

# Basic abiotic conditions for production of perch (*Perca fluviatilis* L.) young-of-the-year in the Gulf of Bothnia

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A recruitment model for perch (*Perca fluviatilis* L.) was used to predict relative abundances of young-of-the-year in habitats with different degrees of exposure to the open sea in the Gulf of Bothnia. The model describes the most basic conditions influencing the recruitment process, namely the influence of day-length and temperature on consumption affecting the growth potential. First year growth in these waters is positively correlated with year-class strength, thus, the size at the end of the first growth season is in the model used as an index of recruitment. The predictions were compared with observations during surveys regarding growth, distribution and abundance. As verified by the survey results, recruitment success should be very low in the most exposed habitats due to a low potential for first-year growth. Only sheltered bays and archipelagos, estuaries and small freshwaters provide favourable conditions for production of recruits in the Gulf of Bothnia. As predicted by the model, recruitment areas with the highest basic quality, the highest temperatures, had the widest extensions in the archipelagos.

## 1. Introduction

In the coastal zone of the Gulf of Bothnia and the Baltic proper the low salinity allows fresh-water species to be common, except in southern parts where the salinity is high enough to restrict their distribution to mainly fresh-water lagoons and estuaries. Perch (*Perca fluviatilis* L.) is an abundant and widespread species throughout Eurasia. The year-class strength of Baltic perch populations is mainly decided by first-year survival and is known to vary by a factor 10 when comparing strong and weak year-classes (Neuman 1976).

Among fresh-water populations, these variations are even greater. The ratio between the strongest and weakest year-classes was reported by Willemsen (1977) to be about 100, and by Kipling (1976) and Buijse (1992) to be about 400.

In Scandinavian waters, inter-annual variations in year-class strength of perch are positively correlated to summer water temperature during the first year of life (Segerstråle 1933, Agnedal 1968, Neuman 1976), a frequent observation in percids (Koonce *et al.* 1977). First-year growth is also positively correlated to temperature (Karås & Neuman 1981, Karås & Thoresson 1992). Furthermore, in fishes,



Fig. 1. Areas studied within the Gulf of Bothnia.

natural mortality is generally negatively correlated with growth rate during the first year of life (see e.g. Pauly 1981, Post & Prankevicius 1987, Miller *et al.* 1988, Pepin 1991). Accordingly, for perch populations in inland, and in Baltic coastal waters positive correlations have been demonstrated between first-year size and thus growth rate and year-class strength (Craig 1982, Karås 1987). The importance of a fast growth rate for populations in Baltic coastal waters was interpreted by Karås (1987) to be related to lower susceptibility to mortality from predation during periods of high mortality and a higher ability to sustain starvation during winter in larger fish. Karås (1987, 1989) suggested a recruitment model predicting first-year growth, primarily based on water temperature conditions but also including day-length effects, as an index of year-class strength. The growth model includes sub-models to define the time of spawning, the duration of embryo development,

larval growth rate and a bioenergetics model for growth from a size of 0.5 g or 38 mm (Karås 1987), which is close to metamorphosis.

Coastal morphometry and water temperature vary considerably in the Gulf of Bothnia, which creates different prerequisites for fish recruitment. Archipelagos, sheltered bays and inlets, with stable and comparably high temperatures, are common in the most northern and southern parts but also in the central. Between these areas upwelling of cold water, creating unstable conditions, occurs regularly along the exposed and open coasts. In this paper, I test the hypothesis that temperature and day-length conditions, through their influence on the potential for growth and survival, make up the basic quality characters of the recruitment areas for perch in coastal waters of the Gulf of Bothnia. Predictions of recruitment made with a growth model (Karås 1987, Karås & Thorsson 1992), based on temperature and day-length data, are compared with results of field surveys in the autumn regarding growth, distribution and abundance of perch young-of-the-year. Habitats representing different degrees of exposure to the open sea were selected for the studies. A brief comparison is also made with abundance observations of young-of-the-year of other common coastal species.

