Management of Dungeness Crab Fisheries

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Management of Dungeness crab fisheries in the states of California, Oregon, and Washington was reviewed by the Pacific Fishery Management Council in 1979 and may be considered in three categories: conservation of the resource, maintenance of product quality, and reduction of conflicts. Size limits and prohibition of landing female crabs are the primary conservation measures. Additionally, escape ports in the crab traps reduce wastage. Season closures maintain product quality by reducing the harvest of recently molted crabs. Area closures reduce conflict between commercial and recreational fishermen.

Current management measures seem sufficient to prevent biological overexploitation but may not be optimal. Size limits reduce the necessity for a prohibition on harvest of females. Size limit levels may be too large when enforcement, optimum yield and genetic selection issues are considered. Consideration of the optimal level of effort in the crab fishery is complicated by the multispecies nature of the west coast's fishing fleet. High crab abundance during the late 1970s resulted in an increase in the size of the crab fleet and a large fraction of legal-sized male crabs are now harvested in the first few weeks of the season. Efforts to deal with this apparent overcapacity must consider the great mobility of vessels between the crab, salmon, albacore, shrimp, and groundfish fisheries.

En 1979, le Pacific Fishery Management Council a évalué la gestion de la pêche aux crabes dormeurs dans les États de la Californie, de l'Oregon et de Washington. Celle-ci peut être divisée en trois catégories, soit la conservation des ressources, le maintien de la qualité du produit et la limitation des conflits. Les principales mesures de conservation sont l'imposition de limites de taille et l'interdiction de débarquer des crabes femelles. De plus, des ouvertures spéciales pratiquées dans des casiers à crabes permettent de réduire les pertes. L'imposition de périodes saisonnières de fermeture permet de maintenir la qualité des produits en réduisant la récolte des crabes qui viennent de muer. L'interdiction de la pêche dans certaines zones aide à réduire les conflits entre pêcheurs commerciaux et sportifs.

Les mesures de gestion pratiquées à l'heure actuelle semblent suffisantes pour empêcher la surexploitation biologique mais ne sont pas nécessairement optimales. Les limites de taille réduisent la nécessité de l'interdiction de la récolte des femelles. Les limites de taille imposées pourraient toutefois être trop grandes en regard de la mise en application des règlements, du rendement optimal et de la sélection génétique. La question du niveau d'effort optimal pour la pêche des crabes est compliquée par le grand nombre d'espèces pêchées par les flottes de la côte Ouest. L'abondance de crabes durant la fin des années 1970 a entraîné un accroissement des flottes de caseyeurs et une grande partie des crabes mâles de taille réglementaire sont maintenant capturés durant les premières semaines de la saison de pêche. Afin de régler la question de cette surcapacité apparente, il faut se pencher sur la question de la grande mobilité des navires entre les lieux de pêche aux crabes, aux saumons, aux germons, aux crevettes et aux poissons de fonds.

Introduction

There are two striking characteristics of Dungeness crab fisheries on the United States' west coast: the fishery in central California (San Francisco area) collapsed in about 1960 to 10% of previous sustained landings and has not recovered, and the fishery in northern California (Eureka area) has oscillated with a period of about 10 yr and an amplitude of more than a factor of 10. Fisheries in Oregon and Washington also have oscillated but with lesser amplitude. Studies of stock dynamics in California (Peterson 1973; Botsford and Wickham 1974, 1978; McKelvey et al. 1980; Wild and Tasto 1983) have not conclusively demonstrated whether these fluctuations are environmentally driven or due to density-dependent mechanisms (Botsford 1986). Regulations intended to conserve the stock were first enacted by the State of California in 1897–1905 and have been modified little since then. These regulations have a biological basis (Miller 1976) but have not been quantitatively scrutinized for their effect on stock dynamics. The Pacific Fishery Management Council (1979), which manages fisheries in the U.S. Fishery Conservation Zone along the coasts of California, Oregon, and Washington, examined the status of crab fisheries and considered options for improved management, but no action was taken. This paper explores justification for current regulations and describes characteristics of the fishery with regard to current interest in control of the level of effort in this and other west coast fisheries.

Fishery History

A recent review of Dungeness crab fisheries in California (Dahlstrom and Wild 1983) identifies commercial landings at San Francisco in 1863 and a substantial fishery using hoop nets by the 1880s. Landings increased from 882 metric tons (t) in 1889 to 1662 t in 1899 then peaked at 2318 t in 1904. During this period there were indications of declining catch rates in the immediate vicinity of San Francisco and area of the fishery expanded. In response to concerns for conservation of the resource, possession and sale of female crabs was prohibited in 1897, a 2-mo closed season was enacted in 1903 and a minimum size limit became law in 1905. These regulations were insufficient to reverse the stock's decline. Landings from 1905 through 1913, although undocumented, apparently declined. When landing statistics became available again in 1915, landings had declined to about 100 t.

