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Dynamics of Native Indian Food Fisheries on Salmon in British Columbia

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Basic components of predation processes are briefly reviewed and data on these components are presented for several native Indian food fisheries. Depensatory mortality emerges as a common effect of these fisheries, which supports findings of earlier workers on Skeena River sockeye salmon (*Oncorhynchus nerka*). Native food fisheries therefore operate like natural "Type II" predators, and descriptive equations are provided for use by salmon managers and modelers.

Key words: fishermen as predators, native, Indian, food, fisheries, salmon, depensation

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L'auteur fait une brève revue des éléments de base de la prédation et présente, pour plusieurs pêcheries de subsistance pratiquées par les Indians, des données sur ces éléments. Comme effet commun de ces pêcheries, émerge une mortalité anticompensatoire, ce qui confirme les observations de chercheurs qui avaient déjà étudié le saumon nerka (*Oncorhynchus nerka*) de la rivière Skeena. Les pêcheries de subsistance des Indiens agissent donc comme prédateurs naturels de «type II», et on donne des équations descriptives pouvant être utilisées pour la gestion et l'élaboration de modèles de pêcheries de saumons.

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NATIVE Indian food fisheries for salmon (*Oncorhynchus* spp.) are important in British Columbia. Many communities have traditionally relied heavily on food catches of salmon, and the Federal government, as part of the salmonid enhancement program, is attempting to evaluate the impact of various enhancement schemes on native peoples. Also, harvest of salmon by native Indians most often occurs upstream as salmon approach spawning grounds. Because Indians are last in line to get a share of the catch, regulation of these fisheries is the last chance for fisheries managers to manipulate escapement levels.

Since 1955, reported food fishery catches in B.C. have ranged from 240 000 to 500 000 salmonids, of which 47 to 70% have been sockeye salmon (*O. nerka*) (McKay 1977). These catches compare with escapement figures for B.C. sockeye and total salmonids of 1–5.2 and 6–17 million fish, respectively. What is not obvious from these total figures is that food fisheries

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can, in specific cases, take a significant portion (>25%) of the fish that are in the river at the point where they are harvested. Several studies in the past have pointed out that food fisheries exert a depensatory mortality effect (Neave's 1953 term); in other words, a higher percentage of the fish is caught at low than at high fish abundance (Larkin and MacDonald 1968; McKay 1977). If common, this pattern is of concern to managers because it means that there is greater danger of underescapement in years of very poor total adult returns.

For these reasons it is important to understand the relation between food fisheries catches and abundance of fish. This paper analyzes responses of native food fisheries to fish abundance, using data from several areas in B.C. Commercial harvesting of salmon by native Indians is excluded from the present analysis; we are only concerned here with freshwater catches taken for food by Indians. The methods traditionally used for this harvest include dip nets, gaffs for hooking fish in pools, gill nets, and various trap mechanisms.

Fishermen as Predators

Various processes which occur in natural predator–prey relations have either been documented for, or included in, models of fishermen–fish interactions. Examples are competition (as implied by the standard exponential catch equation) and cooperation (Rothschild 1977), aggregation of boats in response to certain measures of fish abundance (Loucks and Sutcliffe 1978; Hilborn and Ledbetter 1979; Peterman et al. 1979), and changes in searching efficiency in relation to fish abundance (Paloheimo 1971; Paloheimo and Dickie 1964). With the exception of Ward and Larkin (1964) and Larkin and MacDonald (1968), few studies have attempted to determine the type of mortality (compensatory or depensatory) that results from the combination of these processes in human fisheries.

Here the comparison between Indian fishermen and natural predators will focus on the relation between percentage of food fishing mortality and abundance of fish, using annual data. There are three major components to this relation: the functional, numerical, and competition responses (Solomon 1949; Holling 1959). The functional response is the relation between number of fish consumed per predator per unit time and fish abundance. It reflects the change in efficiency with which prey are captured as fish abundance changes. Four basic shapes of functional responses have been identified and each is associated with a unique relation between prey numbers and percent mortality per predator (Holling 1959). Examples of three types are shown in Fig. 1. The numerical response shows how predator abundance varies with prey numbers, in particular here because of short-term aggregation responses. Finally, competition can occur among predators either directly through crowding or indirectly through depletion of the prey population. These processes are more thoroughly reviewed in a fisheries context by Peterman and Gatto (1978) and Larkin (1979).

