Chapter 28
Effects of stocking fingerlings on recruitment in the Lake Inari whitefish (*Coregonus lavaretus* L. *s.l.*) fishery

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The effect of stocking fingerlings on the recruitment of whitefish (*Coregonus lavaretus* L. *s.l.*) was studied in Lake Inari, northern Finland. Damage to stocks, caused by regulation of the lake for hydropower generation, has been compensated for by stocking fingerlings (length about 10 cm).

One-quarter of the total whitefish catch and one-third of the large, sparsely rakered whitefish catch come from stocking fingerlings. The average yield from 1000 stocked fingerlings is about 20 kg. Ricker's recruitment function accounted for 76% ($r^2 = 0.76$) of the variability in the number of recruits. The recruitment curve is not a simple stock–recruitment relationship but is strongly influenced by intraspecific competition for resources. It was concluded that competition retarded growth, which in turn interacted with predation. The poor yields from stocking in Lake Inari can be explained by these compensatory processes. It was recommended that the number of fingerlings stocked into Lake Inari should be radically diminished to 7–9 fish ha^{-1}.

28.1 Introduction

Understanding of the recruitment process is one of the basic issues in fishery science and management. Recruitment variability can be attributed to environmental (density-independent) and compensatory (density-dependent) mechanisms (Chen, 1987; Houde, 1987), but functional relationships and timing of different factors are still unsolved problems. Density-independent abiotic and biotic environmental factors are the most frequently cited factors affecting recruitment of whitefish (*Coregonus lavaretus* L. *s.l.*), but compensation has also been shown to be important (Taylor *et al.*, 1987; Hartmann, 1988; Freeberg *et al.*, 1990).

Whitefish favour cool, oligotrophic, well-oxygenated waters. They spawn in September–November, depending on the populations. *C. lavaretus* is a relatively highly fecund species (egg production per kilogram of female biomass about $20–40 \times 10^3$), attaining maturity at 3–7 yr old, and the spawning population is usually composed of many year classes. Spawning grounds are located on shallow shore areas in lakes or in running waters in rivers. The species is important both for commercial and recreational fishing, but its stocks have declined in many

lakes. This is the reason for the large-scale stocking carried out, for example, in Finland.

In principle, fish stocking is based on the assumption that population size is at least temporarily determined by density-independent mechanisms and that the population size is below the carrying capacity of the environment. This assumption is justified, for example, in cases where natural recruitment has declined as a result of human-induced environmental changes such as lake regulation or dredging of spawning grounds.

This chapter describes the effect of stocking fingerlings on the recruitment of whitefish in a large regulated lake, Lake Inari.

28.2 Study area

Lake Inari (69°N, 28°E; surface area 1102 km^2) is the central lake in the Paatsjoki water system, which drains into the Arctic Ocean (Fig. 28.1). The water level of the lake is regulated for production of hydroelectric power with a maximum allowed fluctuation of 2.36 m. However, the realized water level fluctuation has been much less, only 1.48 m, over the period 1959–89.

Lake Inari is relatively deep and clear (mean Secchi disc transparency 6.5 m), and its total phosphorus (4–10 $\mu g\,P\,l^{-1}$) and nitrogen (150–260 $\mu g\,N\,l^{-1}$) contents are low. The sum of herbivore and carnivore zooplankton production in the pelagic zone during summer is estimated to be 210–330 $kg\,ha^{-1} \times 3$ months (Selin & Hakkari, 1982). The whole lake is covered with ice during winter (7 months).