Dungeness crab catch at San Francisco remained low (200–900 t) through the 1923–24 season. In 1925–26 landings increased to the level observed in the 1890s but did not attain 2300 t again until 1948–49. Landings ranged from 1000 to 4000 t during 1949–60 (Fig. 1) then collapsed and have not recovered. Current landings, about 600 t, are similar to those of the early 1920s.

Much effort has been directed towards determining the cause of the collapse of central California's Dungeness crab stock in the early 1960s (Wickham 1979; Wild and Tasto 1983). However, the decline in landings during 1905–13 suggests that the 1960s' collapse was not an unique event. Wild et al. (1983) suggests that persistence of warm water and anomalous northward transport after the 1957–58 El Niño caused poor recruitment in central California. This correlation is logical because Dungeness crab in central California are near the southern limit of the species' range. It is possible that earlier changes in abundance of this stock also were due to climatic shifts. Unfortunately, consistent and continuous measurements of marine environmental conditions do not extend prior to the 1920s. Douglas (1980) used tree ring data to infer high air and sea temperatures in southern California during the mid-1800s and Hubbs (1948) noted extreme northward range extensions of many subtropical species during 1853–60. The Dungeness crab fishery which developed in central California during the late 1800s may have been possible because cooler environmental conditions (Douglas 1980) occurred then. Figure 10 in Douglas (1980) indicates warmer water occurred again during the early 1900s. These sparse and indirect data suggest that climatic conditions may play a role in determining abundance of Dungeness crab along the coast of central California.

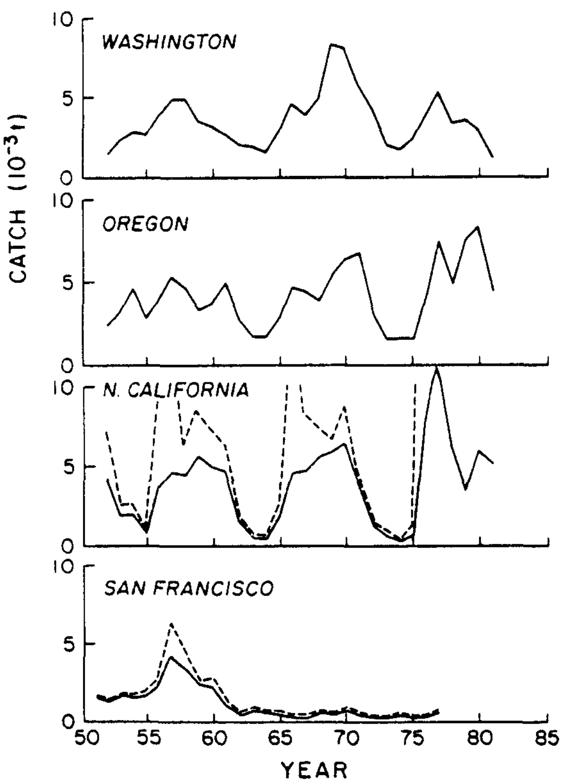

FIG. 1. Commercial landings of Dungeness crabs in California, Oregon, and Washington. Dashed line indicates pre-season abundance estimated form CPUE on cumulative catch (Methot and Botsford 1982). In northern California CPUE remained high throughout three seasons: 1956–57, 1965–66, and 1976–77, so pre-season abundance in these years must have been much greater than the catch.

A major Dungeness crab fishery did not start in northern California until the late 1930s. Expansion of this fishery began after 1941 when the canning prohibition and ban on export of Dungeness crab from several northern California counties were repealed. In the 1945–46 season the northern California catch first exceeded the central California catch. Since then northern California landings have oscillated between high catch periods of about 6 yr duration followed by low catch periods of about 4 yr (Fig. 1). Amplitude of the cycle has been increasing and the stock in 1984 seems near the end of the fourth high catch period which began in 1975–76. Landings off Oregon and Washington also exhibit a cyclic nature, but with lesser amplitude.

Development of Regulations

Management considerations in Dungeness crab fisheries include conservation of the resource, maintenance of product quality, and reduction in user conflicts. Regulations designed to achieve these goals now control size and sex of crab which can be landed, type of fishing gear, fishing areas and fishing seasons.

Concern over decline in stock abundance first became an issue in the San Francisco area during the 1890s. Possession and sale of female Dungeness crab by commercial fishermen was prohibited in 1897 to protect the resource from overfishing. This regulation remains in effect today in California, Oregon, and Washington. Only California's recreational fishermen may take female Dungeness crab.

