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SUMMER FOOD OF PACIFIC COD, *GADUS MACROCEPHALUS*, IN COASTAL WATERS OF SOUTHEASTERN ALASKA

The Pacific cod, *Gadus macrocephalus* Tilesius, is ecologically important in the Gulf of Alaska and may be more extensively utilized in future commercial fishing efforts. Although Pacific cod is one of the most abundant demersal fish in shallower (<200 m depth) waters of the Gulf of Alaska (Alverson et al. 1964; Ronholt et al.[1]), it has not been extensively fished. The total harvest of Pacific cod from the Gulf of Alaska (mostly by foreign fishing fleets) is estimated to be a "small fraction of the maximum sustained yield" and "substantially higher catches" could be supported (North Pacific Fishery Management Council[2]). Because of the recent establishment of the 200-mi United States Fishery Conservation Zone and a concurrent interest in bottomfishing, a domestic fishing industry may develop that could also exploit Pacific cod.

Little research has been done on the Pacific cod in Alaskan waters, especially concerning its foods. Most of the studies on Pacific cod have been conducted by Soviet investigators in the northwestern Pacific Ocean (summarized by Moiseev 1953). Jewett (1978) investigated the diet of Pacific cod near Kodiak Island, Alaska. In this note, I report the foods of Pacific cod in a different region of Alaska, southeastern Alaska.

Methods

Pacific cod were sampled during a cruise conducted by the National Marine Fisheries Service primarily to assess cod resources and evaluate different types of fishing gear used. During a 17-d period in July 1977, 520 Pacific cod stomachs were collected in two regions of southeastern Alaska coastal waters: 17 sites in the Gulf of Alaska between Cape Spencer and Yakutat Bay (outside waters, Figure 1) and 34 sites in protected waters between northern Lynn Canal and Frederick Sound (inside waters, Figure 2). Each site was sampled once.

Pacific cod were caught with traps (360 fish) and gill nets (160 fish) in water 38-176 m deep (Table 1). Most fish were caught in waters <90 m deep. Traps, 0.8×0.8×2.4 m rectangular structures with tunnel openings, were baited with chopped frozen Pacific herring, *Clupea harengus pallasi*, and set on the bottom. Gill nets, 180 m long, made of 15 cm or 17.5 cm diagonal-stretched-mesh monofilament, were set on the bottom or 0.6 m above the bottom. Both gear were set during daylight hours, fished overnight, and retrieved the

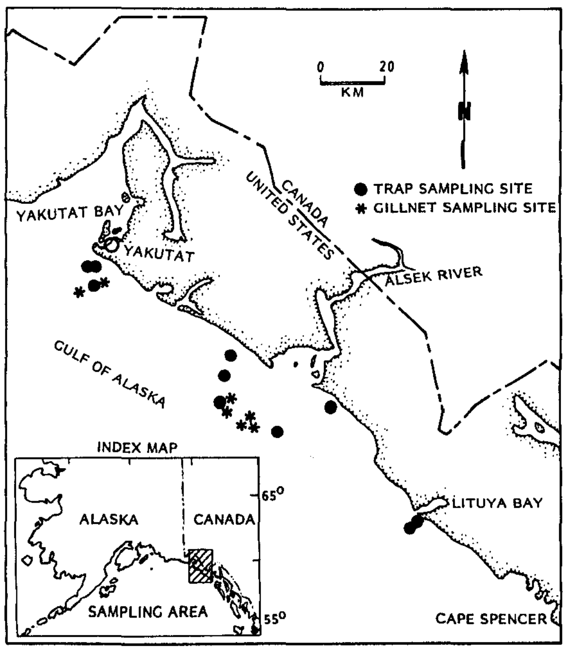

FIGURE 1.—Locations where Pacific cod were sampled in outside waters, southeastern Alaska, July 1977.