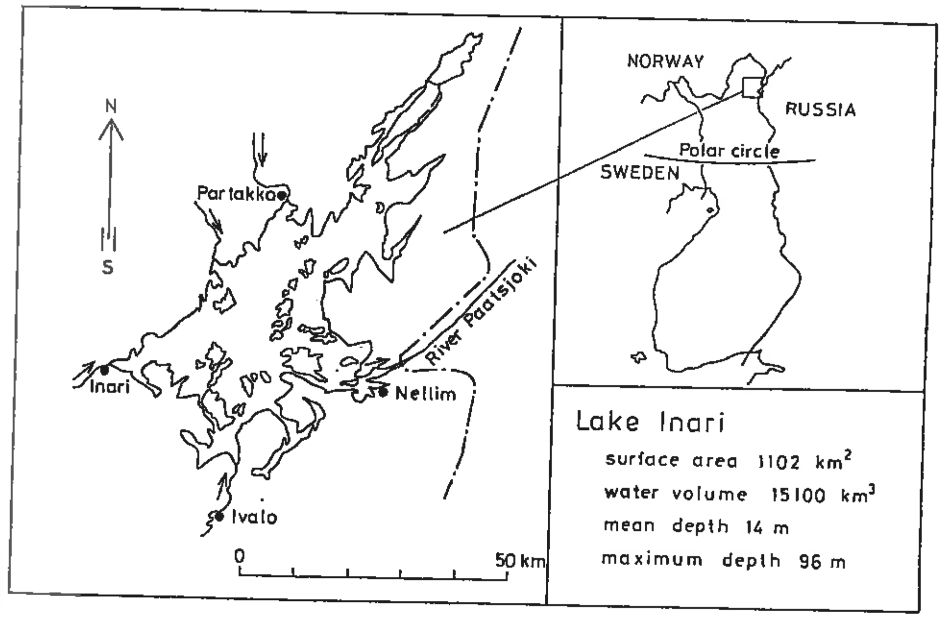

Fig. 28.1 Map of Lake Inari.

The fish fauna is composed of 10 endemic and 4 introduced species. The most valuable species from the point of view of fishing are brown trout (*Salmo trutta*), Arctic charr (*Salvelinus alpinus*), whitefish (*Coregonus lavaretus* L. *s.l.*) and the introduced species vendace (*Coregonus albula*), land-locked salmon (*Salmo salar sebago*) and lake trout (*Salvelinus namaycush*). The total catch for the period 1980–90 was highest in 1989 (560 tons). Traditionally whitefish has been the most important catch species, but now most of the catch is composed of introduced vendace (Mutenia & Ahonen, 1990).

The whitefish species complex of Lake Inari is composed of five endemic forms, the most abundant of which is the large, sparsely rakered whitefish (LSR-whitefish *sensu* Svärdson, 1979; mean number of gill rakers 21.7 ± 1.9 SD). The sixth whitefish form, the northern densely rakered whitefish (NDR-whitefish *sensu* Svärdson, 1979; mean number of gill rakers 54.8 ± 4.2 SD), has been introduced from southern Finland. This chapter deals mainly with the LSR-whitefish.

As with similar lakes, water-level regulation of Lake Inari is considered damaging to the natural reproduction of the lake-spawning whitefish forms (Toivonen, 1966, 1972). Water-level draw-down after spawning is known to cause serious egg losses in lake whitefish (Machniak, 1975; Heikinheimo-Schmid & Huusko, 1988) and feeding conditions are possibly impaired in the larval habitats in spring (Huusko *et al.*, 1988). As a result, the Finnish Water Court made the decision that one million whitefish fingerlings must be stocked into the lake each year to compensate for the damage. The compensation was initiated in the mid 1970s (Fig. 28.2). The mean number of fingerlings stocked in the late 1970s and 1980s was nearly 1.5 million per year.

28.3 Materials and methods

Samples of the whitefish stocks (amounting to 16 792 fish) were collected between 1980 and 1990 from the commercial gill net, fyke and seine net catches. The numbers of gill rakers were counted. The length (mm) and weight (g) of all whitefish sampled were measured, and the sex and sexual maturity determined.

Coded wire (CW) tagging (Bergman *et al.*, 1968) was used to separate stocked LSR-whitefish from natural LSR-recruits. The total number of CW-tagged fingerlings released (1980–86) was 528 222 individuals. A total of 109 880 whitefish were checked for tags and 1209 CW-tagged fish were recovered.

Different whitefish forms and the stocked whitefish were discriminated using gill raker frequencies, differences in growth and CW-taggings. The fish were aged from scales. The age determinations were calibrated using the recaptured CW-tagged whitefish as reference material. Growth was calculated both empirically and by back-calculation (Bagenal & Tesch, 1978). Post-recruitment natural mortality (M) was assumed to be the same as in Lake Oulujärvi (Salojärvi, 1992). Natural mortality of the recruited age groups was in general very low (Vetter, 1988). The instantaneous natural mortality (M) for each age group is shown in Table 28.1.

