In terms of value added, there was little difference in the two scenarios ("EX" and "SM") used to estimate WAP, value added, and percent value added for 2000. Several factors resulted in the decrease in total value added and percent value added in 2001 relative to 2000. First, note from Table 3 that weighted average ex-vessel price per pound was $.21 higher in 2001 likely because of the substantially lower landings in 2001. Second, note that the estimated industry-wide WAP of crab product forms was lower in 2001 across all scenarios. From Table 5 we can see that the percent value added declined for each product form in 2001 relative to 2000 across nearly all the scenarios. One possible explanation for this decline could be the worsening economy in the United States and the 9/11 tragedy in 2001, which reduced consumer confidence and vacation travel.

A key finding of this study was that the percent value added by fresh and live product forms was generally less than that of the frozen and picked meat product forms. If consumers perceive fresh and live product forms as possessing superior quality to the frozen product forms (much of the picked meat product form originates from the secondary processing of previously frozen crab), then presumably this would be manifested in higher prices per pound for the fresh and live product forms, especially if the pulse of landings suppresses this product form. In fact, our analysis suggests that this is not the case. Since estimated percent value added by product forms in Table 5 relates the yield adjusted sales price to a given dollar of purchase cost, it is evident that the frozen (and picked meat) product forms featured higher yield-adjusted prices per pound. From Table 6, we can see that under most scenarios only about half of the Dungeness crab landed in California is processed into fresh or live product forms.

The superior yield-adjusted price for picked meat products might be explained by the notion that many final consumers value convenience over freshness, since picking meat from a Dungeness crab is a somewhat laborious task. In fact, our estimates for percent value added in 2000 are consistent with the picked meat product having the highest yield-adjusted value in the marketplace (though this was less evident in the 2001 estimates). Processors in our interviews noted the importance of maintaining restaurant, cruise ship, and other food service accounts that serve as key market channels for picked meat. The importance of maintaining these picked meat market channels is indicated by trends in the estimated share of total statewide Dungeness crab landings going into the picked meat product form. Note that the percentage of crab processed into a picked meat product generally increased in 2001, when landings had decreased, indicating the importance of protecting market channels for picked meat.

Past studies suggest that derby fisheries result in substantial unmet consumer demand for fresh finfish. The superior market value of fresh finfish product forms over frozen product forms served as the foundation for improved economic conditions in the relevant fisheries when individual quota management systems were implemented. While our analysis can only conjecture about the changes in product forms that might occur as a result of temporally distributing the current pulse of Dungeness crab landings, the higher yield-adjusted market value of frozen and picked meat product forms suggests that the economic benefits may be smaller for crab than have been observed for finfish.

Comparing the scenarios that emphasize the characteristics of small processors (scenarios designated by "SM") with those based on an extrapolation of the overall sample (scenarios designated by "EX") in Table 6 sheds light on the different product form strategies pursued by small and large processors. Our small processor scenarios indicate a focus on fresh "whole cooked" crabs, though large processors appear to produce the larger proportion of the live crab product form.

We were only able to get sufficient information on employment and capital stock from our survey to develop industry-wide estimates for 2001, as illustrated in Table 7. As before, industry-wide estimates were found by extrapolating in-sample employment and capital stock to out-of-sample processors. Note that in 2001 the peak employment estimate ranges from 485 to 552 (during the weeks when the pulse of landings is being processed), depending on scenario, whereas the off-peak "year-round" industry-wide employment (mostly picking lines) estimate ranges from 88 to 142. Note the distinctive employment signatures of small and large processors. Large processors cause the "EX" scenarios to estimate a larger off-peak level of employment than the "SM" scenarios.

In contrast, the greater emphasis on small processors in the "SM" scenarios results in a higher estimate for peak season employment. A likely explanation is that large processors, which produce proportionately more picked meat, operate picking lines throughout the year, whereas small processors produce proportionately more fresh "whole cooked" crab sold during the holiday season. Capital stock is also clearly a marker of large processors. The "SM" scenarios lead to capital stock estimates of around $4 million, whereas the "EX" scenarios lead to capital stock estimates of around $6 million. Clearly this difference reflects the added expense of large freezer capacity held by large processors.

DISCUSSION

Our analysis estimates that picked meat and frozen crab product forms elicit the highest yield-adjusted market prices and value added under the current fishery management system. By freezing crab sections for picking later, the larger processors are able to manage the flow of product into the market, in sharp contrast to the large pulse of fresh crab landed in the season's first weeks. The share of landed crab being processed into picked meat increased when overall landings decreased, which supports the importance asserted by processors we interviewed of protecting market channels for picked meat during years with poor landings. Our findings were somewhat surprising because analysis from finfish fisheries indicates that fresh product forms tend to carry a higher consumer valuation than frozen product forms. We conjecture that many final consumers value the convenience of picked crab over fresh or live crab. These findings suggest that the shift to higher-value product forms resulting from the temporal distribution of landings in finfish fisheries may not necessarily occur if the current derby fishery for Dungeness crab were eliminated.

We hasten to observe that these findings are only suggestive, and that fishery management that expands the temporal distribution of landings significantly (such as through individual quotas) could generate a variety of benefits. These benefits may include improved safety, less incentive to overcapitalize, and stronger incentives for product innovation and marketing efforts. Over time the latter could very well change relative consumer preferences for different Dungeness crab product forms.

Most of the processors interviewed for this report consider Dungeness crab to be a seasonal or luxury food item associated with various celebratory events, with peak consumption of fresh crab products occurring between Thanksgiving and New Year's Day. Processors noted difficulty in moving fresh crab after late January (Super Bowl weekend). The fact that peak consumption of fresh Dungeness crab occurs during the holiday season, which corresponds to the only time in recent years that fresh product is available, suggests that consumer demand may be adaptable to seasonable availability.

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Table 1. Estimate Scenarios

Scenario	Description
2000EX	2000 processor estimates, extrapolating in-sample processor data to out-of-sample processors
2000SM	2000 processor estimates, extrapolating small-processor in-sample data to out-of-sample processors
2001EX00	2001 processor estimates, extrapolating in-sample processor data to out-of-sample processors, based on processor purchases in 2000
2001SM00	2001 processor estimates, extrapolating small-processor in-sample data to out-of-sample processors, based on processor purchases in 2000
2001EX9800	2001 processor estimates, extrapolating in-sample processor data to out-of-sample processors, based on average processor purchases in 1998-2000
2001SM9800	2001 processor estimates, extrapolating small-processor in-sample data to out-of-sample processors, based on average processor purchases in 1998-2000

Table 2. Dungeness Crab Product Forms and Yield

Product Form	Yield	Description
Whole Cooked	87.5%	Frozen or fresh, cooked in brine; frozen product glazed to prevent freezer burn
Clean and Cracked	87.5%	Same as whole cooked product, except legs are scored, often via band saw, for easier access to meat
Frozen Section	~58%	Crab split into legs and sections, glazed
Live	~100%	-
Picked Meat	25%	Whole crab is blanched, hand picked with the picked meat sold fresh, frozen or canned.