Prohibition on female harvest preceded the size limit by 8 yr, but establishment of the size limit weakened the rationale for protecting females. Botsford (1984) concludes that the asymptotic mean size for females is 152 mm carapace width (excluding lateral spines) so few females are larger than the size limit. Females mature at about age 2 (90 mm) (Butler 1961) so they are mature for about 3 yr before approaching the legal size of 159 mm. Thus a size limit applied to males and females would have about the same effect as the current male size limit and female prohibition. Harvesting the few female crabs larger than 159 mm would increase yield little and may cause problems for industry because of claims (Pacific Fisheries Management Council 1979) that meat yields from female Dungeness crab are lower and that sexes would have to be separated before processing if females were landed.

The size limit for male crabs was established to protect crabs until they were mature, but there is no documented scientific analysis which determined the optimal size limit. In 1905 the limit was set at a carapace width of 152 mm (6 inches, including lateral spines). It is likely that processors' preference for large crabs was a factor in determining the level of this limit. The minimum was increased to 178 mm (7 in) in 1911 and the method of measurement was redefined slightly in 1915. In 1965 the measurement was redefined to 159 mm (6.25 in) excluding lateral spines without significantly changing the actual legal size of crab landed.

The size limit is an important constraint on the fishery. A large fraction of legal-sized male crabs are captured each year (Gotshall 1978a). Methot and Botsford (1982) examined decline in catch rate within each crab season and concluded that over 90% of legal-size male crabs were harvested in central California during each season from 1951 to 1955 and that exploitation rates greater than 80% were typical until 1964. In northern California, exploitation rate is commonly over 70%. Without the size limit a large number of smaller males also would be harvested and the possibility of overexploitation would be increased.

The appropriate size limit can be based on size at sexual maturity, yield per recruit, and enforcement problems if many crabs are near the size limit. Male crabs begin to mature at 108 mm and all males > 122 mm sampled in California are sexually mature (Poole 1967) and are about 2 yr post-metamorphosis (Collier 1983). This size is 2 molts below the size limit of 159 mm (Table 1), so males have about 2 breeding seasons before entering the fishery. Size at maturity seems similar to that in the north (Collier 1983) but growth rate (molt frequency) is slower so northern males may have 3 breeding seasons before entering the fishery. Recruitment overfishing probably is not occurring and would not occur if the size limit was decreased.

The proximity of the male crab size limit to expected size at age 4 (Table 1) suggests that genetic selection for slow-growing individuals may occur. Larger age 4 males are available to the fishery and high exploitation rates (Methot and Botsford 1982) indicate that large, available males are unlikely to survive to the following mating season. Slow growing males will be below the size limit at age 4 so are likely to survive and mate for one more year. Genetic selection on male Dungeness crab could be reduced by lowering the size limit to about 150 mm so most age 4 male crabs would be available to the fishery.

Yield per recruit cannot be calculated for male Dungeness crab because growth and natural mortality data are not sufficiently precise. Growth of crabs older than about 4 yr is based primarily on molt growth increment data and does not take into account the fraction of older crabs that do not molt annually. The estimated size at age in Table 1 and size-weight relation in Botsford and Wickham (1978) indicate that weight at age of male crabs that molt annually increases by 71% from age 3 to 4 and by 57% from age 4 to 5. If natural mortality is about 0.50 (61% survival) then mortality would approximately balance growth for 3–5 yr-old male crabs, but natural mortality is not precisely known. An early estimate of 0.15 per year (Jow 1965) is remarkably low for an animal that seems to reach maximum size by age 6-7. Gotshall (1978) estimated natural mortality to be in the range 0.54 to 1.78, and the Pacific Fisheries Management Council (1979) considered values in the range 0.15–0.45. Given this imprecision, yield per recruit cannot guide establishment of the optimal size limit, but the data suggests that extreme growth overfishing is not occurring.

TABLE 1. Growth of male crabs at three locations along the west coast. Data are from Collier (1983) who included the earlier work of Butler (1961). Tabulated values are calculated carapace widths of males after the indicated molt (instar). Ages (yr) are from Botsford (1984). Age 1 occurs in November after hatching the previous winter.