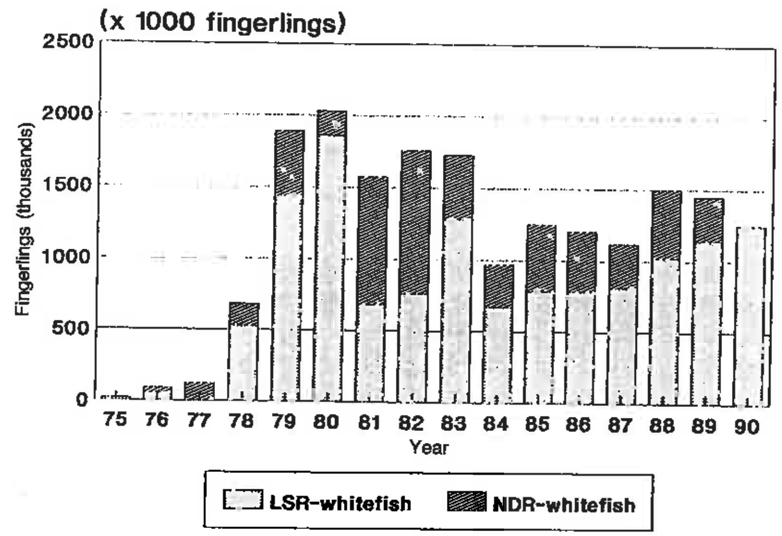

Fig. 28.2 The number of LSR- and NDR-whitefish fingerlings (mean length of fingerlings 100 mm and weight 7 g) released into Lake Inari between 1975 and 1990.

Virtual population analysis (VPA) (Gulland, 1965; Flatman & Stevens, 1987) was used to calculate fishing mortality and the size and biomass of the LSR-whitefish population and the number of recruits. Three different stock–recruitment models (Ricker, Saila–Lorda and Shepherd) were fitted to the data using the FSAS program (Saila *et al.*, 1988). Statistical analysis was performed using the SAS package.

28.4 Results

28.4.1 *Whitefish population*

In the 1980s the proportion of the LSR-whitefish in the catch was on average 73% (range 61–81%), which is less than the about 85% recorded in gill net catches in

Table 28.1 The size of LSR-whitefish population (thousands) by years and age groups, 1980–90, according to VPA in Lake Inari. M is the instantaneous natural mortality coefficient

Age (yr)	M	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
3	0.19	156	155	454	550	525	456	538	480	413	311	184
4	0.18	198	128	128	375	455	434	376	444	389	315	215
5	0.17	112	147	100	101	313	379	361	313	350	293	201
6	0.17	71	78	99	73	80	258	311	296	235	239	169
7	0.16	51	36	47	54	39	52	198	235	200	132	124
8	0.15	16	18	18	22	19	18	35	136	142	107	61
9	0.15	6	4	9	7	8	6	9	22	78	75	48
10	0.15	3	1	2	3	3	3	2	5	11	47	21
11	0.15	1	1	1	1	2	7	1	1	4	6	4
Total		614	570	859	1187	1444	1613	1830	1933	1822	1525	1026

the 1970s (Toivonen *et al.*, 1981). The catch of the LSR-whitefish declined from 43 tons in 1980 to 24 tons in the mid 1980s but increased considerably owing to the initiation of fyke net fishing in the late 1980s (Fig. 28.3).

The mean age of fish at first recruitment in the gill net fishery was 5–6 yr and the age of full exploitation was 7–8 yr. The first age of exploitation by the fyke net fishery was only 2 yr and the age of full recruitment 3–4 yr. These differences, in addition to the greater catch efficiency of the fyke nets and stocking of fingerlings, were the main reasons for the increase in catch in the late 1980s (Fig. 28.3).

The size of the LSR-whitefish stock varied considerably over the study period (Table 28.1, Fig. 28.4). The density was between 5 and 18, 3+ and older LSR-whitefish individuals per hectare with a biomass of between 1.2 and 2.3 kg ha^{-1}. At the same time the LSR-whitefish catch varied between 0.2 and 0.9 kg ha^{-1}.