Source: Processor interviews.

Table 3. California Dungeness Crab Landings, Value Added, and Price

Season	Pounds Landed (Kilograms)	Ex-Vessel Value Added	Price Per Pound (Kilogram)
1999-00	8,769,512 (3,977,013)	$17,799,767	$2.03 ($4.48)
2000-01	5,646,772 (2,560,894)	$12,616,251	$2.23 ($4.92)

Source: PacFIN database and processor interviews.

Table 4. Industry-wide Estimates for Weighted Average Price (WAP), Value Added, and Percent Value Added for California Dungeness crab.

Scenario	WAP in Pounds (Kilograms)	Value Added	Percent Value Added
2000EX	$3.04 ($6.70)	$8,831,287	49.6
2000SM	$2.99 ($6.59)	$8,448,237	47.5
2001EX00	$2.89 ($6.37)	$3,676,024	29.1
2001EX9800	$2.88 ($6.35)	$3,651,140	29.0
2001SM00	$2.86 ($6.31)	$3,534,661	28.0
2001SM9800	$2.85 ($6.28)	$3,487,451	27.6

Source: PacFIN database and processor interviews.

Table 5. Industry-Wide Percent Value Added by Dungeness Crab Product Form

	Percent Value Added				
Scenario	Frozen Whole	Frozen Sections	Frozen Picked Meat	Fresh Whole Cooked	Live
2000EX	39.6	53.6	73.5	28.5	38.6
2000SM	39.6	60.6	76.4	32.4	38.6
2001EX00	25.8	42.3	32.0	21.4	26.3
2001EX9800	26.1	43.3	31.8	20.8	26.2
2001SM00	35.6	51.9	32.1	18.9	26.3
2001SM9800	37.1	55.2	32.1	18.5	26.2

Source: PacFIN database and processor interviews.

Table 6. Industry-wide Estimated Dungeness Crab Product Mix (Percent)

Estimate Scenario	Frozen Whole Cooked	Frozen Sections	Picked Meat	Fresh Whole Cooked	Live
2000EX	3.8	12.3	30.4	21.9	27.2
2000SM	2.6	11.7	22.2	42.1	18.6
2001EX00	4.6	6.6	48.3	19.2	21.4
2001EX9800	4.9	5.9	50.5	20.4	18.3
2001SM00	5.9	7.2	35.4	37	14.6
2001SM9800	6.3	6.9	33.8	41.8	11.2

Source: PacFIN database and processor interviews.

Table 7. 2001 California Dungeness Crab Processing Employment and Capital Investment Estimates

Scenario	Peak Employment	Off-Peak Annual Employment	Capital Investment
2001EX00	485	142	$6,070,475
2001EX9800	506	146	$6,246,654
2001SM00	530	97	$4,291,782
2001SM9800	552	89	$3,995,356

Source: PacFIN database and processor interviews.

II. Costs and Management Options in California's Commercial Dungeness Crab Fishery.

We (Dewees, *et al.*) collected and analyzed data on the economic characteristics of Dungeness crab vessel operations and opinions about twelve potential management tools. The purpose was to collect data to inform long term discussions about management alternatives that possibly could increase net economic benefits of the fishery.

METHODS

Our first step was to review regulatory tools used in other crustacean trap fisheries around the world. Results of our literature review and contacts with fishery managers are summarized in Figure 1. Most of these management tools address issues related to over-capacity in fishing fleets and slowing the pace of harvest. We provided this information to fishermen with our mail survey questionnaire.

Our primary research tool was a six-page mail survey sent to the 616 individuals who purchased California commercial Dungeness crab vessel permits for 2001. We designed our survey based on Dillman (2000). We asked permit holders about characteristics of their fishing business, crab fishing costs, revenues and effort, opinions of the current management system, and opinions of 12 potential management tools. We asked fishermen to rank each management tool on a five point Likert scale (strongly unfavorable to strongly favorable).

Given widespread wariness among fishermen that research might lead to new regulations that would hurt their operations, we actively conducted pre-survey outreach. We met with groups of two to twenty-five crab fishermen at four major ports (Crescent City, Eureka, Noyo, and Bodega Bay) and at a California Salmon Council meeting. At these meetings we distributed summaries of crustacean management tools in use internationally, attempted to assuage fears about participation in the project, answered questions, asked for advice on increasing response rates, and pre-tested and received feedback on draft surveys.

After multiple revisions and two pretests, we mailed our final survey in November 2002 to the 616 California Dungeness crab vessel permit owners. Two weeks after mailing the surveys, we sent a follow-up postcard to all permit holders as a reminder and offer of a replacement survey if necessary.

RESULTS

Response rate

Seven surveys were returned as undeliverable and 243 were returned completed, a response rate of 40%. We believe our sample is generally representative of the total crab fleet. Survey respondents generally reflect the home port distribution of all permit holders (Table 1).

When compared to CDFG permit data, our sample contains a similar proportion of owners of vessels under 30 feet (14.9% vs. 15.4%); medium-sized vessels are slightly under represented (58.6% vs. 70.8%); and vessels over 50 feet (which tend to be the largest producers) are over represented (26.8% vs. 13.8).

Fleet characteristics, activity and costs

Table 2 summarizes general characteristics of survey respondents. The majority own medium sized vessels and about half have at least 20 years of experience fishing for crab. About 75 percent fish with fewer than 400 traps.

By looking more closely at trap usage we found that during the 2000-01 season fishermen deployed an average of 293 traps per vessel during the peak fishing month of December. On average during December, small, medium and large vessels fished 138, 259, and 448 traps, respectively. Trap numbers increased substantially with vessel size, reflecting increasing capability to carry traps. During the first month or two of the season traps were usually hauled daily. As crab density and catch rates declined later in the season, traps were often pulled at 48 to 72 hour intervals. Fishermen will move their traps to different areas or depths in search of improved catch rates.

By extrapolating the mean number of traps by vessel size fished by respondents to the total number of permit owners by vessel size, we estimate that 171,090 traps were deployed in California's crab fishery in December 2000. This compares to estimates of 146,978 and 64,806 traps in Oregon and Washington during the same time period (Didier 2002). While there have been no other estimates of California trap numbers since the 1975-76 season, Didier estimated that from 1971-72 through 1975-76 California trap numbers averaged 29,115. During the same period Oregon and Washington trap estimates were 52,380 and 35,840, respectively. It seems clear that the amount of fishing gear in California waters has increased significantly since 1975-76.

Dungeness crab fishing is just one of several fisheries that fishermen utilize during the year. We were surprised at the relative importance of crab to respondents; 73 % of respondents indicated that more than 40 percent of their gross income came from fishing Dungeness crab (Table 3). For those with vessels less than 30 feet, crab fishing appears to be a relatively minor component of their income.