Instar number	Age (yr)	Central California	Washington	Queen Charlotte Island
10		72.7 mm	68.0	72.7
11	2	90.0	84.6	90.2
		108 mm — males begin to mature		
12		111.2	105.9	111.5
		122 mm — all males are mature		
13	3	136.5	129.2	137.1
		159 mm — males are available to the fishery		
14	4	163.0	154.9	164.5
15	5	190.9		193.7
16		220.3		224.9

Setting the size limit at a local minimum in the size distribution lessens enforcement problems by reducing incidence of crabs trapped near the size limit. Such an enforcement issue was considered in establishment of the size limit for Pacific bonito (Collins et al. 1980). On this basis the current size limit of 159 mm probably is too close to expected size at age 4 (Table 1). A limit of 150 mm is more nearly equidistant between expected size at ages 3 and 4 and could reduce enforcement problems associated with the size limit. Variation in growth (Botsford 1984) will make size modes less distinct and reduce the value of considering enforcement in setting the level of the size limit.

Other regulations assist in resource conservation. Some northern California bays and estuaries were closed to commercial crab fishing in 1933 and 1941. This regulation reduces conflict with recreational crab fishermen common in northern California bays and estuaries. In addition, prohibition of commercial crab fishing in northern California bays and estuaries, which have a high ratio of sublegal to legal size crabs, may reduce mortality of sublegal crabs associated with being captured and released. In central California, San Francisco and San Pablo bays are closed to commercial and recreational fishing to protect sublegal crabs.

Closed seasons conserve the resource by reducing harvest of soft-shelled (recently molted) crabs. If landed, these crabs would be a poor product and, if thrown overboard, they likely have higher mortality than hard crabs. The months of September and October were first closed in 1903. Currently season opening dates are: central California, second Tuesday in November; northern California, December 1; Oregon, December 1; and Washington, January 1 (but usually opens Dec. 1 by emergency regulation). Staggered opening dates are reasonable with regard to the north-south gradient in the date at which a high percentage of male crabs are hard (Pacific Fisheries Management Council 1979), but non-uniform opening dates cause enforcement problems. Closing dates now are in midsummer and vary somewhat among the states. Typically little fishing effort occurs during summer (Methot and Botsford 1982; Botsford et al. 1983) so the closing date has little effect on the fishery. Since 1981 California has experimented with season extensions through about August but little crab fishing effort occurred during the extensions.

Nearly the entire commercial crab harvest is taken in traps. In Washington and Oregon only traps and ring nets are legal gear. Gear restrictions are not specified in California but trawl vessels may have no more than 227 kg (500 lb) of Dungeness crab per landing. All three states require two escape ports in crab traps. These must be 108 mm (4.25 in) in diameter and be located in the upper half of the trap. Studies in Washington and Oregon (Pacific Fisheries Management Council 1979) indicate that this size retains nearly all legal-size crabs and releases many sublegals and females. Results of the Dungeness crab Research Program in California (Wild and Tasto 1983) indicate that an increase to 111 mm (4.375 in) would release about 50% more sublegal males and females with little increase in escapement of legal males. A change in the size limit to a local minimum in the size distribution should increase the effectiveness of escape ports.

About 10% of crab traps are lost each year. It is suspected that these traps continue to attract and capture Dungeness crab. California has a regulation requiring destruct devices on traps but implementation awaits development of a suitable device. The Dungeness crab Research Program (Wild and Tasto 1983) supported implementation of this regulation.

Commercial bottom trawling has been considered to be a source of mortality for Dungeness crab. Reilly (1983) monitored crab mortality aboard a commercial trawler in the San Francisco area. Overall mortality of crabs brought on deck was about 2% but soft-shelled male crabs had 20.2% mortality. The soft-shelled crabs often were crushed by the weight of the load of fish. Reilly (1983) lists several reasons why his observations probably underestimate crab mortality during normal fishing operations. Additionally, his study only addresses mortality of crabs retained by the net. Small crabs may be severely damaged as they pass through trawl mesh and recently molted crabs could be crushed by heavy trawl gear passing over them. California's Dungeness crab Research Program recommendation was to "Eliminate commercial trawl fishing in critical areas of the Gulf of Farallones during periods of peak molting (July–September) for male Dungeness crabs" (Wild and Tasto 1983). Fortunately, two factors reduce the likelihood of major crab mortality caused by bottom trawling. Trawlers cannot fish within 5.5 km (3 miles) of shore in California and they tend to fish in deeper water. Because Dungeness crab tend to occur in shallow water (Gotshall 1978b), much crab habitat is not vulnerable to bottom trawlers. Additionally, trawlers avoid crab areas because of the hazard presented to their nets by crab traps (Reilly 1983).

A second category of management measures concerns maintenance of product quality. Canning, pickling, or preserving crabs was illegal in the early years of the fishery and export of crabs from three northern California counties was prohibited (Dahlstrom and Wild 1983). The rationale for these regulations is uncertain but may be related to public health considerations because crab meat is highly perishable. Both of these regulations were repealed in 1941 and growth of the northern California Dungeness crab fishery began. The only current regulation affecting product quality is the closed season. Without this regulation a larger number of recently molted crabs, which have low meat yields, would be landed. Landing of softshelled crabs is prohibited in Washington.