[1]Ronholt, L. L., H. H. Shippen, and E. S. Brown. 1978. Demersal fish and shellfish resources of the Gulf of Alaska from Cape Spencer to Unimak Pass 1948-1976 (a historical review). Processed rep., 955 p. Northwest and Alaska Fisheries Center, Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

[2]North Pacific Fishery Management Council. 1978. Fishery management plan for the Gulf of Alaska groundfish fishery during 1978. Unpubl. rep., 220 p. North Pacific Management Council, P.O. Box 3136DT, Anchorage, AK 99510.

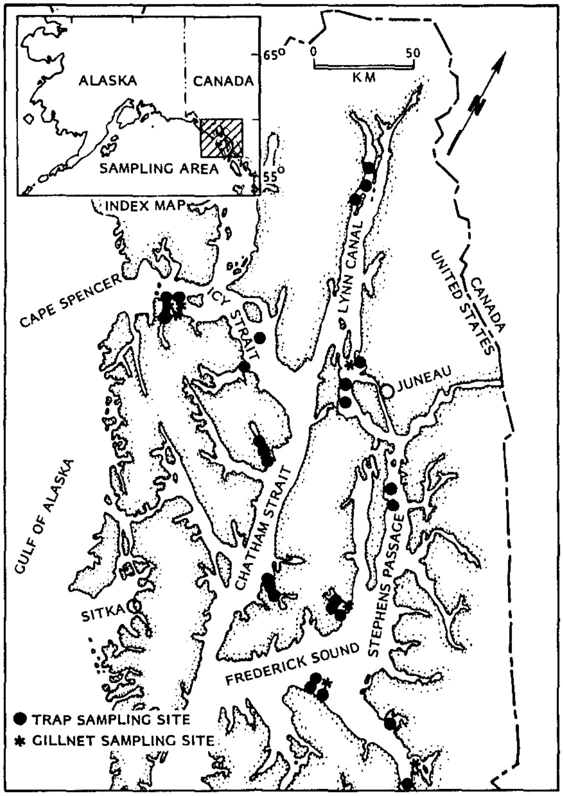

FIGURE 2.—Locations where Pacific cod were sampled in inside waters, southeastern Alaska, July 1977.

TABLE 1.—Summary of samples of Pacific cod caught in gill nets and traps in southeastern Alaskan waters, July 1977. Each site was sampled once.

	Caught in gill nets				Caught in traps			
Area	Sites (no.)	Mean depth (m)	Cod (no.)	Mean length (cm)	Sites (no.)	Mean depth (m)	Cod (no.)	Mean length (cm)
Outside waters	7	149	81	73.9	10	63	135	60.7
Inside waters	7	52	79	72.7	27	70	225	66.0
Both	14	101	160	73.3	37	68	360	64.0

next day. Usually, stomachs were removed from all Pacific cod caught, but random subsamples were taken from a few large catches. Stomachs and regurgitated or undigested food in the esophageal and mouth areas were preserved in Formalin.[3] The sex of each Pacific cod was identified, if possible, and the total length (TL, tip of snout to end of tail) was measured.

Estimated percentage volume of major food categories and frequency of occurrence of each food were determined. The volume of each major food category (i.e., fish, pandalid shrimp) was visually estimated to the nearest 5% for each stomach that arbitrarily appeared to be at least one-fourth full. Foods in stomachs less than one-fourth full were listed only as present and often were slowly digested items, such as fish otoliths or cephalopod beaks in trace amounts. No other allowances were made for stomach fullness. When pooling results, I averaged equally the percentages of each food in all stomachs one-fourth or more full. Visual estimates of the percentage volume of food in each category were generally within 10% of percentages determined by actual measurements of displacement volume. I identified all foods in all stomachs to the lowest taxonomic level possible and calculated the overall frequency of occurrence (expressed as the percentage of stomachs containing the food) of each food.

Volume data on each major food category were analyzed to determine whether relationships existed between foods eaten by Pacific cod and 1) size and sex of Pacific cod, 2) the location at which they were caught (inside waters vs. outside waters), and 3) the type of gear. I arbitrarily separated the Pacific cod into three total length categories to determine whether the different foods eaten were related to size of Pacific cod. The size categories were ≤60 cm, 61-70 cm, and >70 cm. Too few samples were taken at different depths in the same localities to allow analysis of Pacific cod foods by depth.

