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Some consequences of variation in vessel density: a manipulative field experiment

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ABSTRACT

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Recent studies have examined factors which influence the spatial distribution of trollers. Implicit in all these studies is the assumption that increasing vessel density must diminish catch rates of vessels. Existing data often make it impossible to test this assumption because it is difficult to control other variables which may also be influencing catch success. Here, we experimentally manipulated the density of three trollers. The vessels in our study predominantly caught chinook salmon (*Oncorhynchus tshawytscha*), but also regularly landed coho salmon (*Oncorhynchus kisutch*) and spiny dogfish (*Squalus acanthias*). Vessel density had a significant influence on the catch of chinook salmon and spiny dogfish, although there was a significant interaction with tidal velocity. As vessel density increased, there was a decrease in the catch rates of chinook salmon and an increase in the catch rates of spiny dogfish. The catch rates for coho salmon were unaffected by our manipulations. Different responses by these species resulted in a significant change in catch composition with changes in vessel density. Our ability to manipulate vessel density was limited compared with that which is observed during the commercial fishing season. That these manipulations generate observable effects suggests that variation in vessel density may exert a substantial influence on catch rates during the commercial fishing season.

INTRODUCTION

Fishing vessels within a fishery are comparable with predators within any predator–prey system. As such, mechanisms commonly associated with the spatial distribution of predators should also apply to fishing fleets. In particular, foraging rates of predators are known to be affected by the density of predators and their prey (see Milinski and Parker (1991) for a recent review). Evidence of similar mechanisms is beginning to emerge for commer-

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cial fisheries. Previous analyses have demonstrated that catch per unit effort (CPUE) is associated with changes in fish abundance (Peterman, 1980; Peterman and Steer, 1981; Angelsen and Olsen, 1987).

Recently, there has been interest in understanding factors which influence the spatial distribution of fishing vessels (e.g. Hilborn and Ledbetter, 1979; Hilborn, 1985; Hilborn and Walters, 1987; Abrahams and Healey, 1990). Most models assumed that some inverse relationship must exist between catch rate and vessel density.

Abrahams and Healey (1990) suggested that the spatial distribution of the British Columbia salmon troll fleet could be described through a modified form of the ideal free distribution (IFD; Fretwell and Lucas, 1970; Fretwell, 1972). The IFD describes the spatial distribution of animals with respect to their resources. For animals to distribute themselves in accordance with an IFD, they must satisfy two assumptions. First, all animals must have perfect information about the distribution of resources in their environment. Second, all individuals should be equal in their competitive abilities such that they have 'free' access to these resources. When animals conform to these assumptions, they will distribute themselves so that they all receive an equal amount of the resource, regardless of where they occur. (Note that violations of these assumptions also generate typical spatial distributions; Fretwell, 1972; Abrahams, 1986; Houston and McNamara, 1988.)

An assumption of these models is that catch rates of vessels must be influenced by the density of competing vessels (in addition to the absolute abundance of fish), a phenomenon known as interference. Interference may be considered to be the slope of the relationship between predator density and catch rate. This phenomenon has been measured for invertebrate and vertebrate predators and has values ranging between 0.5 and 1.13 (Hassell, 1978).

Fisheries data collected through traditional methods make it impossible to determine whether a similar phenomenon exists within commercial fishing fleets. This is because other variables are often associated with changes in vessel density during the commercial fishing season (e.g. changes in the density of fish) which may account for any correlation between vessel density and catch rates. Here, we experimentally manipulated the density of a small group of trollers in order to directly measure the influence that vessel density has on the catch rate of commercial fishing vessels.

METHODS

Troll vessels off the coast of British Columbia fish for salmon (*Oncorhynchus* spp.) by hook and line, using six lines baited with lures, and flashers placed at different depths. Three commercial troll vessels were used for this experiment. All vessels were approximately 14 m long and employed standard commercial trolling gear. The fishing gear aboard each vessel was operated by two experienced, commercial fishermen.

For these experiments, the fishermen were instructed to fish exactly as they would during the commercial fishing season except for two constraints; all vessels must use the same gear configuration (explained below), and all vessels must fish at the same speed. To minimize the constraints imposed by our experimental procedure, observers were placed aboard each vessel to assist in controlling the vessel's location and to record the information required for our experiment. All vessels fished with six lines in the water and every line contained nine lures, each separated by a distance of 2 m. The top three lures were small spoons, the next three were plugs, the bottom three were flashers and 'hoochies' (soft plastic models intended to resemble squid).