The third category of management measures concerns reduction of conflict. Gear conflicts between crabbers and trawlers, salmon trollers and salmon gillnetters seems only a minor problem (Pacific Fisheries Management Council 1979). The crab fishery operates closer to shore than most trawl fisheries. In California trawling is prohibited nearshore in most areas and crab fishing extends into deep water only during the beginning of the season. The crab and salmon fisheries are separated in time. Little crab fishing occurs after opening of the salmon season in April or May.

Conflict, or at least competition, may occur between commercial and recreational crab fishermen. Regulations to reduce conflict between users include area closures and gear limitations. In Washington some areas of Puget Sound are closed to commercial crab fishing and the entire sound has a limit of 100 traps or ring nets per boat. In Oregon use of traps is prohibited in five major bays. In California major bays and estuaries are closed to commercial Dungeness crab fishing and this area closure extends 1.85 km (1 mile) into the open ocean at two northern California locations. These regulations tend to separate commercial and recreational fishing areas and greatly reduce the commercial fishing activity in juvenile crab nursery areas.

Current Fishery

Dungeness crab is one of the most valuable fisheries on the U.S. west coast. During 1980–83 the value of crab landings in northern California (Table 2) was exceeded only by the groundfish complex (flatfish, rockfish, cod, sablefish). Landings of shrimp during 1980–83 are down from their historical high during the late 1970s and salmon and albacore landings fluctuated by

TABLE 2. Value of landings ($US 10^{-3}) in central (San Francisco area) and northern (Eureka area) California in recent years. Data are preliminary and are subject to modification (California Dep. of Fish and Game).

	1980		1981		1982		1983		Mean	
	N.CA	C.CA	N.CA	C.CA	N.CA	C.CA	N.CA	C.CA	N.CA	C.CA
Crab	9127	590	6902	475	6606	638	6926	994	7390	674
Salmon	6861	4632	7590	5549	9150	7247	1966	1115	6392	4636
Albacore	1212	1107	4189	4212	625	358	731	1732	1689	1852
Groundfish	9342	3367	9873	4393	11742	6186	9216	4900	10044	4707
Shrimp	1318	1	1512	8	2058	3	147	0	1259	3
Herring	156	16416	56	4570	61	9647	45	12437	80	10768
Other	952	863	567	395	1018	1483	335	1028	718	942
Total	28968	26976	30689	19602	31260	25562	19366	22206	27571	23587

about a factor of 5 (Table 2). On a 10-yr time scale the value of Dungeness crab landings also has oscillated about 5-fold, even though changes in price tend to buffer the value of landings from fluctuations in catch (Botsford et al. 1983). During the 1968-69 and 1969-70 seasons the average value in California was $3,940,000 ($3.94 M), during the 1971-72 and 1972-73 seasons the average value was $1.17 M and during the 1979-80 through 1982-83 seasons the average value was $8.06 M (Table 2). The Dungeness crab fishery appears sufficiently valuable to warrant attention of fishery managers.

Evidence presented earlier suggests that current regulations are sufficient to prevent overexploitation of the stock. Recruitment overfishing seems unlikely with the prohibition on female landings and the size limit on males; growth overfishing probably is not occurring but yield per recruit cannot be estimated with available data. Changes in management should not be expected to improve the magnitude of the harvest. The low level of the central California stock and the large amplitude oscillations of the northern stocks currently must be treated as conditions which fishermen and managers react to, but do not control.

A major problem in the west coast's Dungeness crab fisheries is the large capacity of the fleet. West coast fishermen tend not to specialize so any attempt to redistribute excess crab fishing effort requires knowledge of the Dungeness crab fishing fleet in relation to other west coast fisheries. The following section will describe the characteristics and mobility of the crab fishing fleet, then the problem of excess fishing effort will be reexamined.

Dungeness crab tends to be fished by small, multipurpose vessels. Crab vessels usually are converted salmon trollers or bottom trawlers (Frey 1971) and may shift to other fisheries during the off-season for crab and during poor crab fishing years. In a 1968 survey, the mean lengths of crab vessels were 11 m in central California and 12 m in northern California (Dahlstrom and Wild 1983). The Pacific Fishery Information Network, PACFIN, database (Huppert et al. 1984) provides an opportunity for examination of the crab fleet composition during 1981.