When we asked fishermen to estimate the value of their crab permit, estimates increased with vessel size. On average, owners of small, medium and large vessels estimated their permit value at $10,303, $18,187, and $31,111, respectively. Larger vessels are able to load, move and fish more traps. They can also better handle the dangerous winter weather conditions and are more likely to be able to fish day and night. In addition, some of the larger vessels can hold large quantities of crab in live wells onboard, enabling them to take multi-day trips.

As average trap usage increases by vessel size, so do annual and daily variable costs attributed to crab fishing (Table 3). Gear repair primarily involves replacement of lost or worn out traps while trap storage cost occurs in the off season. Crew are typically paid a percentage of the landings proceeds, reflecting traditions of crew motivation and of sharing risk. Crew costs increase with vessel size because larger vessels often require two deckhands to handle the larger number of traps hauled each day, whereas small vessels usually have just one deckhand in addition to the skipper.

Opinions of management tools

The heart of our research was our analysis of fishermen's opinions of management tools. Opinions generally fell into three tiers (Table 4). The majority of respondents expressed a favorable or strongly favorable opinion of only three tools: the current management system, one trap limit for all size vessels, and daylight fishing only. The current management system consists primarily of regulations designed to sustain crab populations, whereas the twelve other management tools relate to vessel operations, economics and allocation of the catch.

The large majority of respondents approved of one trap limit for all vessels rather than having trap limits based on vessel size. There was little support for limiting overall statewide trap numbers by issuing transferable or non-transferable trap certificates to individual vessels. Fishermen expressed almost no support for increasing trap limits during the season as crab densities on the fishing grounds declines.

A majority of respondents also supported confining fishing to daylight hours. This measure would limit the number of traps that could be pulled on a single day. Currently some vessels, primarily larger ones, operate 24 hours a day and are able to fish more traps. Allowing only one pull of traps per day received little support. Respondents expressed concerns about the ability to enforce this regulation short of onboard video cameras.

The use of harvest rights systems such as individual or community quotas, which have been used elsewhere to slow the race for fish and shellfish, garnered little support. Respondents mentioned concerns about aggregation of harvest rights in the hands of a few and CDFG's lack of ability to determine annual quotas as barriers to implementation of these types of quota systems.

Finally, only a minority favored managing the fishery with differing regulations in different zones, even though there are currently different season opening and closing dates in northern and central California.

Vessel size and management opinions

In discussions at our focus group meetings and with fishery managers, we found that much of the historical and current disagreement over alternative management approaches has been among participants with different sized vessels. Industry discussions about trap limits and zonal management have broken down over differences between owners of large as compared to medium and small vessels. For this reason we decided to take a closer look at the differences in opinions of management tools based on vessel size categories (vessel size is also highly correlated with number of traps used, percent income from crab fishing, and number of days fishing for crab annually). Vessels were divided into three length categories: less than 30 feet (small), 30 to 50 feet (medium), and larger than 50 feet (large). These categories are the same as those used by the Pacific States Marine Fisheries Commission in their analyses of California, Oregon, and Washington Dungeness crab fisheries (PSMFC 1993).

We tested the null hypothesis that opinions regarding the thirteen management tools do not differ among vessel size categories (small, medium, and large). We first used a Kruskal-Wallis test (Hays 1988) to determine if there were significant differences in opinions. When the Kruskal Wallis test indicated significant differences among categories, we then used the Kolmogorov-Smirnov test to make specific pair-wise comparisons across vessel size categories. In order to test to whether difference exists in the mean response across two categories, a randomization test based on Manly (1997) and written by the authors was used. We report the mean p-value of the 10,000 simulations here.

Using the Kruskal-Wallis test, we rejected the null hypothesis that respondent opinions are the same across the vessel size categories for five alternative management tools (Table 5). Generally, as vessel size increases, support decreases for one trap limit for all size vessels, trip limits, community quotas, regional management and daylight fishing only. When we tested for pair-wise differences between specific size categories, large vessel owner's opinions were significantly different from both medium and small vessel owners on all five management tools. Differences between small and medium vessel owners' opinions differed only on regional management.

DISCUSSION

Implications of Findings for the Fishery

Though the pace of the Dungeness crab fishing has continued to intensify, it remains a profitable and important fishery. Crab processors have evolved strategies to deal with the huge early season pulse of crab landings (Hackett et al. 2003). At the same time, fishermen continue to struggle to find ways to cope rationally with the increasing intensity of the crab harvest.

There is widespread approval among fishermen of the current crab management regulations based on traditional fishery management tools with seasons. However, when additional regulations are considered that affect fishing operations, opinions become highly polarized or negative.

Trap limits. The great increase in the number of traps fished and the accelerating pace of the fishery has lead to years of discussion of whether to limit the number of traps each vessel may fish. At this time the Pacific Coast Federation of Fishermen's Associations is developing legislation that will establish trap limits (250/vessel is likely) and other restrictions on at least an experimental basis. Our study shows that trap limits are viewed favorably by the majority of the fleet with the exception of the large vessel owners. Many of those survey respondents who oppose trap limits stated that they viewed it as a reallocation of crab to smaller operators. They also expressed concern that the trap limits were unjustified in terms of resources, conservation and were a restriction on their business.

We anticipate that trap limits would at best cap the total number of traps near current levels and prevent large increases in fishing effort. After implementation of trap limits in Maine's lobster fishery, the total number of traps fished increased (Acheson 2001). While the relatively few lobstermen above the trap limit reduced their operations, many of those under the limit increased their trap numbers toward the limit. Depending on the level set for trap limits, California's outcome could be similar to that of Maine. One way potential way to avoid repeating Maine's outcome could be to scale trap limits to vessel length. However, this option was not ranked very favorably by the fleet (Table 4). California should also examine the early outcomes from trap limit systems recently implemented in Washington state. Inside Puget Sound, trap limits are set at 100/vessel and there are six harvest regions. Along the Pacific coast there are trap tiers ranging from 350 to 500 traps/vessel based on catch history (Veneroso 2003).

If the industry wants to reduce the total amount of gear in the water significantly, additional measures that "ratchet down" the trap limit may be necessary. Some form of trap certificates, similar to those implemented in the Georgia blue crab and Florida spiny lobster fisheries (Coastal Fisheries Advisory Committee 1997; Larken and Milon 2000) might eventually need to be considered as a flexible mechanism to reduce the overall number of traps. Such a system would involve setting a total number of traps to be used by the fleet and issuing certificates (one/trap) to be placed on each trap by fishermen. The number of certificates could be reduced each year until the desired fleet-wide total is reached. Certificate transferability and geographic specificity could be included if desired.

Some form of trap limits is the alternative management tool most likely to be implemented because of the high level of approval among fishermen. Trap limits may be implemented together with other restrictions such as daylight fishing only and trap limits that differ between central and northern California. The recently implemented buyback of trawlers (December 2003) administered by the National Marine Fisheries Service (NMFS) included 23 large vessels that also fished for crab in California (US Congress 2003). Fishermen remaining in the trawl, pink shrimp, and Dungeness crab fisheries will repay about 80 percent of the cost of this buyback to NMFS. This 27 percent reduction in large vessels that fish crab may change the dynamics of industry discussions about trap limits.