Results

If data from all areas are combined, regardless of size and sex of Pacific cod and gear type, fish were the most important food of Pacific cod both volumetrically and in frequency of occurrence. Fish accounted for more than 40% of the stomach contents by volume (Table 2) and were in nearly 60% of the stomachs (Table 3). The largest percentage of fish in the stomachs was unidentifiable; however, of the identifiable fish, Pacific herring and walleye pollock, *Theragra chalcogramma*, were eaten most often. Pacific herring ranged from 9 to 25 cm long (mean, 18 cm); walleye pollock, identified by their large and characteristic otoliths, were juveniles and ranged from 10 to 31 cm long (mean, 22 cm). Some of the unidentified fish were probably Pacific herring, pricklebacks

[3]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

TABLE 2.—Mean estimated percentage volume of foods in stomachs of Pacific cod in southeastern Alaskan waters, July 1977 (stomach fullness one-fourth or greater).

	All areas						Outside waters				Inside waters			
Food item	All fish	All males	All females	≤60 cm	61-70 cm	>70 cm	All fish	≤60 cm	61-70 cm	>70 cm	All fish	≤60 cm	61-70 cm	>70 cm
Fish	42.5	39.4	44.9	17.1	35.4	66.0	35.1	11.9	27.8	61.9	48.0	22.7	40.5	68.7
Crab	26.1	26.5	25.2	38.0	30.3	14.3	44.9	57.7	56.7	21.1	12.1	16.3	12.4	9.8
Shrimp	16.9	21.8	13.9	23.0	20.3	9.1	4.7	6.3	5.0	2.7	26.1	41.6	30.7	13.4
Pandalid	9.7	14.2	7.3	5.6	13.7	7.1	1.0	1.7	.5	.9	16.2	9.9	22.7	11.2
Crangonid	3.5	3.4	3.4	9.6	2.6	1.1	2.6	3.5	2.7	1.5	4.3	16.3	2.6	.9
Hippolytid	2.3	2.9	2.0	4.9	2.5	.6	.3	1.1	.1	0	3.8	9.2	4.0	.9
Unidentified	1.4	1.3	1.2	2.9	1.5	.3	.8	0	1.7	.3	1.8	6.2	1.4	.4
Gammarid amphipods	3.5	4.3	3.0	6.9	3.8	1.1	3.8	8.7	2.1	2.3	3.2	4.9	5.0	.2
Cephalopods	3.1	2.2	3.9	2.8	3.6	2.9	1.0	2.9	.5	.2	4.7	2.8	5.6	4.6
Mollusks other than cephalopods	1.7	1.2	1.9	2.7	1.8	1.0	.9	.7	1.5	.9	2.3	4.8	2.0	1.2
Polychaetes	2.2	1.1	2.9	3.0	2.3	1.7	4.2	5.0	3.6	4.3	.7	.8	1.4	0
Other food items and unidentified	4.0	3.5	4.3	6.5	2.5	3.9	5.4	6.8	2.8	6.6	2.9	6.1	2.4	2.1
Cod sampled (no.)	439	163	266	90	193	156	187	47	78	62	252	43	115	94
Mean total length (cm)	67.0	65.2	68.6	53.7	65.6	77.0	65.7	52.2	65.4	77.6	67.7	55.4	65.8	76.6

(Stichaeidae), and eelpouts (Zoarcidae), which are not as distinguishable as walleye pollock and may have been eaten more frequently than the values in Table 3 indicate. Flatfish (Pleuronectidae) were easily recognized and, because few were found, were probably not an important food for Pacific cod in these waters during July.