Experiments were conducted off the west coast of Vancouver Island from 21 to 23 May 1989. Preliminary sampling by these vessels identified a concentration of fish at a fishing bank located approximately 17 km offshore (48°39′N, 125°25′ W).

These experiments measured the catch rates of these vessels at three different densities (low, medium, and high). Low density experiments had the vessels spaced approximately 500 m apart, at medium density the vessels were 250 m apart and at high density they were approximately 50 m apart. The first experiment of the day was low density. This provided a survey of our experimental area to confirm that the fish were still present. For each day, the order of the three densities was randomly selected. Experiments were then carried out through this random order for an entire day.

For each experiment, vessels were lined three abreast at a predetermined location along the fishing bank. These positions were accurately obtained using the Loran-C (TM) navigational system. Once all vessels were in the appropriate position for a particular density, they deployed their gear simultaneously. Onboard observers recorded the vessels' exact initial location, and the length of time for the gear to be fully deployed. The vessels fished three abreast, each proceeding along a specific Loran-C transect. Onboard observers monitored each vessel's navigational equipment to insure that the vessel remained on its specific transect line and one observer also monitored vessel locations relative to each other to insure a constant vessel density for the duration of the experiment. Landed fish were classified as either coho salmon (*Oncorhynchus kisutch*), chinook salmon (*O. tshawytscha*), spiny dogfish (*Squalus acanthias*), Pacific halibut (*Hippoglossus stenolepis*), or other (all other species), and their location on the gear was recorded.

After the vessels had fished a transect for 1 h, all gear was removed from the water. Observers recorded the length of time required by each vessel to remove all lines from the water, the location at which the vessel started to pull its gear, and the final location at which all gear was removed from the water.

Seventeen experiments were repeated as described above (five on 21 May, six each on 22 May and 23 May) with a different, randomly chosen, density and vessel positions. These experiments were conducted continuously from approximately 06:00 h to 18:00 h. Tidal information for these experiments was obtained from a Fisheries and Oceans tidal recorder located approximately 19 km northeast of the research site.

For statistical analysis, each experiment was considered an independent replicate. We used the catch rate for the vessel in the center position as the observation for each experiment since that vessel should be most affected by density manipulations. All parametric analyses carried out used the SAS GLM procedure. The model we tested examined the effect of density, tidal velocity, and their interaction on vessel catch rates. Since we did not have an equal number of observations for each experimental treatment, we used type III sums of squares to test hypotheses of equality of marginal means.

RESULTS

Over the duration of this experiment, coho salmon, chinook salmon and spiny dogfish were the species of fish predominantly captured by the trollers. Consequently, analyses of catch rates consider only these three species.

The catch rate data exhibited no significant deviation from a normal distribution for any of the species captured (Shapiro–Wilk statistic, $W > 0.945$, $P > 0.38$ for all species). At the low density treatment, no detectable differences in catch rates were observed for any of the species, both between days and between boats (Table 1). Therefore, any variation that existed in the abundance of fish through time would not be of a sufficient magnitude to generate changes in observed catch rates. Furthermore, no significant differences existed in catch rates between boats. Therefore the particular vessel

TABLE 1

Summary of two-way ANOVA statistics for the effect of boat and day on the catch rates of coho salmon, chinook salmon, and dogfish at low vessel densities. Error degrees of freedom for all reported statistics are 6

Species	Source	DF	*F*	*P*
Chinook salmon	Day	2	0.03	0.971
	Boat	2	0.52	0.621
	Interaction	3	0.42	0.747
Coho salmon	Day	2	0.46	0.637
	Boat	2	0.13	0.833
	Interaction	3	0.37	0.780
Spiny dogfish	Day	2	3.33	0.106
	Boat	2	1.76	0.251
	Interaction	3	0.06	0.991

DF, degrees of freedom.

which fished in the central position should not influence the results of these experiments.

The majority of the fish captured by our fishing vessels were chinook salmon (69.6%). Catch rate of the center boat was significantly influenced by the density manipulations ($F_{2,11}=4.45, P=0.038$) and tidal velocity ($F_{1,11}=4.61$, $P=0.055$). Although the general trend was for a decrease in catch rate with increasing vessel density (Fig. 1), the exact nature of this effect is difficult to interpret due to a significant interaction with tidal velocity ($F_{2,11}=5.04$, $P=0.028$).