Quota systems. Quota systems would assign specified harvest rights for a proportion of the total allowable catch to individuals or communities. They are generally perceived of unfavorably by all sectors of the crab industry. In theory and in practice, however, these harvest rights systems create incentives that slow the race for fish/shellfish and provide opportunities for innovative marketing to add value (Casey *et al* 1995; NRC 2001); both results might improve the economic performance of the fishery. With assured access to a proportion of the total catch, quota holders could time their fishing and configure their fishing operation to maximize profitability. Some processors currently are able to do this to some degree by freezing crab harvested early in the season and then processing and selling the meat during the year to meet high value demand by restaurants.

Respondents expressed concerns focused primarily on the potential excessive aggregation of harvest rights and difficulties in making the accurate annual crab abundance estimates needed to set individual or community quotas. If quota systems were ever implemented these concerns would have to be addressed. In addition, individual or community quotas would have to be specified geographically to be effective.

Given the current unfavorable opinion of quota systems by the industry, they are unlikely to be considered seriously in the near future even though they would likely slow the pace of the fishery. The Pacific Fishery Management Council's recent (Fall 2003) decision to examine individual fishing quotas for the groundfish trawl fishery might affect future knowledge levels and attitudes about quota systems in the crab fleet. The British Columbia (Canada) groundfish trawl fishery has operated profitably in recent years under an individual quota system. This has provoked a high level of awareness and interest from the U.S. Pacific coast trawl fleet.

Regional or zonal management. There is a tendency for owners of larger vessels to view spatial management unfavorably. Their comments indicated a desire to be able to move freely throughout the state to take advantage of the earlier season opening in central California as well as maintaining flexibility in their operations. Some fishermen would like to see trap limits for Central California only and a uniform season opening date statewide. We feel that regional differences are likely to be part of any changes in crab management because crabs are usually more abundant in northern California and the northern vessels, on average, are larger.

Daylight fishing only and single trap haul. These two management tools could be used to slow the fishery by reducing the fishing efficiency and harvest capacity of the fleet. Not surprisingly, daylight fishing only was significantly more popular with smaller vessel owners for whom night fishing is impractical and risky. Daylight fishing only would also reduce small vessel competition from large vessels that can fish many more traps, 24 hours per day, and in adverse weather conditions.

Where is the fishery headed?

This study clearly shows that the majority of the vessel owners favor some type of trap limits and some limitations on fishing at night. The larger higher producers, who are fewer in number, tend to view further restrictions negatively because they would hamper their ability to fully utilize their harvesting capacity. These decades-long differences in opinions due to vessel size continue to make management changes difficult.

The most likely near-term outcome is the adoption of some form of trap limits, at least on an experimental basis. The crab fishery in Washington recently adopted tiered trap limits and the state of Oregon is seriously considering them. If Oregon implements trap limits, it seems likely that excess gear from Oregon could wind up being used in California and further intensify the fishery. That would likely push California towards trap limits.

Any trap limit program should be closely evaluated after implementation, as was done for Maine's lobster fishery (Acheson 2001). Other than preventing explosive growth in the amount of gear fished, a single level of trap limits (250 traps/vessel is proposed in current pending legislation) alone would likely have little effect on the overall fishery other than some transfer of catch from larger operations to smaller ones. As in many other common-pool natural resource settings, the potential for redistribution of profits serves as a potent barrier to change (Hackett 1992).

If the fishermen's goal is to reduce the total amount of gear fished significantly below the current total of approximately 170,000 traps, some plan for systematically lowering total trap numbers will be needed. Some options include:

- Use trap certificates (transferable or non-transferable) that fit under an overall statewide or regional trap total. This total could be adjusted downward in an orderly fashion over the years to reach a generally acceptable number. Setting a target trap total(s) at the beginning of the process may help fishermen to accept the program.
- Set vessel trap limits lower each season until reaching a target level. Larger vessels would be likely to oppose this approach. Trap limits could be scaled to vessel size.
- Buy out those interested in leaving the fishery, similar to the recently implemented trawl fleet buy back through a loan from government. Those remaining in the fishery would reimburse government over time. Some restrictions on traps would be needed to prevent excessive expansion by those remaining in the fishery.
- Implement some form of a harvest rights system (transferable or non-transferable) that would allow quota holders to rationalize their business operation. This would require improved estimates of crab abundance, improved enforcement, quotas within geographic zones, and agreed upon quota aggregation limits.
- Leave things as they are and let attrition under the current restricted access program gradually reduce fleet size and perhaps the number of traps fished. This would likely take many years.

Trap limits appear to be the only alternative with a likelihood of adoption in the near term, but the long-term consequences of that approach are unclear.

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Figure 1. Definitions of Management Tools

Current management system in California's Dungeness crab fishery -- This includes biologically oriented measures such as season, size limit, male-only harvest and gear requirements (trap escape ports and destruct panels) combined with a limited entry program.

Trap limits – These establish the maximum number of traps a vessel can fish. They can include:

- **one maximum trap limit** that applies to all vessels,
- **multi-tier trap limits** with several different maximum limits for different size vessels or other criteria,
- **graduated trap limits** that change over the season (for example, trap limits that increase as crab abundance declines or as the season goes on).

Trap certificates -- Certificates allow individual fishermen to use a certain number of traps for the season. Each certificate represents one trap. Trap certificates can take the form of:

a) **transferable trap certificates** that are a portion of an overall trap total allocated to fishermen and can be sold or leased in or out by fishermen (either freely or within agreed upon constraints).
b) **non-transferable certificates** that allow fishermen to choose a tier within a per vessel maximum trap limit.

Trip limits -- Individual vessels have limits on the landings they can make per trip.

Individual fishing quotas -- Each fisherman is allocated a portion of the total allowable catch (TAC) based on agreed upon criteria such as catch history or vessel characteristics. IFQs can include:

a) **individual transferable fishing quotas** that can be sold or leased (either freely or within agreed upon constraints) among fishery participants,
b) **individual fishing quotas** that are not transferable.

Community quotas -- Part or all of the total allowable catch is allocated to a community or group of associated individuals to allocate locally among fishery participants.

Regional/area/zonal management -- Management differs between locations (for example, seasons, trap limits, and total allowable catches differ by locale).

Daylight fishing -- Harvest is permitted during daylight hours only.

One trap haul (pull) per day -- Hauling gear to the surface is permitted once per day.