## 2. Study areas

The Gulf of Bothnia consists of two major basins, the Bothnian Bay and the Gulf of Bothnia, divided by a shallow sill named the Northern Quark (Fig. 1). Five study areas were selected; Råneå, Holmöarna, Valsörarna, Hornslandet and Gräsö. Råneå (Fig. 2a) represents an archipelago in the northern part of the Bothnian Bay. The inner parts of the area are relatively shallow (less than 6 m deep) and are sheltered and influenced by two small rivers. The negative effects of ice movements on vegetation are very pronounced and larger areas with underwater vegetation (*Potamogeton* spp. and *Myriophyllum* spp.) mainly appear close to the river mouths. The geomorphometry of the inner parts of the archipelago allows the lowest rates of water exchange and wave action in addition to the most stable water temperatures.

Holmöarna (Fig. 2b) and Valsörarna (Fig. 2c) represent shallow areas in the Northern Quark. On the Finnish side there is a relatively large archipelago (Osala 1988). Because of land upheaval, which is about 9 mm/year in this area, and the lowland surroundings, numerous small bays (termed: fladas) with very narrow sills and small fresh-waters close to the shore line (termed: glo-lakes) are continuously developing. The in-

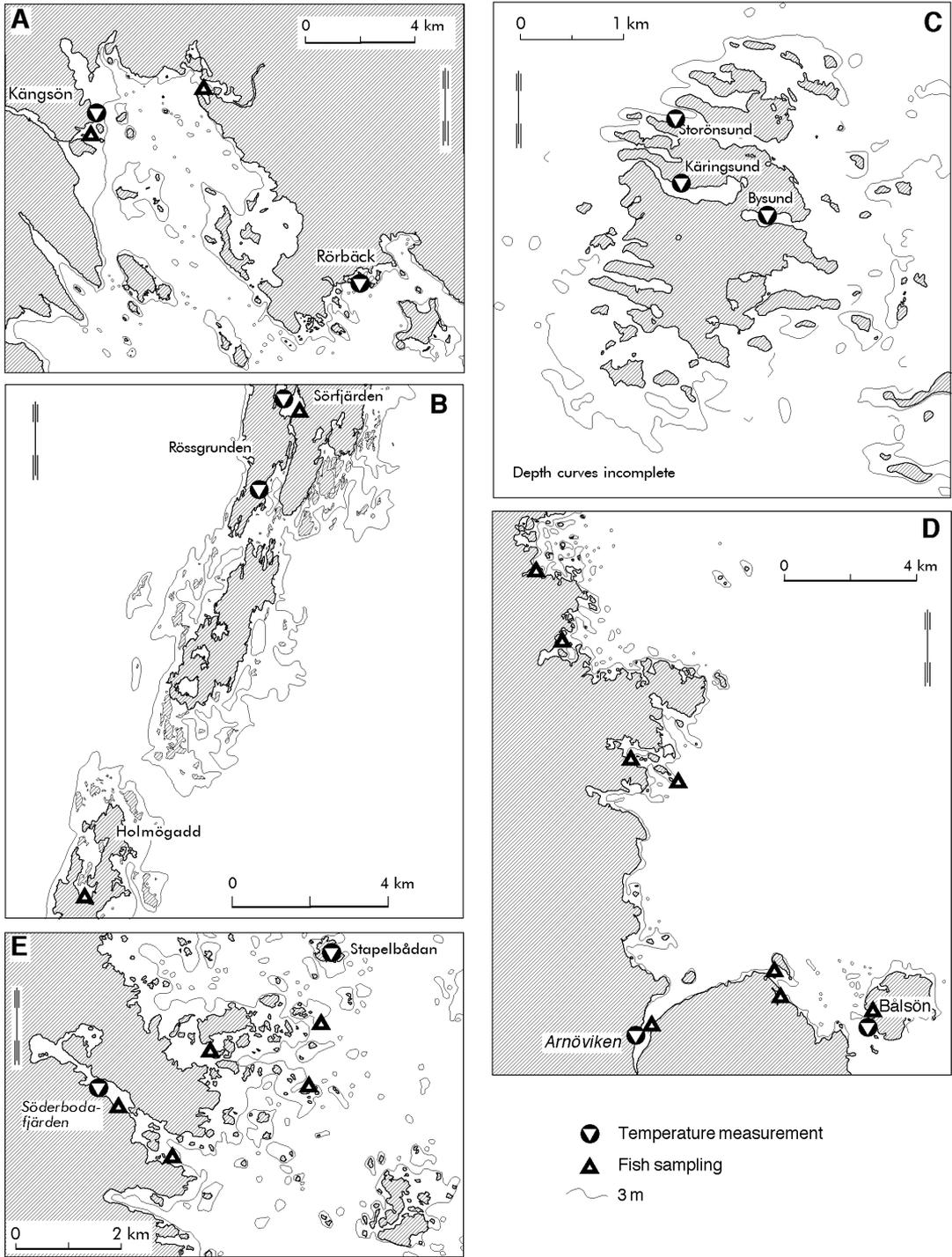


Fig. 2. Temperature measurement and fish sampling stations in the different areas studied. — A: Råneå. — B: Holmöarna. — C: Valsöarna. — D: Hornslandet. — E: Gräsö.

fluence of ice is very pronounced in more exposed areas and, thus, a well-developed benthic vegetation (*Potamogeton* spp. and *Myriophyllum* spp.) is only present in the most sheltered bays and in fladas and glo-lakes.

The commonly occurring wind exposed areas with upwelling are represented by Hornslandet in the western Gulf of Bothnia (Fig. 2d) with deep water close to the shore line. However, this area also has a few bays with sills and islands at the mouth protecting them from exposure to the open sea. Here, underwater vegetation is well developed, mainly composed of *Characeans*, *Potamogeton* and *Myriophyllum* species.