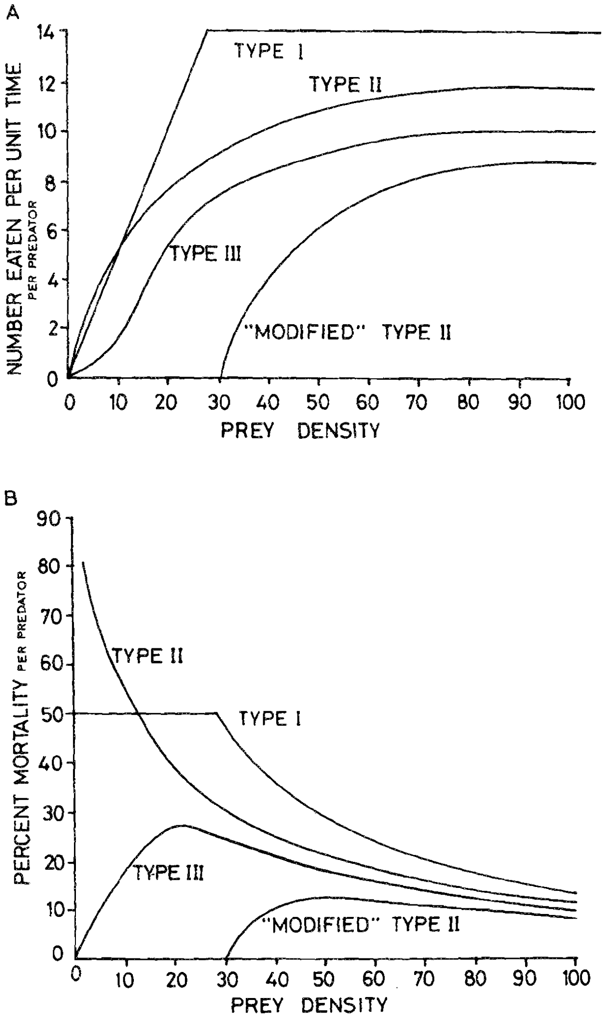

FIG. 1. Shapes of different types of functional responses (A) and their corresponding percent mortality curves (B). Reprinted with permission from Peterman and Gatto (1978).

Methods

SOURCES OF DATA

The relationships described above for natural predator were examined for Indian food fisheries on several stock of salmon in B.C., using data from 1947 through 1976 Annual catches and escapements for Skeena River fisherie were provided by Zyblut (E. Zyblut, Fisheries and Marin Service, Vancouver, B.C., 1976, personal communication). Fraser River sockeye food fishery catches, escapements, and permit data are from International Pacifi Salmon Fisheries Commission (IPSFC) Annual Report

Ricker and Manzer (1974), and McKay (1977). Annual catch data represent the reported freshwater catch only; illegal catch by native Indians is an unknown quantity and is excluded from this analysis. Fishing effort is expressed as number of permits issued per year, with usually one permit going to each family head even if several family members fish. Recently, permits have been issued to band councils instead (such as the band that harvests Birkenhead River sockeye) (McKay 1977). For the years discussed here, the major regulation on Indian food fisheries has been area closures, aimed at obtaining sufficient escapements.

Total numbers of fish available in the river were estimated by adding annual upriver escapements to reported annual Indian catches. This method assumes that there is no significant mortality agent (such as sportfishing) upriver between harvest areas and spawning grounds. Cases were carefully chosen to ensure that this assumption was met. Total escapements were used for all systems except the Harrison–Birkenhead, where jacks were subtracted from totals because the gill nets used there do not catch these immature adults (J. Woodie, International Pacific Salmon Fisheries Commission, personal communication). The size of the pool of fish which was to be harvested was then related to fishing effort, catch, and percent mortalities to see if regular, predictable patterns appeared which were analogous to those of natural predators.

TYPES OF RESPONSES

The numerical response was examined very simply. Effort levels were regressed on fish abundance of that same year, and separately on abundance of the previous year to determine if there was an aggregation response of fishermen.