Table 1: Home port distribution of vessels with California Dungeness crab vessel permits compared to home port distribution of survey respondents

City	Respondents (%)	Permitted Vessels (%)*
Crescent City	19.5 (n=46)	20.0
Trinidad	4.8 (n=11)	3.9
Eureka	14.0 (n=33)	11.6
Fort Bragg	13.1 (n=31)	8.8
Bodega Bay	12.3 (n=29)	11.3
San Francisco	6.8 (n=16)	13.6
Half Moon Bay	11.4 (n=27)	8.9
Santa Cruz	1.7 (n=4)	2.1
Moss Landing	0.4 (n=1)	1.8
Morro Bay	1.7 (n=4)	1.1
Avila Beach	1.8 (n=3)	1.3
Other CA ports	4.8 (n=11)	6.1
Oregon ports	8.7 (n=20)	9.6

* Source: California Department of Fish and Game (April 2003)

Table 2: Characteristics of individuals with California Dungeness crab vessel permits (number of respondents)

Length of primary crab fishing vessel	**n**
≤ 30 feet	35
> 30 feet to ≤ 50 feet	137
> 50 feet	63
Tenure in fishery	
0 to ≤ 9 years	42
> 9 to ≤ 19 years	61
> 19 to ≤ 29 years	77
> 29 years	56
% of gross income from Dungeness crab fishing, 2002	
≤ 20%	17
> 20 to ≤ 40%	46
> 40 to ≤ 60%	66
> 60 to ≤ 80%	83
> 80 to 100%	23
Mean number of days fishing Dungeness crab, 1998-2000	
≤ 50 days	32
> 50 to ≤ 100 days	53
> 100 to ≤ 150 days	62
> 150 to ≤ 200 days	50
> 200 days	19
Mean number of traps fished, 1998-2000	
≤ 200 traps	67
> 200 to ≤ 400 traps	96
> 400 to ≤ 600 traps	40
> 600 traps	21

Table 3: Mean Dungeness crab fishing costs of survey respondents, by vessel size.

Vessel Size (feet)	Annual Costs ($)		Daily Costs ($)		Other	
	Gear Repair	Trap Storage	Bait	Fuel	Other Variable Costs	Crew Share (%)
Small: < 30	2,239 (1,932)*	149 (228)	57 (63)	41 (44)	40 (54)	15 (10)
Medium: 30 - 50	4,006 (3,259)	626 (936)	155 (233)	68 (137)	41 (52)	24 (11)
Large: > 50	6,656 (4,072)	1,650 (2,237)	226 (163)	150 (83)	62 (29)	31 (10)

* Standard deviation in parentheses

Table 4: Frequency of crab survey respondent opinions on management tools

Management Tools	Strongly Favorable or Favorable	Neutral	Strongly Unfavorable or Unfavorable	Mean Score * (Standard Deviation)
	Opinions of Management Tools			
Current Management System (n=198)	153	19	26	4.11 (1.18)
One Trap Limit for All Size Vessels (n=196)	138	9	49	3.85 (1.63)
Daylight Fishing Only (n=222)	143	15	64	3.59 (1.67)
Transferable Trap Certificates (n=188)	72	17	99	2.68 (1.74)
Non-Transferable Trap Certificates (n=168)	61	16	91	2.67 (1.72)
Trip Limits (n=186)	67	17	102	2.60 (1.67)
Different Trap Limits for Different Size Vessels (n=187)	72	9	106	2.60 (1.66)
One Trap Haul per Day (n=211)	62	36	113	2.59 (1.60)
Regional/Area/ Zonal Management (n=206)	69	23	114	2.54 (1.64)
Transferable IFQs (n=197)	45	16	136	2.08 (1.34)
Non-Transferable IFQs (n=190)	26	15	149	1.80 (1.53)
Community Quotas (n=205)	20	14	171	1.62 (1.14)
Graduated Trap Limits (n=148)	9	23	116	1.61 (0.98)

* Scale: 5= highly favorable, 4=favorable, 3=neutral, 2=unfavorable, 1=highly unfavorable

Table 5: Opinions of crab management tools by vessel size category.

Management Tools	Vessel Size Class Small < 30 ft.	 Medium 30 to 50 ft.	 Large > 50 ft.
Current Management System	4.3	4.1	3.9
One Trap Limit for All Size Vessels†	4.1§	4.3§	2.8
Daylight Fishing Only†	4.5§	3.8§	2.6
Transferable Trap Certificates	2.8	2.6	2.6
Non-Transferable Trap Certificates	2.3	2.9	2.5
Trip Limits‡	3.1	2.7§	2.1
Different Trap Limits for Different Size Vessels	3.1	2.3	3.0
One Trap Haul per Day	2.9	2.7	2.2
Regional/Area/Zonal Management†	3.3§#	2.7§	1.7
Transferable IFQs	1.9	2.0	2.3
Non-Transferable IFQs	2.2	1.7	1.7
Community Quotas†	2.2§	1.7§	1.1
Graduated Trap Limits	1.8	1.7	1.3

* Scale: 5=Strongly favorable, 4=Favorable, 3=Neutral, 2=Unfavorable, 1=Strongly unfavorable

† Vessel size categories significant, Kruskal-Wallis Test, p=.01

‡ Vessel size categories significant, Kruskal-Wallis Test, p=.05

§ Significantly different from large vessels, Kolmogorov-Smirnov Test, p=.01

¶ Significantly different from large vessels, Kolmogorov-Smirnov Test, p=.05

Significantly different from medium vessels, Kolmogorov-Smirnov Test, p=.05

III. Dungeness Crab Mortality Rates and Indicators of Mating

Biological research in this project had two primary objectives: (1) Estimate natural and fishing mortality rates of sublegal and legal sized male Dungeness crabs, and (2) Determine whether or not so-called *mating marks* (Butler 1960) are a reliable indicator of mating activity in male Dungeness crabs. To our knowledge, the only existing estimates of natural mortality rates of male Dungeness crabs were presented by Smith and Jamieson (1989) who estimated an annual instantaneous natural mortality rate (*M*) of 2.9-4.5 for sublegal-sized male Dungensss crabs. Because adult male Dungeness crab molt at most once a year, this high estimated range for natural mortality rates for sublegal-sized male Dungeness crabs seem *a priori* unreasonable because it implies that fewer than 5 % of sublegal- crabs survive to become legal size. Mating marks have been frequently been used as an indicator of mating activity in male Dungeness crabs and studies have repeatedly reported much higher mating mark incidence among sublegal-sized crabs as compared to legal-sized crabs. This has raised concerns that the intensive fisheries (annual exploitation rates may exceed 90%) directed on male Dungeness crabs may prevent many legal-sized male crabs from participating in mating. Based on additional field observations that male crabs generally exceed the size of female crabs when mating takes place, Smith and Jamieson (1989) speculated that a large fraction of females may go unmated in many fisheries. In this three year project we carried out a twice a year (see Brownie et al. 1975) tag recovery experiment in an attempt to estimate natural and fishing mortality rates. Our study of mating marks involved a combination of field observations of mark presence throughout the mating season and laboratory experiments designed to determine factors that may affect formation of mating marks.