The pre-recruitment (ages 0–2) growth of the stocked LSR-whitefish was, according to the CW-taggings, very poor. On the basis of beach seine samples, the length of the stocked LSR-whitefish was 10.7 ± 1.2 cm (mean ± SD) 1 yr after stocking (age 1+), 13.1 ± 1.1 cm after 2 yr (2+) and 16.8 ± 2.3 cm after 3 yr. The growth rate was very poor considering that the mean size of fingerlings at the time of stocking (age 0+) was about 10 cm.

The age-specific length of the LSR-whitefish is negatively related to the stock size (Fig. 28.5) and consequently, in the 1980s, growth was dependent on stock size in the 1980s in Lake Inari. By contrast, in the 1960s and 1970s, the growth of LSR-whitefish was good and fairly constant (Toivonen *et al.*, 1981; Heinonen, 1985), suggesting that growth prior to stocking was independent of adult stock size.

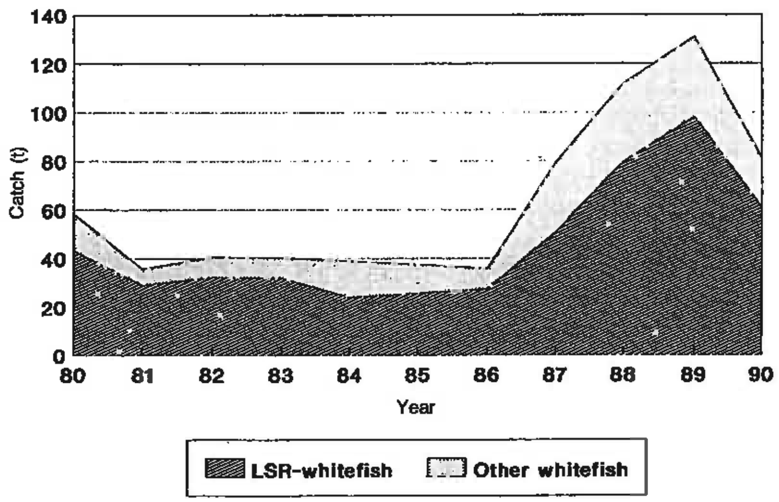

Fig. 28.3 Catches of whitefish in Lake Inari and the proportion of LSR-whitefish in the catch between 1980 and 1990.

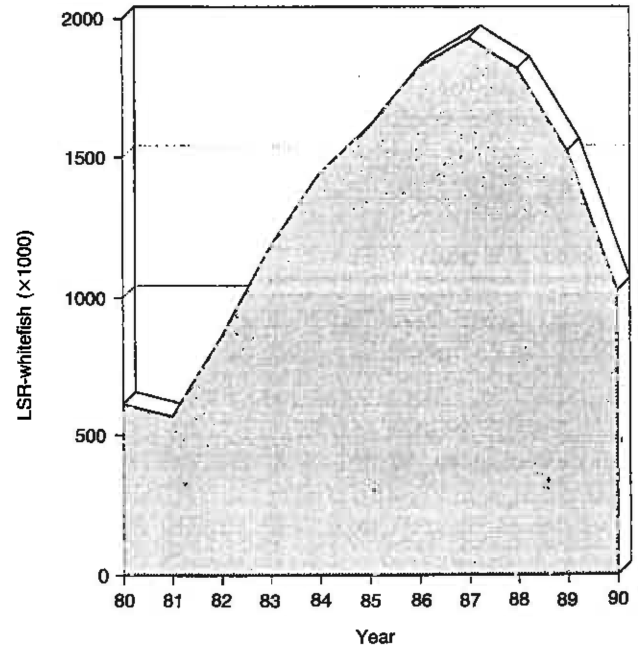

Fig. 28.4 Population size of LSR-whitefish in Lake Inari between 1980 and 1990 (estimates based on VPA).