The form of the functional response was identified by examining plots of the data and by fitting with a nonlinear least-squares procedure a generalized predation equation (C. S. Holling, University of British Columbia, Vancouver, B.C., 1975, personal communication):

$$y = (a \cdot X)/([b \cdot \exp(c \cdot X)] + X)$$

where X is fish abundance, y is catch, and a, b, and c are parameters. Certain parameter conditions lead to a Type III response ($c > 1/b$) and others ($c = 0$ and $< 1/b$) indicate a Type II. For cases where a Type II response was indicated, another equation with more biologically meaningful parameters was used. This equation is the Michaelis–Menten [$y = a \cdot X/(b + X)$], and its parameters were also estimated by a nonlinear, least-squares method. The parameter "a" represents the maximum catch and "b" is the fish abundance which results in half the maximum catch.

Results

NUMERICAL RESPONSE

Effort data were only available for sockeye salmon (*O. nerka*) food fisheries on the Harrison–Birkenhead, Chilcotin, Stuart, Nechako, and North Thompson rivers. In no case was there a tendency for any change in effort with changes in fish available at the location where harvesting is done ($P > 0.1$, all sample sizes >17). This is true for both regressions on present year abundance and previous year numbers. In other words, effort seems to be independent of fish abundance. There are two cautions in drawing this conclusion. First, there could actually be more members of each family fishing in years of greater fish abundance, and this would not be reflected by number of permits which have been until recently one per family. Second, the amount of time spent fishing per individual varies but is not accounted for by number of permits issued.

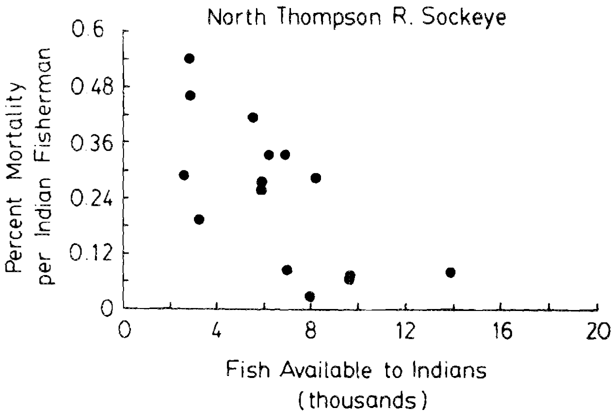

FIG. 2. Percent mortality per permit as a function of fish abundance for food fishery on North Thompson River sockeye salmon.

FUNCTIONAL RESPONSES

Any reporting errors would make it difficult to distinguish between the different types of functional responses if we only examine plots of catch per effort as a function of prey abundance (see Fig. 1A). However, the distinction is more easily made if we plot percent mortality per unit effort as a function of fish abundance (Fig. 1B). When this is done, four of the five rivers show clear depensatory mortality; i.e., higher mortality per unit effort at low than at high fish abundance (example in Fig. 2). These four cases are sockeye fisheries on the Chilcotin, Nechako, North Thompson, and Stuart rivers. This monotonically decreasing percent mortality per unit effort conforms to Neave's (1953) depensatory mortality and the so-called Type II functional response (Holling 1959). This type of response is most clearly illustrated by the catch per effort curve for the Stuart River sockeye fishery (Fig. 3).

Parameter values estimated for the Holling generalized predation equation support the above conclusion that a Type II response is the best explanation of most of the data. In no case was there the parameter condition which indicates a Type III response. Data for the five species caught on the Skeena, and sockeye of the Nechako and Harrison–Birkenhead rivers are widely scattered, or measured over a relatively narrow range of fish abundances; for these cases *all* types of responses fit equally poorly. But in the other stocks, Type II responses were clearly indicated.

It should be noted that there is some concern that

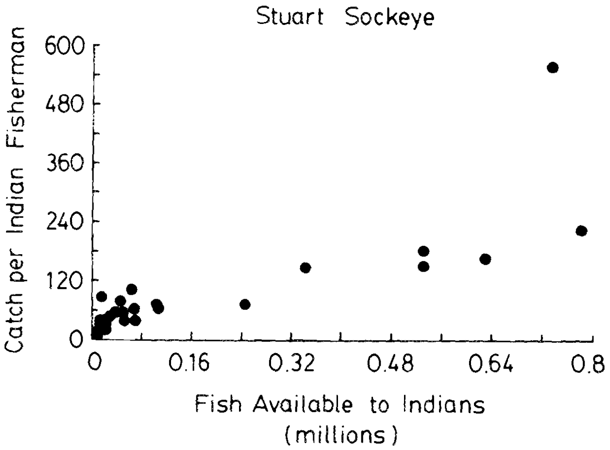

FIG. 3. Indian food catch per permit in relation to fish abundance for Stuart River sockeye salmon.

recent years of high salmon prices may have resulted in higher-than-normal catches (J. Woodie, IPSFC, 1977, personal communication). However, fishing mortality rates since 1973 have *not* usually been higher, *for a given abundance of fish in the river*, than in previous years. Hence the present analyses are not biased upward. The effect of higher prices on unreported catch is another matter, outside the scope of this paper.