The archipelago east of the island Gräsö in the south-western Gulf of Bothnia (Fig. 2e) has a morphometric character similar to the Råneå area. Underwater vegetation in protected bays is dense and dominated by *Characeans*, *Potamogeton* and *Myriophyllum* species. In the outermost parts of the archipelago *Fucus vesiculosus* is common.

### 3. Material and methods

Recruitment of perch in Baltic coastal waters is mainly restricted to water depths of 0.5 to 3 m (Karås 1987, Urho *et al.* 1990). Temperature measurements and field surveys of fish were performed within this depth range (Fig. 2a–e) in habitats representing coastal areas of different exposure to the open sea, from glo-lakes, fladas, and sheltered bays, to open sea coasts and outer parts of archipelagos. Daily tem-

perature measurements were made both manually using a thermometer and by means of automatically recording instruments (Aanderaa, Sensor scanning unit 3110) (Table 1). Additional temperature data representing Gräsö were available from a similar archipelago close to the mainland at a distance of 20 km.

The field samplings of 0+ fish were performed at the end of the growth season, mainly in September, using an underwater detonation technique (Karås & Neuman 1981). A 20 g charge of dynamite was detonated in the middle of the water column at bottom depths of 1–3 m. All floating dead or stunned fish were collected. Total length (mm) was recorded on fresh material. This technique gives measures of relative abundance expressed in numbers per detonation. Sampling for first-year growth of perch was done in all areas (Table 2). At Valsörama, only a few individuals were caught and, thus, this area was excluded from the growth analysis. Distribution and abundance studies were made at Hornslandet and Gräsö. Three categories of shallow areas with different exposure were studied: (1) very sheltered areas exemplified by almost enclosed small bays, (2) areas protected by islands with narrow openings, and (3) fully wind exposed areas.