Crab and shrimp were the next most important foods. The volume of crab in Pacific cod stomachs was greater than the volume of shrimp; however, the frequency of occurrence of shrimp was greater than the frequency of occurrence of crab. Snow crab, *Chionoecetes bairdi*, the crab most often eaten by Pacific cod, were juveniles and ranged from 5 to 42 mm carapace width (mean, 20 mm). As many as 30 snow crabs were found in some stomachs. Dungeness crab, *Cancer magister*, was the only other crab eaten in more than incidental numbers. Pagurids (hermit) and other anomuran crabs were rarely eaten. Pandalid shrimp, particularly *Pandalus tridens* and *P. borealis*, were more frequently eaten than either crangonid or hippolytid shrimp, and all three families of shrimp were often found together in stomachs.

Other invertebrates were found in the Pacific cod stomachs, but their volumes and frequencies were small. Cephalopods were in more than 14% of the stomachs but constituted only 3.1% of the mean volume. Often only the cephalopod's horny beaks were present; however, whole *Octopus* sp. formed the bulk of the stomach contents of a few Pacific cod. Gammarid amphipods were in 14% of the stomachs. Pelecypods, mostly *Nuculana* sp., were infrequently eaten. The large polychaete *Aphrodita* sp. ("sea mouse") was found in some stomachs and composed most of the volume for the polychaetes. Planktonic foods, such as euphausiids or mysids, were rarely found and then, only in trace amounts.

At all locations, the size of the Pacific cod affected the kinds of food eaten (Table 2). Small Pacific cod (≤60 cm) fed mostly on crab and shrimp; only 17% of the estimated volume of their stomach contents was fish. Large Pacific cod (>70 cm long) fed predominately on fish (66% by volume). The diet of intermediate-sized Pacific cod (61-70 cm) was transitional between the diets of the small and large Pacific cod.

Sex of Pacific cod did not appear to be related to the major foods eaten (Table 2). Fifty-nine percent of the Pacific cod were females, 38.7% were males, and 2.3% were of unidentified sex. Females had a mean of 68.6 cm TL; males, 65.2 cm TL. The minor differences that did arise between the foods of each sex can probably be attributed to the greater mean length of females.

Foods of Pacific cod in outside waters were different from foods of those in inside waters (Tables 2, 3). Pacific cod in outside waters ate a larger volume of crabs (mostly juvenile snow crab) than those in inside waters; however, in inside waters, the volume of shrimp (particularly pandalid shrimp) in the stomachs was much higher than in outside waters. These differences in the volume of foods eaten were especially pronounced for small and intermediate-sized Pacific cod. All sizes of Pacific cod ate more fish in the inside waters than in the outside waters. Pacific herring, especially, were heavily consumed in inside waters.

The two gear (gill nets and traps) probably did not significantly bias the results. Comparison of foods in Pacific cod caught by gill nets and foods in

TABLE 3.—Frequency of occurrence of food items ≥1.0% in stomachs of 492 Pacific cod, southeastern Alaskan waters, July 1977 (based only on stomachs containing food).[1]