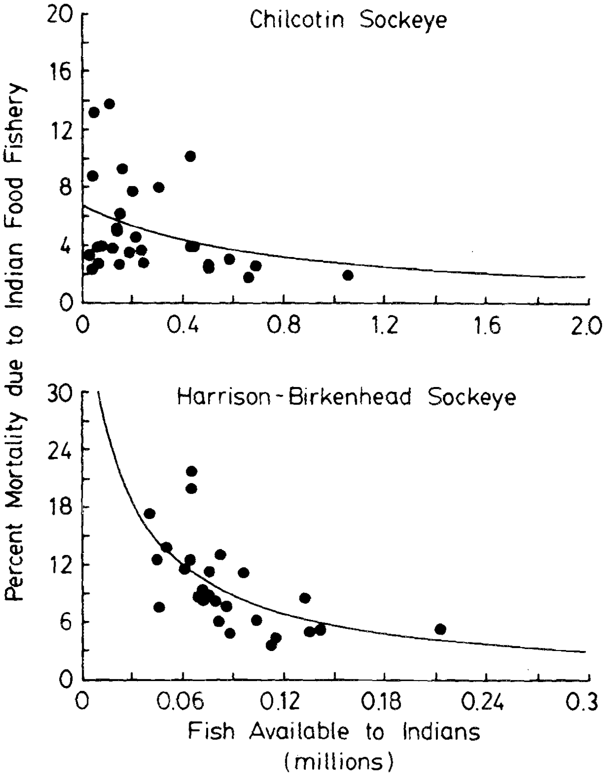

FIG. 4. Total percent mortality from Indian food fisheries as a function of fish abundance for Chilcotin and Harrison–Birkenhead rivers sockeye.

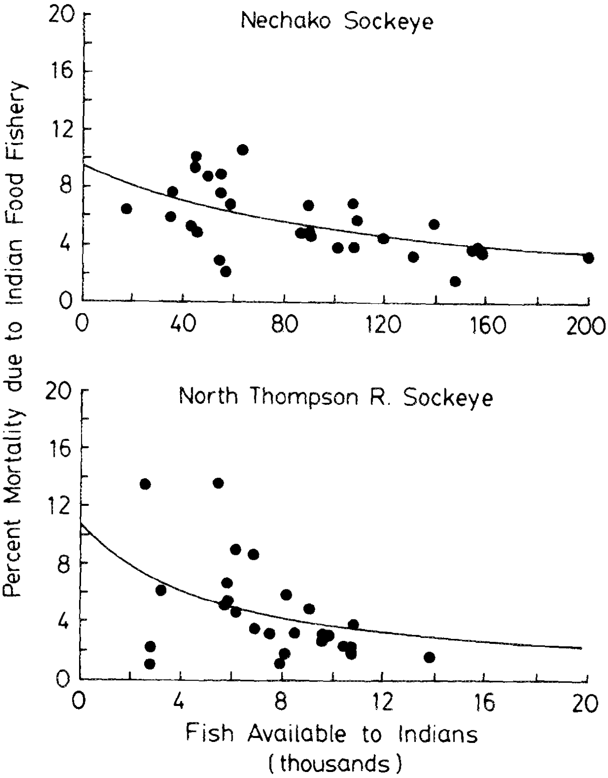

FIG. 5. Total percent mortality from Indian food fisheries as a function of fish abundance for Nechako and North Thompson rivers sockeye.

TOTAL RESPONSE

The product of effort levels and functional responses gives the total response of the Indian food fisheries. Data for several stocks in Fig. 4–6 show the depensatory nature of this harvesting process. Most striking is the relation between percent mortality and fish abundance for the total Fraser River sockeye (Fig. 6B); there is a surprisingly good fit despite variance contributed by occasional closures. Table 1 lists parameter values fo the form of Michaelis–Menten equation used to describe these relations, plus the sum of squared deviation of data from this relation, and sum of squared deviations from fitting just the arithmetic mean. Forma *F*-tests cannot be used to compare these sums of square because one parameter enters nonlinearly in th Michaelis–Menten equation. However, any reductio in sums of squares is useful from a management poin of view, because predictability is improved.