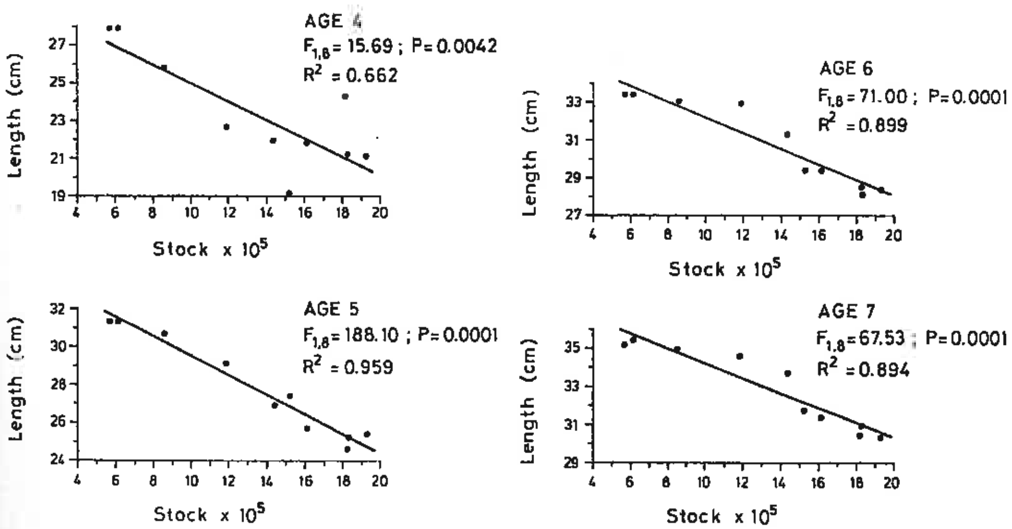

Fig. 28.5 Relationship between the length of LSR-whitefish at ages 4 to 7 and the size of the LSR-whitefish stock in Lake Inari (*F*-statistics and the associated probability (*P*) and coefficient of determination (*R*) given).

28.4.2 *Yield from stocking*

According to CW-taggings, one-quarter of the total whitefish catch and one-third of the total LSR-whitefish catch arises from fingerling stocking. The average yield from 1000 stocked fingerlings is about 20 kg (range 13–31 kg), so about 50 fingerlings are needed for 1 kg of catch. The yield from stocking is very low compared with that in other lakes in Finland (Salojärvi & Huusko, 1990; Salojärvi, 1988, 1991). However, the yield from the releases of LSR-whitefish fingerlings is better than that from fingerling stocking with NDR-whitefish in Lake Inari (Salojärvi & Mutenia, 1989).

28.4.3 *Recruitment*

The abundance of recruits showed great variability with time (Table 28.1), which was reflected in the CPUE of fishing during the spawning season (Salojärvi & Mutenia, 1991). A 3.5-fold variation in the abundance of 3+ recruits was observed, with the strongest recruitment from the 1980 year class. The linear relationship between the number of stocked fingerlings and recruitment was not statistically significant ($P > 0.05$).

On the basis of CW-tagging, the estimated number of young-of-the-year (YOY) whitefish (including both natural and stocked whitefish) was roughly 5 million in the 1980s, assuming equal growth, mortality and vulnerability to fishing.

All three stock–recruitment functions fitted fairly well to the recruitment data. Ricker's stock–recruitment model (Fig. 28.6) accounted for 76% ($R^2 = 0.76$; adjusted $R^2 = 0.66$), Saila–Lorda's 77% ($R^2 = 0.77$; adjusted $R^2 = 0.61$) and Shepherd's 73% ($R^2 = 0.73$; adjusted $R^2 = 0.52$) of the variability in the number of recruits of LSR-whitefish. These results suggest that the adult stock size for optimum recruitment is about 7 to 9 whitefish individuals per hectare in Lake Inari.

28.5 Discussion

The estimates of numbers of recruits are susceptible to errors owing to the methods used and the quality of the data (Pope, 1977; Rivard, 1989). In this study, the errors attributable to Gulland's (1965) VPA method were not, on the basis of sensitivity tests, detrimental to the stock–recruitment relationship.