TAG RECOVERY PROJECT METHODS

To fully understand the logic of our tag recovery project, it is necessary to review timing of events in the northern California commercial fishery for male Dungeness crabs. Adult male Dungeness crabs molt annually during late July through September when the commercial and recreational fisheries are closed. Unless crabs are not yet sufficiently full with meat or there is a preseason market dispute, the northern California commercial fishery opens annually on December 1 and closes (usually) the following July 15. Although there are a limited number of commercial fishing permits for Dungeness crabs in northern California, there are no restrictions on gear deployment or time of day when fishing may take place. As a consequence, many fishermen have invested in extremely large numbers of traps (several hundred or more) which they fish intensively on a 24 hour basis during the early part of the fishing season. A classic derby fishery (the focus of economic research in our project) results and 80% or more of annual landings may be taken in the first 4-6 weeks of the fishing season. By the end of March, more than 90% of annual catches have typically been landed.

In three successive years, we tagged approximately 2,000 crabs with bright orange FLOY model FD-68B anchor tags during each of two periods: November (Fall), just prior to the commercial fishing season, and late March or early April (Spring) by which time almost all commercial catch had been landed. Theoretically, through at least March or early April of the intensive commercial fishing season essentially all mortality should be caused by fishing, whereas from about April though November essentially all mortality should be due to natural causes. Thus, the difference in commercial fishery recovery rates of crabs tagged during April as opposed to November of a given year should be due almost entirely to natural mortality: crabs tagged in April would suffer natural mortality prior to fishery capture whereas crabs tagged in November would suffer little or no natural mortality prior to capture. Tagging was usually accomplished within one month, with approximately three trips a week, although weather delays were a common problem.

FLOY tags were sequentially numbered and inserted in the posterior suture line where the crab carapace splits during molting. With this method, tags should be retained through at least one molt.

All crabs were double-tagged during the 2001-2002 and the 2002-2003 fishing seasons; a mixture of single- and double-tagged crabs were released for the 2003-2004 fishing season. Tagging with one or two anchor tags was designed to allow us to determine tag retention rates (by examination of the fraction of crabs recovered with two tags given tagged with two tags) and possible effects of tagging on mortality of crabs (comparison of recovery rates for crabs receiving one or two tags). Crabs were typically captured in waters approximately 30 m deep and release locations were recorded using GPS.

Sublegal crabs for this project were defined as those between 150.0 mm CW and 158.0 mm CW. Crabs at this size are likely to be captured with conventional commercial gear, will likely go through an annual molt, and those that do molt will be legal sized following the molt. All tagged crabs, both legal and sublegal, were examined for missing appendages, and shell condition was recorded as new-shell (had molted in the most previous molting season) or old-shell (had not molted in the most recent molting season). No crabs were captured in a soft shell condition, indicating very recent molting.

Flyers and posters placed in and around Woodley Island Marina, Trinidad Pier, Crescent City Harbor, and other locations notified commercial fishermen of the presence of tagged crabs. For the 2001-2002 and 2002-2003 fishing seasons, a $10 reward was offered for the return of legal crabs and a $5 reward was offered for the return of sublegal crabs. Rewards for the 2003-2004 season were increased to $15 and $10 for legal and sublegal crabs, respectively. To facilitate the return of tagged crabs, special recovery barrels were placed at the two marinas in Eureka and on the Trinidad Pier, and a commercial fishing supply store in Crescent City accepted recovered tagged crabs. In the first two project years, a $3,000 grand prize was given annually to the fisherman who had returned a randomly chosen tag selected from all of the recovered tags from a given fishing season.

TAG RECOVERY RESULTS AND DISCUSSION

Release and recovery data are summarized by numbers and by percentages in Tables 1 and 2, respectively. We tagged and released 10,735 male Dungeness crabs during 6 release sessions from November 2001 through April 2004; of these, 1,446 tagged crabs were returned to us by commercial or sport fishermen. Data summarized in Tables 1 and 2 reveal several surprising features. First, overall percentage recovery rates for individual groups of tagged crabs have ranged from a low of about 5% to a high of about 27% and have been substantially below our original proposal projections of about 40% - 50%. Second, recovery rates during the spring period for crabs released in April of the same year have been much higher than expected; in 2004, spring recovery rate for legal-sized males released in April was about 24%! Finally, a very minor number of recoveries have been for crabs that have been at large for more than one period. That is, the vast majority of recoveries from both legal- and sublegal-sized crabs have been obtained in the period immediately following their release. This recovery pattern was anticipated for legal-sized crabs tagged and released during fall (November), immediately prior to the opening of a commercial fishing season, but it was not anticipated for sublegal- or legal-sized crabs tagged during spring (April).

We modified our tagging and release protocols in the third project year in an attempt to determine the probable causes for the unexpected structure of the tag recovery data. First, two methods of release were used in the third and final year of tagging: (a) tagged crabs were released as soon as possible after tagging, or (b) tagged crabs were held on deck for several hours until all crab tagged on a given date were released in one location. Second, approximately one-half of the crabs captured during these two tagging sessions in the third year were tagged with a single tag. The two methods of release were designed to allow us to determine if tag recovery rates were strongly related to release location or “holding time” prior to release. Tagging with one or two tags was intended to allow us to determine whether or not tag loss and/or high mortality rates following tagging with two tags rather than one might be primarily responsible for the low recovery rates for crabs more than a year following release. Tag loss for the whole project is summarized in Table 3; Table 4 compares tag loss between single- and double-tagged for sublegal-sized and legal-sized crabs, respectively.

Preliminary analysis of supplementary tag recovery data from crabs tagged with two tags suggests that tag loss is not the primary cause for low recovery rates. With the exception of the first project year, during which time some commercial fishermen physically removed one of the two tags present prior to bringing crabs to recovery locations, less than 10% of recovered double-tagged crabs had just a single tag in place. Very few of these crabs had molted prior to recovery, however, so these data cannot be used to determine tag loss through molting. Preliminary inspection of recovery data for crabs receiving one or two tags suggests that insertion of two tags as compared to just a single tag did not have a detectable effect on recovery rates and, by inference, survival rates of tagged crabs.

MATING MARKS METHODS

So-called "mating marks" were first described by Butler (1960) as abrasions on the inner surface of male crab's claws that were believed caused by direct exoskeletal contact between hard-shelled male and female crabs during the premating embrace, a precursor activity to actual mating. We conducted a critical review of published literature concerning mating marks and we also conducted laboratory mating trials in an attempt to determine the mechanisms of mating mark formation during premating activity. In these laboratory mating trials, we varied the relative sizes of males and females in premating embraces to determine how mating mark formation might be related to the relative and absolute sizes of crabs, and we used continuous video recordings to help us develop good descriptions of actual premating behaviors (premating embraces may last several days) . We supplemented these laboratory observations with a detailed field-based observational study of mating mark presence on male Dungeness crabs in the northern California fishery. Male crabs were examined for mating marks between 25 January 2004 and 19 July 2004 to describe the occurrence of mating marks before, during, and after the spring mating season (typically mid-March to mid-June). Male crabs were collected from a contracted commercial crab fishing vessel, using a combination of conventional (open escape ports) and modified (closed escape ports) crab pots. Male crab carapace width (CW) was measured and the presence or absence of mating marks on each claw was recorded. Numbers of crabs examined for mating marks and the resulting frequencies of mating marks, by size classes, were calculated for each day of observation. Mating mark characteristics were described and photographed.