Temperature recordings covering the whole growth season for perch, from spawning until temperature drops below 10°C, were used to predict first-year growth in different habitat's using submodels for the time of spawning, embryo development, larval and juvenile growth. The time of spawning was, according to Karås (1987), set as the date in spring in the middle of the period with the sharpest temperature rise between 6 and 10°C. Embryo development up to hatching was calculated to require 101 day-degrees above 5°C (Guma'a 1978). Size at hatching was set to 6 mm. The larval growth model is based on field studies in different temperatures in the south-western Gulf of Bothnia (Karås 1987). In this model, growth rate ( $G$ ) in mm/day is calculated from temperature ( $T$ ) as:

$$G = 0.066T - 0.65.$$

Table 1. Temperature registrations. A: automatic registration in the middle of the water column, B: measured midday by hand close to the surface.

Area	Year	Technique	Time interval	Water depth
N Bothnian Bay				
Sheltered archip.	1988	B	daily	0.3 m, 2 m
	1991	A	3 h	2 m
Exposed	1991	A	3 h	2 m
W Northern Quark				
Sheltered archip.	1991	A	3 h	1.5 m, 2 m
Lake	1991	A	3 h	2 m
E Northern Quark				
Flada	1990	A	3 h	1 m
Sheltered bay	1990	A	3 h	2 m
Exposed coast	1990	B	daily	2 m
W Gulf of Bothnia				
Exposed bay	1991	A	3 h	0.5 m, 2 m
Exposed island	1991	B	daily	1 m
SW Gulf of Bothnia				
Sheltered bay	1992	B	daily	0.5 m
Sheltered archip.	1992	A	3 h	2 m
Exposed	1992	A	3 h	0.5 m, 2 m

Table 2. Sampling data of fish young-of-the-year.

Area	Habitat	No. of sampling occasions	No. of detonations/occasion
N Bothnian Bay	Sheltered bay	1	32
W Northern Quark	Sheltered bay	1	10
	Lake	1	10
W Gulf of Bothnia	Sheltered bay	1	10
	Exposed bays	1	20
	Exposed	1	20
SW Gulf of Bothnia	Sheltered bay	2	10
	Sheltered archip.	2	30
	Exposed archip.	2	20

From 38 mm in length to the end of the growth season the bioenergetics model of Karås and Thoresson (1992) was used to predict growth. Assuming a condition factor of 0.85, the weight simulations started at 0.47 g (wet weight). Besides the temperature conditions, this model also includes the effect of day-length on consumption, assuming non-feeding during night-time (sunset until sunrise). Day-length was calculated based on the latitude. The predictions were made under the assumption that consumption was at maximum and that the energetic cost for swimming corresponded to 10% of the standard metabolic rate as demonstrated by Karås (1987) for a population in the SW Gulf of Bothnia. First-year growth predicted by the model was used as an index of recruitment according to Karås (1987) (see also Böhling *et al.* 1988). The accuracy of the growth simulations and predictions of relative abundance was evaluated in comparisons with field observations.

## 4. Results

### 4.1. Temperature conditions

The temperature conditions in the sheltered Rössgrunden bay at Holmöarna and Bysund bay at Valsörarna (Fig. 2b and c) were similar and much warmer in summer than the exposed habitat at Valsörarna (Fig. 3a). Differences in temperature between these kind of habitats were characteristic, as they could be seen also in comparisons at Råneå (Fig. 3b), Gräsö and Hornslandet (Fig. 3c). At Hornslandet, upwellings often cause sharp temperature drops (Fig. 3c). Similar conditions also appeared in the exposed parts of the archipelago at Råneå (Fig. 3b). The flada studied at Valsörarna and, during the summer period also the glo-lake, were somewhat warmer than the bays (Fig. 4a and b). Water temperature at the 0.5 m depth was, in general, higher than at 2.0 m (Fig. 5a and b).