The proportions of recruits from natural spawning and from stocking were based on assumption of equal mortality and growth rates. However, the size of 1+ natural fingerlings was less than that of 1+ stocked whitefish. Thus the proportion of natural (YOY) recruits was underestimated because natural mortality is known to be size dependent (Vetter, 1988). Conversely, the possible errors in tagging (tag shedding, differential mortality, differential growth and differential susceptibility to fishing) tend to underestimate the proportion of the stocked LSR-whitefish in the catch. In view of these possible errors, the estimates

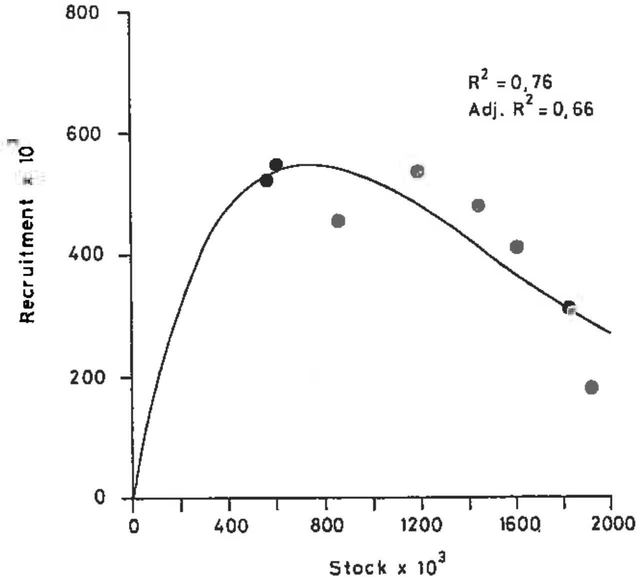

Fig. 28.6 Ricker's stock–recruitment function for LSR-whitefish in Lake Inari. The relationship is described by: $R = aP\exp(-bP)$, where R is no. of recruits; P is size of adult stock and a and b are constants with values of 1.972 and 0.001332 respectively.

of whitefish recruitment in Lake Inari can be considered tentative. The final analysis of the tagging data will be carried out in 1993, when the present project is finished.

Good fits of recruitment data to the theoretical stock–recruit models have rarely been produced (Cushing, 1971) and only one such curve has been derived for whitefish (Henderson *et al.*, 1983). The high variability of recruitment data was the reason why Fletcher & Deriso (1988) criticized the use of stock–recruit models in fisheries management. They stated that "we are still obliged to view every known spawner–recruit formulation as an unsubstantiated hypothesis." They, and others (Chen, 1987; Saila *et al.*, 1987; Christensen & Goodyear, 1988), pointed out the importance of stochastic environmental factors on the success of recruitment. The relation between adult stock size and the number of recruits in Lake Inari is not a simple stock–recruitment one, but there is a good fit of the recruitment data to the three theoretical stock–recruitment models (Ricker, Saila–Lorda and Shepherd). These data may, therefore, provide further insight into the mechanisms underpinning population regulation.

There is a wide consensus that recruitment is determined in early life stages. Contradictory opinions, however, exist as to whether recruitment is dependent on stock size or whether it is caused by factors independent of stock size (Shepherd & Cushing, 1980; Houde, 1987). Irrespective of the recruitment mechanisms and their functional relationships (Fig. 28.7), mortality is high in egg and larval phases and small changes in survival rate can dramatically affect subsequent recruit numbers.