In laboratory studies, potential effects of male and female crab size on formation of mating marks were examined first by creating matings of small, medium, and large females with each category of small, medium, and large males. Second, the three sizes of males were allowed to mate up with up to three females to determine if multiple matings generated more prominent mating marks. We placed some individual males in premating embraces with three separate females Finally, to determine whether mating marks could result from male-male agonistic interactions, we allowed combinations of two or three males to compete for a single female collected from a premating embrace. These mating experiments were conducted on natural substrates and/or in a dynamic environment to more closely mimic the natural conditions of Dungeness crab mating pairs. All experiments were closely observed to allow accurate description of mating behaviors and determine if mating marks could be produced during captive breeding.

MATING MARKS RESULTS AND DISCUSSION

Over three spring mating seasons from 2002 to 2004, 118 female crabs were mated during the laboratory experiments. The duration of the premating embrace was variable: some females molted within a day of being embraced by a male whereas other males embraced a single female for 10 days. During 2002, 8 males were mated with 3 females each to test if multiple mating events would affect the formation of mating marks. The experiments of 2003 were designed to test if the competition between males could affect mating mark formation and 18 mating trials were conducted. These experiments involved placing a premolt female in a tank with three males and recording the victor male through visual observation and video recording. Additional competitive matings were conducted in 2004 using a natural sand or gravel substrate, but in these experiments, a single male was allowed to grasp a female in a premating embrace and another male, either larger or smaller, was then added.

Analysis of data collected in these studies is only preliminary, but we were surprised to find that none of the males showed clear evidence of mating mark formation as a consequence of the controlled matings that we generated in the laboratory environment. Several interesting behaviors were described that could have conceivably produced marks on the males' claws, but none of these behaviors generated marks on claws that were similar to the marks observed on field-collected crabs captured during the spring mating season. If mating marks are indeed the result of male-female interactions and abrasions that take place during the period of the mating premating embrace, then our laboratory mating experiments may not have been sufficiently similar to the conditions under which crabs are actually found in premating embraces. Alternatively, perhaps formation of mating marks requires that a male spend considerably longer cumulative time in a premating embrace than was typical in our laboratory experiments. Based on the average duration of the premating embrace and actual mating activities and the approximate duration of the spring mating season, Hankin et al. (1997) concluded that an individual male may mate with up to 6-12 females in a given mating season.

During the mating experiments of 2003 and 2004, when up to three males were allowed to compete for a single female, some extremely competitive behavior among males was observed. Frequently, males would vigorously fight for the premolt female, often dislodging a female from a premating embrace with a competing male. In 10 of the 18 experiments conducted in 2003, when a premolt female was added to a tank containing three males of different or similar size, the largest male was the victor. In 2004, 70% of the competitive matings resulted in the larger male seizing the premolt female.

In contrast to laboratory experiments that failed to generate clear evidence of so-called mating marks, at-sea observations of apparent mating marks were made throughout the 2004 mating season. On fourteen days, 3,467 legal- and sublegal-sized crabs ranging from 122.5 mm to 198.2 mm carapace were collected and examined for mating mark presence. When male crabs were being examined, the condition of the inner surface of the claw was described as belonging to one of three classes: definite mating marks present, slight mating marks present, and mating marks absent. Mating mark frequency on sublegal-sized and legal-sized crabs generally increased as the mating season progressed, but on a given day the percentage of crabs with mating marks, including those with slight marks was similar for the two size categories of crabs (Figure 1). These observations are at odds with those of previous researchers (e.g., Smith and Jamieson 1991 and others) who found that mating mark frequency was much higher in sublegal crabs. Mating mark frequency did increase throughout the spring mating season, suggesting that mating mark formation is indeed associated with the annual mating season. The percentage of crabs with mating marks, including those classified as having slight marks, peaked on 16 April 2004, when 79% of sublegal-sized crabs and 66% of legal-sized crabs were found to have mating marks. During July, the percentage of sublegal crabs with mating marks reached 95%.

Photographs were taken to detail the range of mating mark characteristics as the degree of abrasion or scratches varied considerably among individuals. In addition, crabs that were examined in April were tagged as a part of the Dungeness Crab Tagging Project and these individuals were examined again upon recovery. Mating marks present on these crabs have been classified into 2 or 3 distinct types. Currently, these data on variable mating mark severity and characteristics are being analyzed by crab size. Preliminary analysis suggests that mating marks are much more severe in smaller sublegal crabs compared to larger legal crabs.

Old-shell crabs were found on every day of examination. These crabs are characterized by epizootic fouling (barnacles), worn shells and black discoloration at joints (see Hankin et al. 1989). On these old-shell crabs, mating mark occurrence was extremely high. Mating marks on such old-shell crabs can complicate interpretation of the observed frequencies of crabs with mating marks if shell condition is not first accounted for. For example, during the at-sea observations of mating marks on 25 January 2004, of the 172 sublegal-sized crabs examined, 9 crabs had mating marks. This finding was surprising because the mating season typically does not begin until late February. However, 8 of the 9 crabs with mating marks were classified as old-shell; thus, their mating marks had been generated during the previous year.

Our inability to create so-called mating marks in laboratory experiments, the relatively small and inconsistent different between mating mark frequencies on sublegal-sized and legal-sized male Dungeness crabs, and the confounding effect of skip-molt males on potential use of mating marks as an indicator of mating success, have heightened our skepticism that mating marks are an indicator of mating success, much less a reliable indicator of mating success. We intend on publication of a paper that calls into question the use of the marks as an indicator of mating success. In northern California, at least, there is absolutely no empirical evidence that the intensive fishery on males has resulted in low mating success among large adult females. Oh and Hankin (2004) presented compelling evidence for nearly 100% mating success among large (> 140 mm CW) females following the 1997 fishing season in northern CA, and an essentially identical finding was previously reported by Hankin et al. (1997) following the 1995 mating season.

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Table 1. Summarized release and recovery data through August 2004. Numbers of sublegal and legal crabs tagged are reported by six tagging sessions from Fall (November) 2001 through Spring (April) 2004. Numbers of recoveries are classified by the fishing season of recovery (typically 01 December – 31 July) and whether the recoveries occurred before or after the Spring tagging session of that respective season.