In 1981, 1439 vessels landed Dungeness crab. Vessels were categorized into high and low income groups based on total exvessel value of all species, into principal species groups based on the species which contributed the greatest fraction of the vessel's total value and into regions based on the port at which the vessel landed the greatest value. Low income vessels (< $10,000 exvessel value) were small, about 9 m, and landed only 6.3% of the Dungeness crab in 1981. High income vessels with Dungeness crab as their principal species composed 31% of the crab fleet (Table 3) and landed 66% of the crab (Table 4). These vessels averaged 11.7 m in length. High income vessels with a species other than crab as their principal species landed the second highest fraction of crab, 28%, and composed 33% of the crab fleet. These vessels were slightly larger, 12.8 m, than the principal crab vessels. Much of the crab catch by high income, principally non-crab vessels was by 15-30 m vessels fishing in Oregon and northern California (Table 4). These larger multispecies vessels seem to be the major change in composition of the crab fleet between 1968 and 1981.

In 1981, 51% of high income vessels which landed crab obtained more income from another species. Fishermen may shift to different fisheries within and between years. Within year shifting is facilitated by the limited duration of several fisheries. Crab, salmon, shrimp, and herring fishing are limited by seasonal closures and albacore fishing is limited by seasonal migration pattern (Table 5). The timing of these seasons is sufficiently staggered so that a fisherman can fish during the peak of the crab, salmon and albacore seasons or the crab and shrimp seasons. The importance of within season switching in 1981 can be considered with the PACFIN database (Huppert et al 1984). The high income vessels which landed crab comprised only 6% of the fleet but landed substantial fractions of other species groups (Table 6): herring, 8%; groundfish, 12%; salmon, 13%; albacore, 19%; and shrimp, 37%. The high value for shrimp may be due to depressed shrimp landings since the late 1970s. This latter factor may have reduced the number of vessels which target on shrimp so those vessels which fish crab and shrimp land a large fraction of the total shrimp. This argument suggests that between year shifting out of the shrimp fishery has influenced the analysis within 1981. In years with poor salmon or albacore catch (i.e. 1983, Table 2), it is likely that a higher fraction of the catch of these species is

TABLE 3. Sizes of fishing vessels in 1981. Vessels are categorized according to total exvessel value of their landings (< or > $10,000), to the state of their principal port and their principal species. Principal port is defined by the total exvessel value of landings. Principal ports in California are divided at Monterey into a south region and a north region which contains the San Francisco and Eureka areas. Principal species is determined by the exvessel value of each species landed: CRAB+ indicates that a vessel's principal species was crab, CRAB− indicates that the principal species was not crab but some crab were landed, CRAB0 indicates that no crab were landed by that vessel in 1981. Weighted mean vessel length uses the vessel's crab catch as the weighting factor. Data are from the annual vessel summary file of the 1981 PACFIN database (Huppert et al. 1984).

	Vessel length class (m)					Length (m)	
	0–9	10–15	16–21	>21	Total Number	Mean	Wt. mean
		Exvessel value < $10,000					
CRAB+							
WA	141	41	3	0	185	8.1	8.4
OR	21	40	2	4	67	11.5	11.9
N.CA	62	42	3	1	108	9.4	10.2
TOTAL	224	123	8	5	360	9.1	9.6
CRAB−							
WA	25	10	0	0	35	9.0	8.9
OR	27	19	1	0	47	9.2	9.1
N.CA	46	20	1	0	67	8.9	8.8
S.CA	1	1	0	0	2	9.8	9.8
TOTAL	99	50	2	0	151	9.0	8.9
CRAB0							
TOTAL	8494	2463	140	39	11136	8.3	—
		Exvessel value > $10,000					
CRAB+							
WA	32	63	3	0	98	10.7	12.0
OR	22	145	8	1	176	11.7	12.0
N.CA	30	129	17	1	177	12.2	13.2
TOTAL	84	337	28	2	451	11.7	12.5
CRAB−							
WA	21	45	5	0	71	11.4	12.1
OR	21	93	43	7	164	13.8	15.9
N.CA	30	168	26	6	230	12.5	15.4
S.CA	3	6	2	0	11	11.7	15.9
TOTAL	75	312	76	13	476	12.8	15.4
CRAB0							
TOTAL	669	1480	458	216	2823	14.1	—

by vessels that also fish crab. Conversely, in years with low crab abundance a large amount of effort must shift to other fisheries. Continuation of the PACFIN database for several years should provide the information necessary for separation of between and within year shifts in effort. Better definition of between and within year effort shifting is critical as schemes to control effort in these fisheries are evaluated.