	Frequency of occurrence (%)		
Food item	All areas	Outside waters	Inside waters
Fishes	58.5	54.2	61.5
Clupea harengus pallasi	9.6	1.0	15.5
Theragra chalcogramma	8.7	8.5	8.9
Stichaeidae	2.8	.5	4.5
Unidentified stichaeids	2.2	.5	3.4
Pleuronectidae	1.8	2.5	1.4
Unidentified pleuronectids	1.0	.5	1.4
Zoarcidae	1.2	.5	1.4
Unidentified	36.4	38.3	35.1
Shrimps	46.5	24.9	61.5
Pandalidae	25.4	7.0	38.1
Pandalus tridens	5.5	4.5	6.2
P. borealis	4.7	0	7.9
P. danae	1.8	0	3.1
P. hypsinotus	1.6	0	2.7
Unidentified pandalids	15.2	1.7	24.1
Crangonidae	18.9	16.9	20.3
Crangon spp.	8.9	6.0	10.7
Argis sp.	1.0	2.0	.3
Unidentified crangonids	9.2	9.0	8.6
Hippolytidae	9.6	1.5	15.1
Unidentified shrimp	7.7	4.5	10.0
Crabs	39.6	62.7	23.7
Brachyuran crabs	32.3	58.2	14.4
Chionoecetes bairdi	26.2	44.8	13.4
Cancer magister	4.1	10.0	0
Hyas lyratus	1.0	1.5	.7
Unidentified brachyurans	2.2	4.0	1.0
Anomuran crabs	3.7	1.0	5.5
Unidentified pagurids	2.8	.5	4.5
Unidentified crabs	2.6	2.5	2.7
Cephalopods	14.4	9.5	17.9
Octopus sp.	4.1	1.5	5.8
Unidentified cephalopods	10.0	7.0	12.0
Gammarid amphipods	14.0	16.4	12.4
Pelecypods	11.4	7.5	14.1
Nuculana sp.	7.5	3.0	10.7
Unidentified pelecypods	3.3	3.0	3.4
Polychaetes	6.5	10.9	3.4
Aphrodita sp.	3.7	8.5	.3
Unidentified polychaetes	2.6	2.5	2.7
Gastropods	3.9	2.5	4.8
Natica sp.	1.2	2.0	.7
Unidentified gastropods	2.2	0	3.8
Algae	3.0	3.0	3.1
Euphausiids	3.0	0	5.1
Isopods	1.6	2.5	.3
Rocinela sp.	1.6	2.5	.3
Mysids	1.0	0	1.7
Unidentified food items	2.6	3.5	2.1

[1]Also present at frequencies <1.0%: Fishes—*Lumpenus maculatus*, *L. sagitta*, *Hippoglossoides elassodon*, *Lepidopsetta bilineata*, *Lycodes brevipes*, *L. palaeris*, *Dasycottus setiger*, *Coryphaenoides* sp., *Raja* sp. embryo, unidentified fish eggs; shrimps—*Pandalus stenolepis*, *P. goniurus*, *P. platyceros*; crabs—*Oregonia gracilis*, *Lopholithodes* sp., *Labidochirus splendescens*; cephalopods—*Rossia pacifica*; pelecypods—*Siliqua patula*, *Chlamys rubidus*, *Serripes groenlandicus*; polychaetes—*Abarenicola* sp.; gastropods—*Lora* sp., *Neptunea* sp.; barnacles—*Lepas* sp., unidentified barnacles; sipunculids; hydroids; ophiuroids; nemerteans; anthozoans; poriferans; foraminifera; unidentified invertebrate eggs.

Pacific cod caught by traps was difficult because the two gear, which tend to catch different sizes of fish, were frequently set at different localities or depths (Table 1; Figures 1, 2). However, when traps and gill nets caught similar-sized fish in the same areas, foods were also similar (see Table 4, Pacific cod 61-70 cm TL in outside waters and >70 cm TL in inside waters). In other cases, locality rather than gear appeared to be the overriding factor determining kinds of food eaten. Of the 24 Pacific cod sampled in the 61-70 cm TL gill net category in inside waters, 15 were taken in Idaho Inlet. There, Pacific herring apparently were so abundant that all sizes of Pacific cod caught in both gill nets and traps fed upon them.

The volume of gammarid amphipods in the stomachs of Pacific cod caught in traps may have been artificially high. Gammarid amphipods were almost exclusively found in Pacific cod caught in traps (Table 4). These amphipods were probably attracted to the baited traps where Pacific cod in the traps fed upon them. In contrast, other invertebrates, such as shrimp or crabs, appeared to be found equally in stomachs of Pacific cod caught in either traps or gill nets.

Discussion

The major foods identified in this study are similar to the major foods of Pacific cod in other regions of the North Pacific Ocean. Walleye pollock and Pacific herring were among the predominate fish species in stomachs of Pacific cod from Asian waters, and the crab *Chionoecetes* sp. was the most common invertebrate (Moiseev 1953). Flatfish and the sand lance, *Ammodytes* sp., however, appeared frequently in Moiseev's samples of Pacific cod stomachs but were rare or absent in my samples. The results of Jewett's (1978) study are in close agreement with the results of my study: he found fish, crab, and shrimp to be the most frequent items in Pacific cod stomachs collected near Kodiak, Alaska, during summer. In Jewett's study, walleye pollock was the most common fish eaten, and snow crab was the most common crab; Pacific herring were rarely eaten.