Season of Tagging	Size at Tagging	Number Tagged	2001-2002 Fishing Season		2002-2003 Fishing Season		2003-2004 Fishing Season		
			Recovered Dec. 1 – April 1	Recovered April 1 – July 31	Recovered Dec. 1 – April 1	Recovered April 1 – July 31	Recovered Dec. 1 – April 1	Recovered April 1 – July 31	Totals
Fall 2001	sublegal	520	98	6	0	0	0	0	104
	legal	793	200	14	0	0	0	0	214
Spring 2002	sublegal	1198		68	2	0	0	0	70
	legal	148		11	1	0	0	0	12
Fall 2002	sublegal	713			69	4	2	0	75
	legal	1309			132	3	0	0	135
Spring 2003	sublegal	1513				67	14	0	81
	legal	451				40	17	3	60
Fall 2003	sublegal	676					78	0	78
	legal	1396					303	10	313
Spring 2004	sublegal	1069						73	73
	legal	949						231	231
Totals		10735	298	99	204	114	414	317	1446

Table 2. The number of crabs tagged by six tagging sessions from Fall 2001 through Spring 2004 and recoveries expressed as a percentage of original numbers marked and released. See Table 1 for further explanation.

Season of Tagging	Size at Tagging	Number Tagged	2001-2002 Fishing Season: Recovered Dec. 1 – April 1	2001-2002 Fishing Season: Recovered April 1 – July 31	2002-2003 Fishing Season: Recovered Dec. 1 – April 1	2002-2003 Fishing Season: Recovered April 1 – July 31	2003-2004 Fishing Season: Recovered Dec. 1 – April 1	2003-2004 Fishing Season: Recovered April 1 – July 31	Totals
Fall 2001	sublegal	520	18.85	1.15	0	0	0	0	20.00
	legal	793	25.22	1.77	0	0	0	0	26.99
Spring 2002	sublegal	1198		5.68	0.17	0	0	0	5.84
	legal	148		7.43	0.68	0	0	0	8.11
Fall 2002	sublegal	713			9.68	0.56	0.28	0	10.52
	legal	1309			10.08	0.23	0	0	10.31
Spring 2003	sublegal	1513				4.43	0.93	0	5.35
	legal	451				8.87	3.77	0.67	13.30
Fall 2003	sublegal	676					11.54	0	11.54
	legal	1396					21.70	0.72	22.42
Spring 2004	sublegal	1069						6.83	6.83
	legal	949						24.34	24.34

Table 3. A summary of tag loss for all tagged crabs recovered during the 2001-2002, 2002-2003, and 2003-2004 fishing seasons. Recoveries for the 2001-2002 season are excluded from this table because during the first year of the project several fishermen were removing one tag from project crabs prior to bringing them to recovery locations.

Season of Tagging	Size Category	Number Double-Tagged	Number Recovered with 2 Tags	Number Recovered with 1 Tag	Percent of recovered crabs missing 1 tag
Spring 2002	sublegal	1198	67	3	4.29
	legal	148	12	0	0.00
Fall 2002	sublegal	713	71	4	5.33
	legal	1309	129	6	4.44
Spring 2003	sublegal	1513	77	4	4.94
	legal	451	64	6	10.00
Fall 2003	sublegal	394	15	3	5.45
	legal	717	152	15	8.98
Spring 2004	sublegal	551	31	3	8.82
	legal	429	101	8	7.34

Table 4. Recovery rates of sublegal-sized and legal-sized Dungeness crabs tagged with 1 (single-tagged) or two (double-tagged) FLOY Model FD-68B anchor tags during the Fall 2003 and Spring 2004 tagging sessions.

Size Group/ Season of Tagging	Tag group	Number tagged	Number recovered	Percent recovered
Sublegal-Sized				
Fall 2003	single-tagged	282	32	11.35
	double-tagged	394	55	13.96
Spring 2004	single-tagged	518	39	7.53
	double-tagged	551	34	6.17
Legal-Sized				
Fall 2003	single-tagged	679	136	20.03
	double-tagged	717	167	23.29
Spring 2004	single-tagged	520	122	23.46
	double-tagged	429	109	25.41

More sophisticated analyses of tag recovery data will be carried out over the next year and will incorporate recoveries received during the 2004-2005 fishing season.

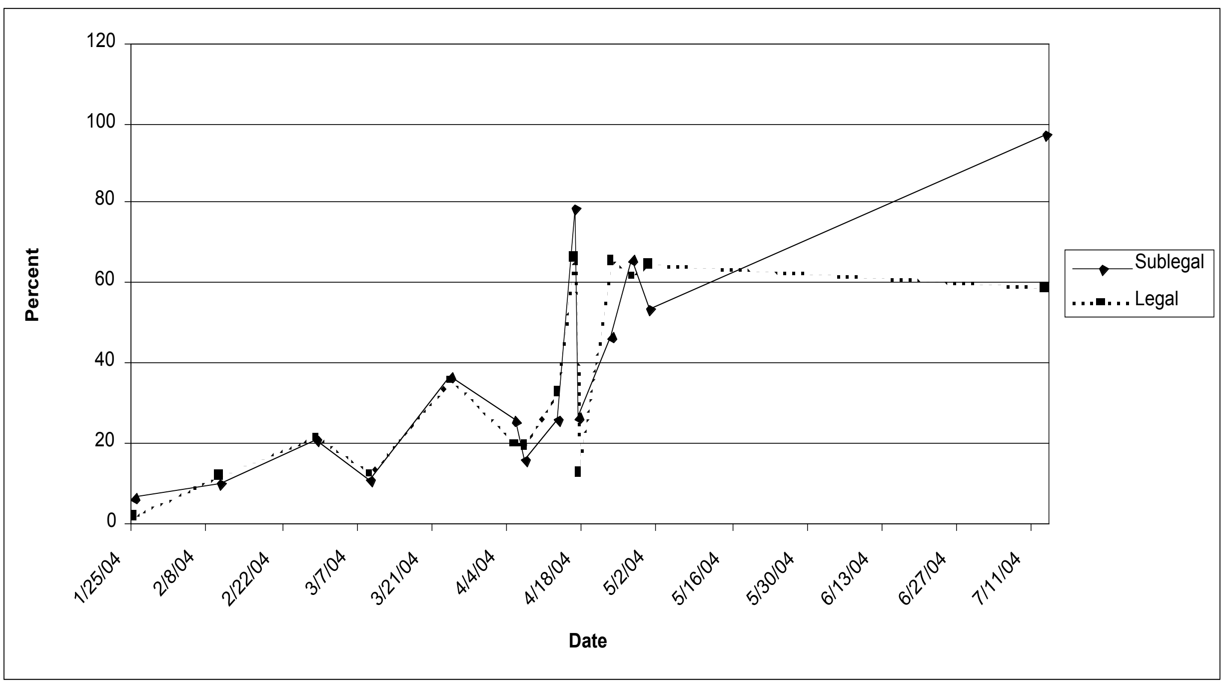

Figure 1. The percent of crabs, legal and sublegal, with noticeable mating marks (classified as having clear or slight marks) based on field observations made from 25, January 2004 to 14, July 2004 off Trinidad, CA.