The number of vessels landing Dungeness crab in northern California has fluctuated similarly to the 10-yr cycle of catch (Botsford et al. 1983). At low points in the catch cycle (1954–55, 1963–64, and 1973–74) only 95, 117, and 93 vessels respectively have fished Dungeness crab. By the end of each high catch period the number of vessels had doubled: 196 vessels in 1951-52, 213 vessels in 1960-61, and 250 vessels in 1970–71. At the onset of the current high catch period in the 1975–76 season, the number of vessels increased at an unprecedented rate (299 vessels in 1975–76) and during the calendar year 1981, 418 high income vessels and 177 low income vessels fished crab in California (Table 3).

The number of vessels in the fishery influences seasonal distribution of catch (Table 7). The fraction of the season's catch landed in December through February has fluctuated between 50% and 90% during the 1960s–early 1970s (Methot and Botsford 1982). Higher values tend to occur at the end of the high catch periods as the number of vessels increases and at the beginning of the low catch periods as the vessels' exit from the fishery lags behind the decline in abundance (Botsford et al. 1983). Catch during the final months of the season tended to parallel the total season catch. This indi-

TABLE 4. Total crab landings (t) by vessels in 4 length categories. The vessels also are categorized according to total value of landings, the state of their principal port and whether their principal species was crab. See Table 3 for definition of categories. Data are from the annual summary file of the PACFIN database (Huppert et al. 1984).

	Landings (t)				
	Vessel length class (m)				
	0–9	10–15	16–21	> 21	Total
	Exvessel value < $10,000				
CRAB+					
WA	204.7	76.1	4.1	—	284.9
OR	28.8	71.0	4.7	7.1	111.7
N.CA	65.4	59.9	9.7	1.0	136.0
TOTAL					532.5
CRAB–					
WA	14.5	4.6	—	—	19.1
OR	11.2	8.4	0.1	—	19.8
N.CA	21.6	7.9	0.3	—	29.8
S.CA	0.1	0.1	—	—	0.2
TOTAL					68.9
	Exvessel value > $10,000				
CRAB+					
WA	209.1	955.7	57.3	—	1222.2
OR	169.4	1883.2	128.9	5.9	2187.3
N.CA	284.1	2085.9	454.4	32.6	2857.0
TOTAL					6266.6
CRAB–					
CA	43.5	157.3	9.4	—	210.3
OR	34.7	626.1	525.3	76.0	1262.2
N.CA	51.4	663.3	274.8	194.3	1183.8
S.CA	1.1	1.0	43.2	—	45.2
TOTAL					2701.5

TABLE 5. Seasonal distribution of landings (t) of major species groups which have strong seasonal patterns. The seasonal patterns for these species, except albacore, are dictated by closed fishing seasons. The tabulated values are for all of California in 1981 (preliminary data obtained from California Dep. of Fish and Game).

	Landings (t)				
	Crab	Salmon	Albacore	Herring	Shrimp
JAN.	657	0	0	2962	0
FEB.	244	0	9	1216	1
MAR.	79	0	< 1	83	0
APR.	109	3	0	< 1	375
MAY	64	767	0	< 1	450
JUNE	20	287	5	< 1	230
JULY	6	893	532	6	209
AUG.	7	602	3210	84	199
SEPT.	< 1	179	3157	0	289
OCT.	< 1	< 1	1648	< 1	97
NOV.	54	0	259	0	1
DEC.	2477	0	7	1492	1

cates that large early season harvests, which occurred in some high catch years, were not large enough to depress the late season harvests.

During the 1980s the late season catch was low despite high total season catches (Table 7). The number of vessels in the crab fishery is at a record high and the fraction of the total season catch landed during December through February also is at record levels. The fraction landed during December alone is at a very high level: 1980–81, 86%; 1981–82, 66%; and 1982–83; 77%.

The probable cause of the low late season harvests is reduction in abundance of legal-sized males caused by the large early season harvest. Historically the fishery has been able to land up to about 90% of legal males in a season (Methot and Botsford 1982). Currently they seem able to achieve this exploitation rate in the first few months of the season. Another possible cause for low late season catches is increased within year shifting of effort. As the catch rate of crab declines within the season the multi-purpose fishing vessels may be capable of making more money by shifting effort to salmon, shrimp or groundfish. Thus increased participation by multi-purpose fishing vessels may have exaggerated the within season fishery dynamics.