### 4.2. Growth

The time for hatching predicted varied considerably between areas and habitats within areas (Table 3) due to the influence of temperature on the date for spawning and the rate of embryonic development. Consequently, there were considerable differences in the start of the larval and juvenile growth periods. Weight predicted after the first growth season was below one gram when simulations were made for the most exposed habitats (Fig. 6 and Table 3). In

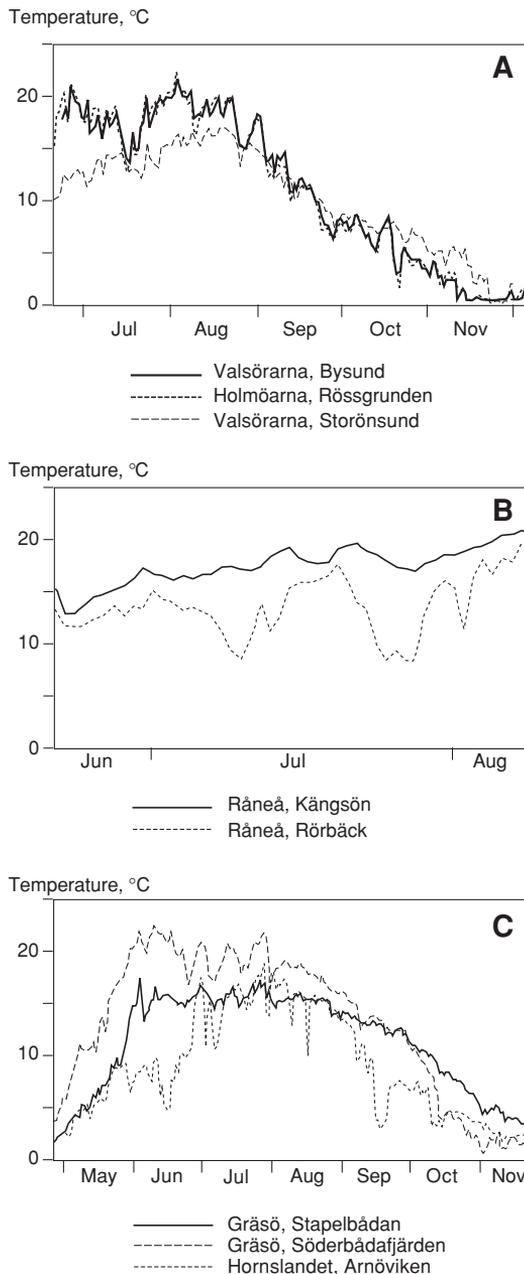


Fig. 3. Temperature conditions in the middle of the water column at a 2-m depth in different habitats in the sea. — A: sheltered bays: Rössgrunden and Bysund, exposed: Storönsund. — B: sheltered bay: Kängsön, exposed archipelago: Rörbäck. — C: sheltered bay: Söderbodafjärden, exposed archipelago: Stapelbådan, exposed bay: Arnöviken.