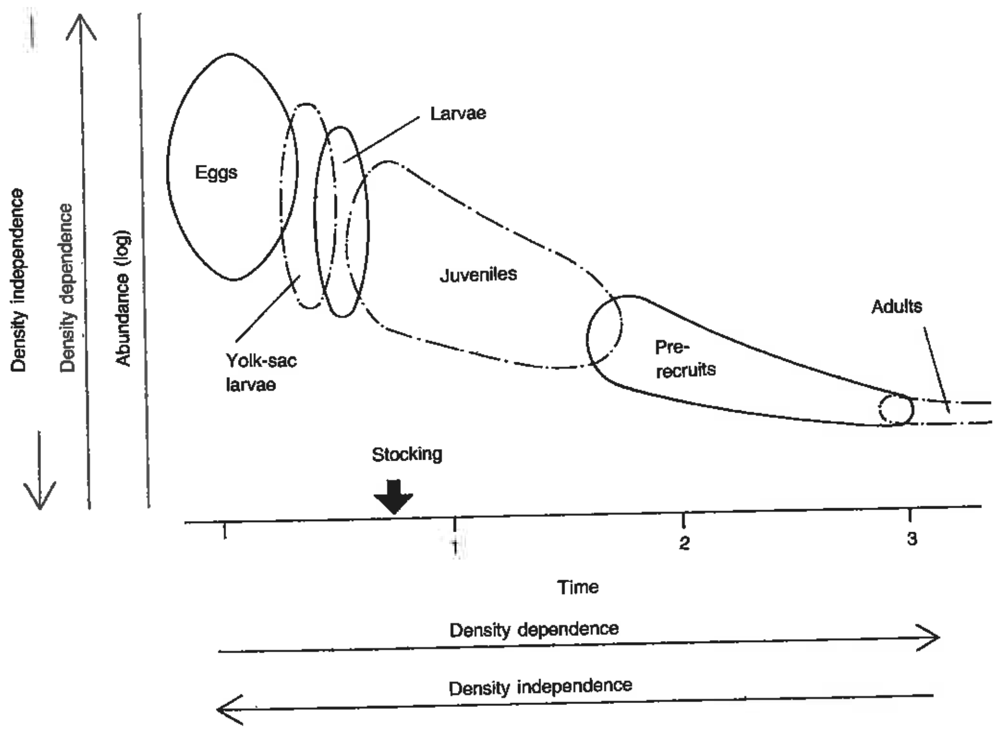

Fig. 28.7 A conceptual model of the recruitment process (modified after Houde, 1987) in whitefish separated by developmental stages. The graph shows that density dependence increases as abundance increases and also as a function of time, and that density independence decreases in the opposite direction.

No data on the egg or larval stages of whitefish in Lake Inari are available, but circumstantial evidence indicates that, prior to stocking, recruitment was probably controlled through density-independent mechanisms in an early life stage. This conclusion is supported by catch statistics and historical data on growth patterns. Whitefish catches varied many-fold before the 1980s (Mutenia & Ahonen, 1990), but only slight variation was observed in length and weight at ages (Toivonen *et al.*, 1981). this suggests that the stock fluctuated below the carrying capacity of the environment.

On the basis of the previous arguments it was assumed that mortality in the early life stages owing to abiotic and biotic environmental factors, including lake regulation, was so high before the period of intensive fingerling stocking that adult stock size did not reach the level where growth was retarded by intraspecific competition for food. This notion is consistent with the goals of fish stocking presented in the introduction of this chapter.

Stocking changed the population regulation process (Fig. 28.7), shifting it to the phase where compensatory processes in and after juvenile stages determine stock size. The stock–recruitment curve (Fig. 28.4) exhibits a strong compensatory effect. The mechanism can be asymmetrical intraspecific competition for food or displacement of young whitefish into marginal areas or habitats by abundant adult fish (Johnson, 1976). Cannibalism is common in whitefish (Grimm, 1951; Korhonen & Turunen, 1991), but whitefish are not known to prey on fingerling-sized fish in Lake Inari (Keränen, unpublished).

Competition for food strongly retarded the growth of whitefish, which was seen, for example, in the CW-data. This retardation suggests the influence of growth on population regulation in juvenile stages. It gives support to the basic hypothesis that competition is mediated through changes in growth rates during the pre-recruitment phase, which in turn interact with predation rates (Sissenwine, 1984; Werner, 1986; Houde, 1987; Luecke *et al.*, 1990). The poor yield from stocking and the decreasing trend in recruitment can be explained by density-dependent population regulation.

Implications for fisheries and fisheries management are that population size of whitefish can be increased by stocking, but there is a danger of overstocking, which can lead to retarded growth and decreasing recruitment. This has happened in Lake Inari. The stocking programme has been too efficient and therefore the numbers of fingerlings stocked should be reduced.

Salojärvi & Mutenia (1991) recommended that only 0.5 million fingerlings per year should be stocked in future. Numbers stocked should also be adjusted according to fishing pressure (Salojärvi, 1988), because intraspecific competition can, to a certain extent, be reduced by fishing. The mean size of fish in catch decreases as a function of increased fishing effort, which reduces the monetary value of the catch (the market value of large fish being greater than that of small fish).

There is evidence to suggest that overcompensation may also have adverse ecological effects through species interaction. Whitefish predate on vendace eggs and larvae, and in certain circumstances this can affect the recruitment of vendace. Species interactions therefore should be one of the key areas of future research in Lake Inari.

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