Other studies have demonstrated, as did my study, that larger codfishes become more piscivorous. As the size of Atlantic cod, *Gadus morhua*, increased, the diet changed from smaller invertebrates to larger fish (Powles 1958; Popova 1962; Rae 1967). Both Moiseev (1953) and Jewett (1978) found similar trends in their investigations of Pacific cod: cod <50-60 cm long ate mostly crustaceans; cod >60 cm primarily ate fish.

Some of the differences I found in foods of Pacific cod in outside and inside waters may be related to the availability of pandalid shrimp and Pacific herring. The results of my food study appear to reflect an increased abundance of both of these two foods in inside waters. Data from exploratory

TABLE 4.—Mean estimated percentage volume of food in stomachs of Pacific cod, by total length of cod and gear type, southeastern Alaskan waters, July 1977 (stomachs one-fourth full or greater).

	Outside waters						Inside waters					
	≤60 cm		61-70 cm		>70 cm		≤60 cm		61-70 cm		>70 cm	
Item	Nets	Traps	Nets	Traps	Nets	Traps	Nets	Traps	Nets	Traps	Nets	Traps
Fish	80.0	10.4	31.0	26.2	69.8	37.4	68.3	19.3	67.2	33.5	74.2	63.3
Crab	0	58.8	54.2	57.8	12.4	48.3	1.7	17.5	5.2	14.5	7.9	11.8
Shrimp	10.0	6.4	8.2	3.6	2.4	3.7	30.0	42.4	17.7	33.9	11.1	15.7
Pandalid	0	1.7	.6	.5	.4	2.4	30.0	8.4	16.2	24.2	8.0	14.5
Crangonid	10.0	3.6	3.0	2.6	1.6	1.3	0	17.5	1.5	2.9	1.5	.2
Hippolytid	0	1.1	.2	0	0	0	0	9.9	0	5.1	1.3	.6
Unidentified	0	0	4.4	.5	.4	0	0	6.6	0	1.7	.3	.4
Gammarid amphipods	5.0	8.8	.6	2.8	0	9.7	0	5.2	0	6.4	0	1.5
Mollusks												
Cephalopods	0	2.9	1.0	.3	.2	.3	0	3.0	9.6	4.5	4.6	3.5
Other mollusks	0	.8	0	1.7	.7	.3	0	6.0	.3	2.3	1.3	.9
Polychaetes	0	5.1	3.4	3.8	5.5	.3	0	0	0	2.0	.1	0
Other foods and unidentified	5.0	6.8	1.6	3.8	9.0	0	0	6.6	0	2.9	.8	3.3
Cod caught (no.)	1	46	25	53	47	15	3	40	24	91	47	47
Mean total length (cm)	44.0	52.4	65.4	65.4	78.8	73.7	58.3	55.2	66.9	65.5	76.4	76.7

trawling surveys indicate pandalid shrimp are very low in abundance in outside waters (Schaefers and Smith 1954; Hitz and Rathjen 1965; Ronholt et al.[4]). From 1969 to 1975, no pandalid shrimp were commercially landed in this area (Ronholt et al. footnote 1). However, in the inside waters of southeastern Alaska around Petersburg, near the southern portion of my sample area, pandalid shrimp have been fished commercially since 1916 (Barr 1970). In northern inside waters, pandalid shrimp have also been reported as abundant (Ellson and Livingstone 1952). Similarly, since commercial fishing records were first kept in the 1920's, Pacific herring have been abundant in inside waters south of Cape Spencer (Reid 1971). No catches of Pacific herring have ever been reported for outside waters north of Cape Spencer apparently because of the scarcity of Pacific herring in this area.