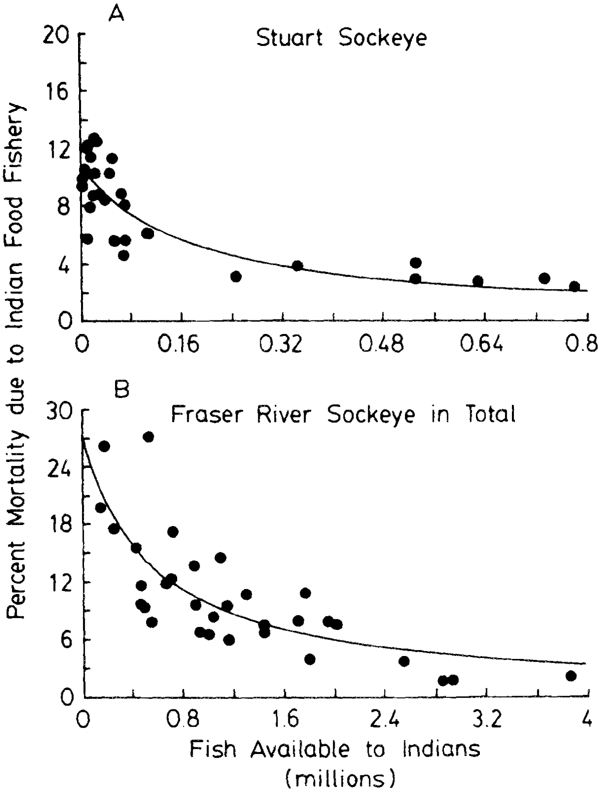

FIG. 6. Total percent mortality from Indian food fisheries as a function of fish abundance for Stuart River (A) sockeye and total Fraser River system sockeye (B).

Discussion

Findings in this study show that many Indian food fisheries act as depensatory mortality agents, as shown earlier for two sockeye fisheries by Larkin and MacDonald (1968). However, it cannot be assumed that these food fisheries take essentially a constant catch. Figure 7 shows that for the Stuart sockeye fishery, catches do drop off as fish abundance decreases, despite the fact that percent mortalities increase.

TABLE 1. Parameter values and sums of squares for the relation between total percent mortality due to Indian food fisheries and fish available, corresponding to Fig. 4–6. The equation for this relation is $Y = a \cdot 100/(b + X)$, where Y is in percent mortality and X is number of fish available. SS $\bar{x}$ is sum of squares for fitting with the mean percentage of mortality and SS equation is for fitting with the above relation. Skeena stocks are omitted because they do not clearly show the depensatory mortality pattern.

Species	River	a	b	SS $\bar{x}$	SS eq.
Sockeye	Chilcotin	47575.4	715988.0	298.0	262.0
Sockeye	Harrison–Birkenhead	9860.3	23076.0	566.0	340.0
Sockeye	Nechako	10949.0	117080.0	159.0	112.0
Sockeye	North Thompson	577.5	5314.9	284.0	236.0
Sockeye	Stuart	18775.0	175520.0	321.0	102.0
Sockeye	Fraser (total system)	149988.0	550208.0	1187.0	472.0

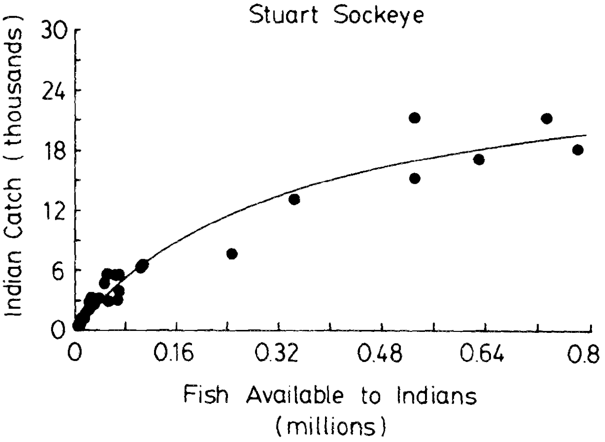

FIG. 7. Total Indian food fishery catches of Stuart River sockeye in relation to fish abundance.