Coho salmon and spiny dogfish made up a smaller proportion of the fish captured (22.2% and 8.6% of the catch, respectively). Furthermore, catch rates of coho salmon were not affected by variation in vessel density ($F_{2,11}=0.56$, $P=0.59$) or tidal velocity ($F_{1,11}=0.37$, $P=0.55$). Catch rates of spiny dogfish were affected by vessel density ($F_{2,11}=3.42$, $P=0.07$). Unlike the chinook salmon, the general trend was for an increase in catch rates with increasing vessel density (Fig. 1). As with the chinook salmon, however, the exact nature of this effect is difficult to interpret due to interaction with tidal velocity ($F_{2,11}=3.19, P=0.08$).

As the catch rates for spiny dogfish increased while the catch rates for chinook salmon declined with increasing vessel density, we tested whether vessel density had an influence on the overall catch composition. Catch composition was quantified using the Shannon–Wiener diversity index (Pielou, 1966).

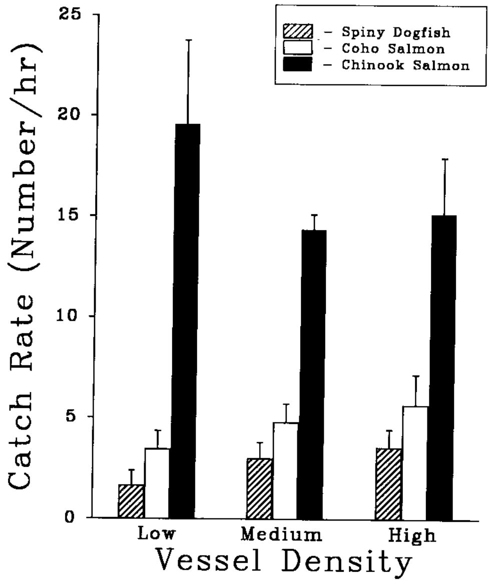

Fig. 1. Summary of the average catch rates for coho salmon, chinook salmon, and spiny dogfish at three different vessel densities. Error bars correspond to one standard error.

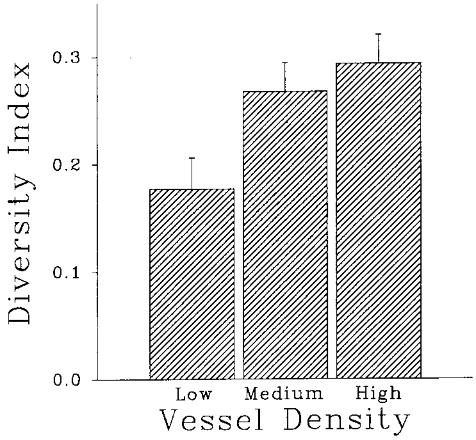

Fig. 2. Change in catch composition at different vessel densities as measured by the Shannon–Wiener diversity index. Error bars correspond to one standard error.

The Shannon–Wiener diversity index is derived from information theory and is calculated as $\Sigma p_i(\log p_i)$ where p_i is the proportion of the catch consisting of species *i*. The minimum value occurs if the catch consists of only one species. The index increases as the catch consists of an equal proportion of a large number of species.

The calculated values for the diversity index exhibited no significant deviation from a normal distribution (Shapiro–Wilk statistic, $W=0.960$, $P=0.62$). A significant effect existed for the influence of vessel on the catch composition of the central boat (ANOVA, $F_{2,14}=4.43$, $P=0.032$). An unplanned contrast among means tests indicated statistically significant differences in catch composition between the lowest and highest vessel densities (Scheffé's test, $P<0.05$). Catch composition increased with increasing vessel density (Fig. 2). Specifically, the catch was dominated by chinook salmon at low vessel densities. As vessel density increased, the proportion of coho salmon and dogfish increased with a corresponding decline in the proportion of chinook salmon.

DISCUSSION

When interpreting these data, two factors must be considered. First, these data are unique within fisheries science in that they are a result of an experiment to directly manipulate the density of fishing boats. Thus, it is easier to attribute cause and effect in our results rather than infer it from correlations. Second, only three vessels were used to measure the consequences of variation in vessel density on catch rates. With only three vessels and a highly variable catch rate, the size effect (the ratio of the difference in mean catch rates divided by the standard deviation; Cohen, 1988) was small, which limited the power of our experiment. During the commercial fishing season, 300–500 vessels may fish on the same fishing bank used for these experiments. Since interference is the measure of the relationship between vessel density and catch rate, and vessel density may increase by over 100 times that used in our experiment, the size effect observed during the commercial fishing season should be larger than we observed in our experiment.

The influence of vessel density on catch rates was complicated by interaction with tidal velocity. However, there appears to be a general trend for a decline in catch rates for chinook salmon with increasing vessel density, suggesting that fishing vessels are subject to interference. This result supports an assumption necessary to use ideal free models to describe and understand the spatial distribution of commercial troll vessels (see Abrahams and Healey (1990) for a more complete description of this model).