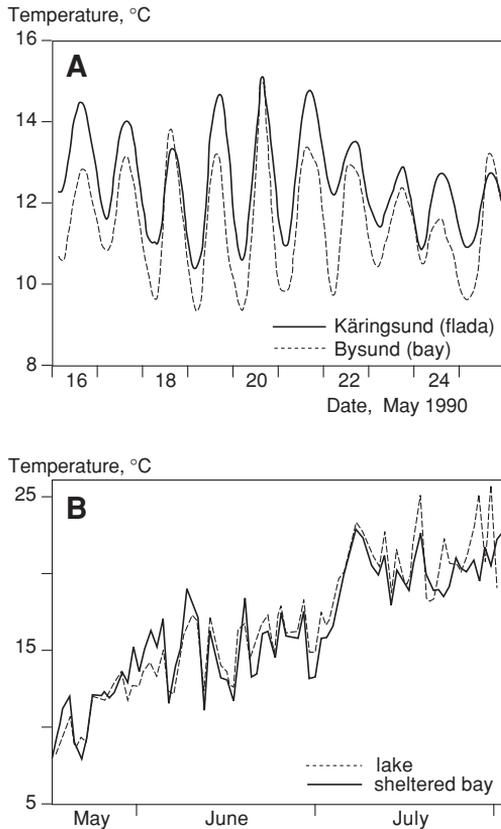


Fig. 4. Temperature conditions in the middle of the water column. — A: at a depth of 2 m in a bay in the sea and at a depth of 1 m in a flada. — B: at a depth of 2 m at Holmöarna in a sheltered bay and in a lake (redrawn from Karås & Hudd 1993).

sheltered bays and archipelagos, first-year growth predictions in general varied between one and five grams. The growth predictions agreed with observations made during the field samplings in corresponding habitats (Fig. 7). First-year growth was fastest in the warmest habitats at Råneå, Gräsö and Hornslandet.

#### 4.3. Distribution and abundance

Due to the patchy distribution of 0+ perch in the autumn there was a large variation between samples in the number of individuals caught (Table 4). Most observations with no fish occurred in the exposed areas. In these coolest habitats few individuals were caught while abundances were much higher in shel-

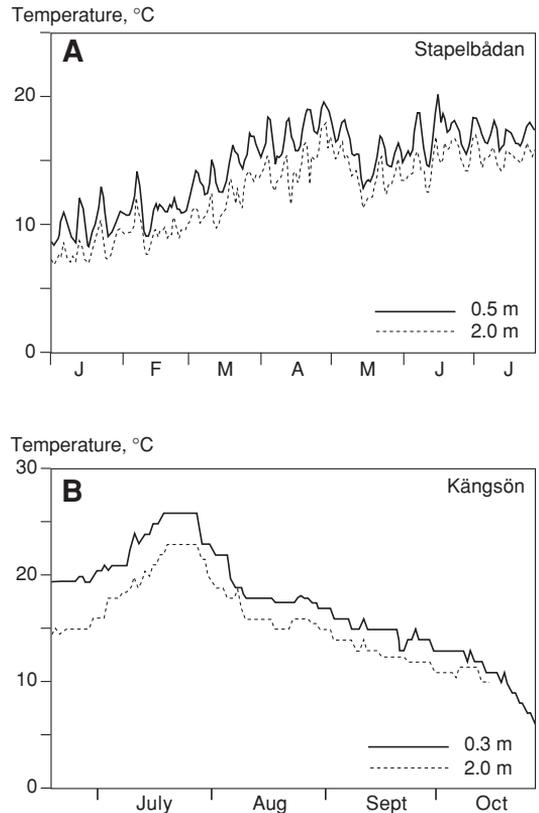


Fig. 5. Temperature conditions in the sea in the middle of the water mass at different depths. — A: exposed archipelago at Gräsö. — B: sheltered bay at Råneå.

tered areas (Fig. 8). At Gräsö the highest abundances were noted in the sheltered archipelago, except for the inner parts of the almost closed bay. At Hornslandet, only the bays produced 0+ perch; the most sheltered one having the highest abundances.

Among juveniles of other species caught, cyprinids (rudd *Scardinius erythrophthalmus* (L.), silver bream *Blicca bjoerkna* (L.) and bleak *Alburnus alburnus* (L.)) dominated in the inner parts of the most sheltered habitat at Gräsö. Pike (*Esox lucius* L.) also had the highest abundance in this habitat. Herring (*Clupea harengus* L.) was the dominant species outside this subarea. In the most exposed habitat, only herring and gobies (*Pomatoschistus* spp.) appeared in high numbers. At Hornslandet, Cyprinids and pike were only found in the sheltered bays and gobies only in exposed areas while minnow (*Phoxinus phoxinus* (L.)), sticklebacks (*Gasterosteus acu-*