Relations such as the ones shown here are potentially useful for salmon managers because percent removals by food fisheries can be reasonably well predicted, if numbers of fish escaping past commercial fisheries can be estimated from test fisheries. Desired escapements can therefore be more accurately achieved.

Relatively large percentages of fish available in the river can be removed by food fisheries at low fish abundance: 27% for Fraser sockeye, 17% for each of Skeena chinook, chum, and coho salmon. These significant precentages can help to keep small or declining runs down and affect their population dynamics, to the point of helping to maintain cyclic dominance (Ward and Larkin 1964; Larkin 1971).

The shapes of the observed relations are interesting from a theoretical viewpoint as well. The close correspondence between the form of some natural predator functional responses and those found in many Indian

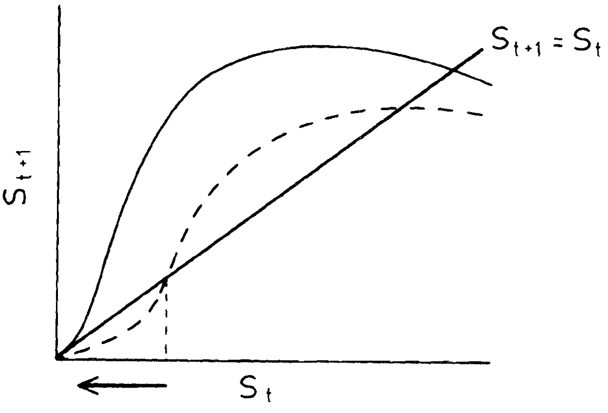

FIG. 8. Schematic representation of noncritical (solid line) and critical (broken line) depensation in plot of spawners (S) in generation $t + 1$ as a function of spawners in the previous generation.

food fisheries reemphasizes the similarity of limiting rate factors that operate on all predators. For example, the asymptote of the Type II functional response can arise from handling time or searching efficiency limitations (Holling 1959). Indian fishing gear can sweep only a limited volume of water, so with a large abundance of fish, only some maximum catch per effort can be realized. In addition, handling time limits catch per permit at high fish abundance because even if fishing gear becomes immediately filled with fish, significant time is needed to bring gear out of the water, empty and reset it.

There also is a "socially" determined upper limit to reported catch per permit set by the tendency for fishermen to take only what is needed for food (McKay 1977).

From the above analysis, it seems reasonable for the purposes of modeling salmon population dynamics to include the effect of Indian food fisheries as a depensatory mortality process. *At a minimum*, this will create what Clark (1976) calls noncritical depensation, where there is an S-shaped ascending limb on the relation between parents and progeny surviving to spawn (Fig. 8). This relation results in a slower recovery from heavy exploitation than would be the case if the stock behaved according to the standard Ricker model.

Critical depensation (Clark 1976) is the term given to the situation where the broken curve in Fig. 8 crosses below replacement levels at low stock sizes. That is, there is a critical stock size below which the population tends to move toward extinction. Fishery managers can determine if they are operating in this critical depensation mode by applying the simple guideline shown below in eq. 2.

Let

S_t = spawners in generation t
R_{t+1} = recruits to commercial fishery (preseason forecast), resulting from S_t
F = fish available to Indians
a = proportion of R harvested by commercial fisheries
b = proportion of F harvested by Indians.

From these definitions we have

$$(1) \quad S_{t+1} = R_{t+1} \cdot (1-a) \cdot (1-b).$$

Critical depensation is defined by the condition that $S_{t+1} < S_t$ for all levels of spawners $\leq S_t$. Therefore, using any method of estimating R_{t+1} from S_t, there will be critical depensation if, on average,

$$(2) \quad R_{t+1} \cdot (1-a) \cdot (1-b) < S_t.$$

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Jim Woodie (IPSFC) provided useful detailed information on Fraser River fisheries, as did Les Goodman of Canadian Department of Fisheries and Environment. Ed Zyblut generously provided data for Area 4 (Skeena River) food fisheries, Max Ledbetter helped code the Fraser River data, and Greg Steer assisted with some of the final curve fitting. P. A. Larkin, C. J. Walters, and F. E. A. Wood provided useful criticism of the manuscript. This research was begun while I worked for the Canadian Department of Fisheries and Oceans at the Institute of Animal Resource Ecology, University of British Columbia.

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