Packing the catch into the first few weeks of the season has several adverse consequences: competition between fishermen increases as each deploys more gear to get a share of the harvest, processors must freeze

TABLE 6. 1981 landings in California, Oregon and Washington of 6 important species groups by 6 categories of fishing vessels. CRAB+ vessels obtained most of their income in 1981 from Dungeness crab. CRAB− vessels landed some Dungeness crab but obtained most of their income in 1981 from a different species group. CRAB0 vessels did not land Dungeness crab in 1981. These data are from the annual summary file of the 1981 PACFIN database (Huppert et al. 1984)

Species group	Vessels with < $10,000			Vessels with > $10,000			TOTAL (t)
	CRAB+	CRAB−	CRAB0	CRAB+	CRAB−	CRAB0	
	Percent of landings						
Crab	5.6	0.7	0	65.5	28.2	0	9569
Salmon	0.3	0.8	25.9	4.2	8.8	60.0	17817
Albacore	<0.1	0.1	3.3	5.0	13.7	77.9	12973
Groundfish	<0.1	<0.1	1.1	1.0	11.1	86.7	113691
Shrimp	<0.1	<0.1	0.2	4.2	32.4	63.2	18139
Herring	<0.1	0.3	6.2	0.9	7.1	85.5	7013
	Percent of vessels						*N* vessels
	2.3	1.0	72.3	2.9	3.1	18.3	15405

TABLE 7. Trends in catch and effort in the northern California (Eureka area) Dungeness crab fishery (Methot and Botsford 1982; Botsford et al. 1983). Data for the seasons 1980-81 through 1982-83 are preliminary figures from the California Dep. of Fish and Game

Season	Total catch (t)	Percent in Dec.-Feb.	Catch in May-Aug. (t)	*N* Vessels
1960-61	4555	75	382	213
1961-62	1475	90	70	190
1962-63	409	82	29	124
1963-64	370	66	39	117
1964-65	1805	72	89	164
1965-66	4528	53	332	169
1966-67	4672	73	271	168
1967-68	5508	86	186	173
1968-69	5828	85	337	194
1969-70	6397	81	318	237
1970-71	3555	42[a]	476	250
1971-72	1153	88	87	190
1972-73	523	80	59	153
1973-74	160	46	26	93
1980-81	4691	99	31	—
1981-82	3672	94	50	595[b]
1982-83	1915	90	22	—

[a]Low harvest in January, probably price dispute between fishermen and processors.
[b]Number of crab vessels in calendar year 1981 from PACFIN database (Huppert et al. 1984).

more crab for longer periods, and distributors have only a brief supply of fresh crab. The foreshortened season may be the major problem with the Dungeness crab fishery (Meyer Resources Inc. 1983), but effort management schemes which would distribute the catch more evenly over the season will be difficult to evaluate and implement. The great decline in crab catch per effort within in each season (Methot and Botsford 1982) and the seasonal availability of opportunities to shift into other fisheries are two obvious complicating factors.

Excess capacity in the Dungeness crab fleet also may indicate a situation of economic overfishing. Total harvest seems to be divided among too many fishermen so the average profit per fisherman is less than it could be. Schemes for reducing effort in the crab fishery were considered by the Dungeness Crab Project of the State/Federal Fisheries Management Program (Collinsworth and Silverthorne 1976). The Project attempted to determine optimum level of effort (number of traps) for the coastwide fishery and considered three means of regulating effort at an appropriate level: licensing vessels and/or traps, taxes on landings, and quotas for individual fishermen. The Project did not explicitly consider the multispecies aspect of this fishery. The propensity of fishermen to shift effort between fisheries confounds economic analysis of effort limitation in any one of the fisheries. The concentration of crab fishing effort into the early part of the season may not be the optimal scheme for harvesting the crab resource, but fishing heavily on crab then shifting to other species may be the optimal multispecies fishery. An additional complication, if a license or individual quota scheme is to be implemented, is determining current fishery participants. This determination is hindered by the between and within year shifting of effort between fisheries. Not all potential crab fishermen will fish crab every year.

Interviews with fishermen indicate that crab fishermen do not feel that a major problem exists in the crab fishery (Meyer Resources Inc. 1983). The overcapacity problem is greater in the salmon fishery and recent poor shrimp abundance has created overcapacity in that fishery. The problem in the crab fishery is the shift of vessels from these other fisheries into the crab fleet.

The anticipated decline in crab landings over the next few years will have repercussions outside of the crab fishery. The great capacity of the current crab fleet probably will not hinder a recovery of the stock; the female prohibition and male size limit seem more than adequate to protect the reproductive potential of the stock. However, while the stock is at the low level, fewer vessels will be able to fish crab profitably. Vessels which currently are not able to operate profitably in the salmon or shrimp fisheries will not have the option of supplementing their income by fishing crab during the winter. As vessels leave the crab fleet during the mid 1980s, there seem few opportunities for them in other species. If the Pacific Fisheries Management Council is to consider management of the effort in the salmon and groundfish fleets, they must simultaneously consider the Dungeness crab fishery.

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