Catch rates for spiny dogfish responded in the opposite direction. These data suggest that spiny dogfish are more attracted to the lures used by trollers when they are presented at higher density. They may also be attracted to fish which are impaled on the trolling gear. Both these stimuli will increase in intensity as the vessels fish closer together. This result is of particular significance to trollers as they depend on obtaining a high quality catch which commands a higher price. Increased numbers of spiny dogfish around their gear may result in an increased proportion of their catch being mutilated by sharks.

It should be noted that catch rates of dogfish could not continue to increase indefinitely with increasing vessel density, but must eventually begin to decline. This is because a school fish can only occupy a finite space. As trollers must fish while in motion, they would have to spend an increasing amount of their time fishing away from the target school. Furthermore, increasing concentrations of fishing vessels will require fishermen to spend proportionally more time avoiding other vessels and their gear. Both factors would further contribute to reduced fishing efficiency at higher densities.

A consequence of interspecific differences to vessel density manipulations was a change in catch composition. Although it is impossible to determine whether this is a general phenomenon, this may have important implications for the understanding of fish populations. Catch per unit effort is the standard index used to estimate population abundance. However, these data suggest that this index will be species-specific and affected by tidal velocity and vessel density. Because our ability to manipulate vessel density was limited, it is difficult to estimate the magnitude of this effect. However, fisheries scientists should be aware that data obtained during the commercial fishing season may not only be affected by variation in the abundance of fish but also by the competitive processes associated with the fishery.

Through direct field manipulation, these data illustrate some of the potential complexities associated with the fishing process. Although our data are not definitive, they do point to areas worthy of further study, particularly how the competitive processes associated with a commercial fishery affect harvest rates and the information provided to fisheries scientists. A better understanding of the nature of fisheries data can only improve its interpretation.

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REFERENCES

Abrahams, M.V., 1986. Patch choice under perceptual constraints: a cause for departures from an ideal free distribution. Behav. Ecol. Sociobiol., 19: 409–415.

Abrahams, M.V. and Healey, M.C., 1990. Variation in the competitive abilities of fishermen and its influence on the spatial distribution of the British Columbia salmon troll fleet. Can. J. Fish. Aquat. Sci., 47: 1116–1121.

Angelsen, K. and Olsen, S., 1987. Impact of fish density and effort level on catching efficiency of fishing gear. Fish. Res., 5: 271–278.

Cohen, J., 1988. Statistical Power Analysis for the Behavioral Sciences. Erlbaum, Hillsdale, N.J., 567 pp.

Fretwell, S.D., 1972. Populations in a Seasonal Environment. Princeton University Press, Princeton, N.J., 217 pp.

Fretwell, S.D. and Lucas, H.L., 1970. On territorial behaviour and other factors influencing habitat distribution in birds. Acta Biotheor., 19: 16–36.

Hassell, M.P., 1978. The Dynamics of Arthropod Predator–Prey Systems. Princeton University Press, Princeton, N.J., 237 pp.

Hilborn, R., 1985. Fleet dynamics and individual variation: why some people catch more fish than others. Can. J. Fish. Aquat. Sci., 42: 2–13.

Hilborn, R. and Ledbetter, M., 1979. Analyses of the British Columbia purse seine fleet: dynamics of movement. J. Fish. Res. Board Can., 36: 384–391.

Hilborn, R. and Walters, C.J., 1987. A general model for simulation of stock and fleet dynamics in spatially heterogenous fisheries. Can. J. Fish. Aquat. Sci., 44: 1366–1369.

Houston, A.I. and McNamara, J.N., 1988. The ideal free distribution when competitive abilities differ: an approach based on statistical mechanics. Anim. Behav., 36: 166–174.

Milinski, M. and Parker, G.A., 1991. Competition for resources. In: J.R. Krebs and N.B. Davies (Editors), Behavioural Ecology: an Evolutionary Approach. Blackwell Scientific, Oxford, pp. 137–168.

Peterman, R.M., 1980. Dynamics of native Indian food fisheries on salmon in British Columbia. Can. J. Fish. Aquat. Sci., 37: 561–566.

Peterman, R.M. and Steer, G.J., 1981. Relation between sport-fishing catchability coefficients and salmon abundance. Trans. Am. Fish. Soc., 110: 585–593.

Pielou, E.C., 1966. The measurement of diversity in different types of biological collections. J. Theor. Biol., 13: 131–144.