Acknowledgments

I thank Don Mortensen of the Northwest and Alaska Fisheries Center Auke Bay Laboratory, NMFS, and the crew of the NOAA Ship *John N. Cobb* who collected the samples for this study, H. Richard Carlson who provided guidance throughout the study, Bruce Wing who aided in invertebrate indentification, and Lin Sonnenberg and Evan Haynes who reviewed the manuscript.

[4]Ronholt, L. L., H. H. Shippen, and E. S. Brown. 1976. An assessment of the demersal fish and invertebrate resources of the northeastern Gulf of Alaska. Yakutat Bay to Cape Cleare, May-August 1975. NEGOA Annual Report, 183 p. Processed rep. Northwest Fisheries Center, Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Boulevard E., Seattle, WA 98112.

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USE OF GRIFFIN'S YIELD MODEL FOR THE GULF OF MEXICO SHRIMP FISHERY[1]

For analyzing the harvest of the Gulf of Mexico shrimp fishery, Griffin et al. (1976) have developed an equation that relates shrimp yield to freshwater discharge of the Mississippi River and fishing effort of Gulf shrimp vessels. The yield equation (referred to as Griffin's equation) is a modified Spillman production function (Heady and Dillon 1972). The Spillman function had its origin in agriculture where it was derived to predict the results of fertilizer experiments on tobacco yield in North Carolina. An important feature of the function is that it allows for environmental considerations in predicting yield. The modified form of the equation proposed by Griffin et al. (1976) is:

$$Y = \beta_0 D^{\beta_2} (1 - \beta_1^E) \qquad (1)$$

where Y = yield of shrimp (million pounds),[2]
D = average daily discharge of the Mississippi River during the months that shrimp are in their nursery grounds (cubic feet per second),
E = vessel effort (thousand units),
$\beta_0, \beta_1, \beta_2$ = parameters to be estimated from data of the fishery.

The coefficients of Equation (1) were estimated from individual vessel records collected by the National Marine Fisheries Service and from measurements of water flow rates on the Mississippi River for the years 1962-74. According to Griffin and Beattie (1978), the fit was quite good, namely: "All estimated coefficients were significant at the 1% level; R^2 was 78.5; and the Durbin-Watson statistic was 2.25. The simple correlation coefficient between catch and effort was 0.64 and between catch and discharge was −0.63."

Griffin's equation has found numerous uses in the Gulf shrimp management literature. Griffin and Beattie (1978) used the equation to estimate the impact of effort reallocation as a result of Mexican extended jurisdiction; the Gulf Coast Research Laboratory at Ocean Springs, Miss., (Christmas and Etzold 1977) used the equation for similar purposes; and the Center for Wetland Resources, Louisiana State University[3] used the equation to estimate maximum sustainable yield for management considerations.

Despite the extensive usage, users have not critically reviewed Griffin's equation. Such a review is necessary because of the large-scale potential impact of proposed shrimp management plans. In view of this need, therefore, I subjected Griffin's equation to such a review.

The review consisted of two tests relevant to the usage of Griffin's equation in management decisions. In the first test, I estimated the error in expected yield introduced by the typical user who ignored the fact that the independent variables—effort and river discharge—have variances. For convenience, this was termed the "expected value test." In the second test, I depicted the error in yield estimate that would result from misspecification of model parameter estimates. For convenience, this test was termed the "sensitivity test."

The results were mixed. The expected value test produced a large absolute error in expected yield of shrimp. However, when compared with expected yield, the error was proportionally small. The sensitivity test produced some startling results. Yield turned out to be very significantly sensitive to a fixed model parameter whose constancy was conceptually questionable in the first place. This extreme sensitivity of yield raises questions regarding the reliability of Griffin's equation as a shrimp management tool.

Each test is discussed below in detail.

[1]Contribution No. 80-54M, Southeast Fisheries Center, National Marine Fisheries Service, NOAA, Miami, Fla.
[2]The original equation was estimated by Griffin et al. (1976) in nonmetric units and its nonlinear nature excludes conversion to metric units.
[3]Louisiana State University. 1979. Draft fishery management plan for shrimp fishery. Prepared by Center for Wetland Resources, L.S.U., Baton Rouge, 226 p.