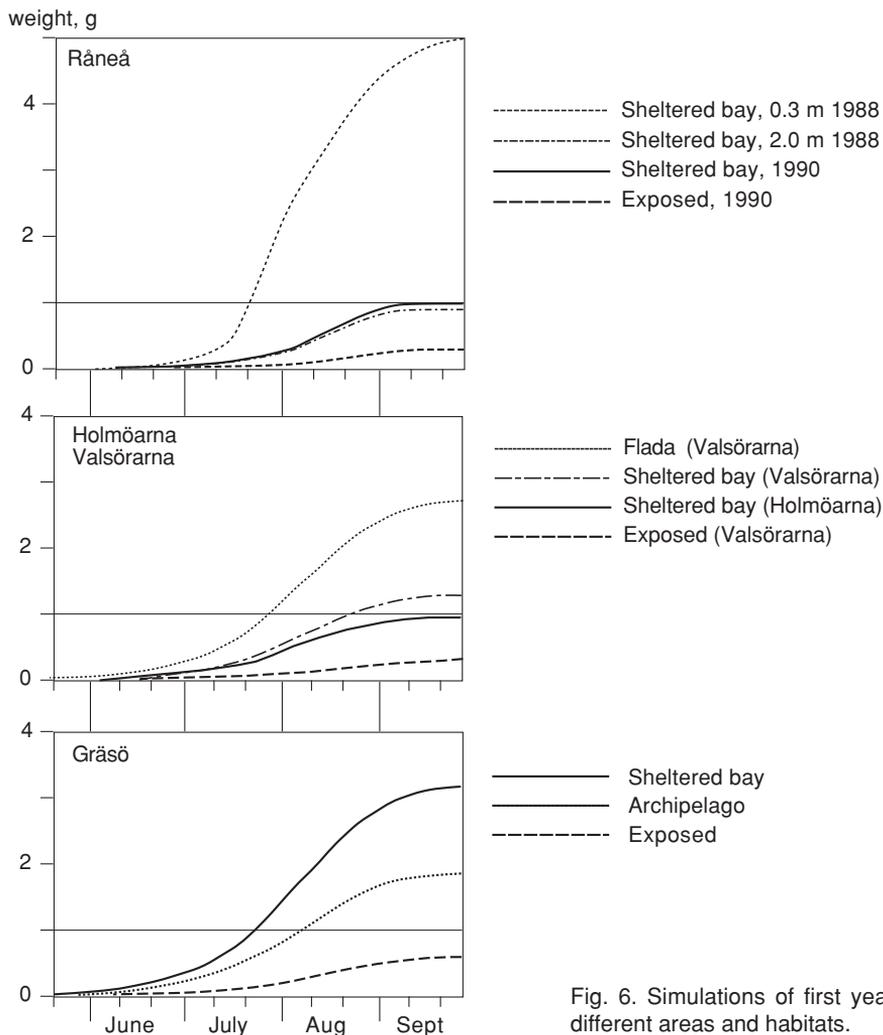


Fig. 6. Simulations of first year growth of perch in different areas and habitats.

*leatus* L. and *Pungitius pungitius* (L.) and 0+ herring were abundant in both habitats.

## 5. Discussion

During its first year of life, perch is distributed within the depth range down to about 3 m (Karås 1987, Urho *et al.* 1990). Within this interval, temperature conditions vary between depths and habitats in accordance with the degree of exposure (Figs. 3–5). By using a temperature-based growth and recruitment model (Karås 1987, 1989) it was demonstrated that habitat characteristics greatly influenced the potential for first-year growth (Table 3 and Fig. 6) and survival

until the end of the first growth season (Fig. 8).

A first-year growth of about 1 g or 50 mm might, according to Karås (1987), be close to the lower limit for survival in the southern Gulf of Bothnia. During the short winter days, often accentuated by long periods of ice-cover, starvation may be a critical problem for the visually feeding perch. The smaller the fish the faster its energy supply will be depleted (Karås 1987). Since the duration of the winter period is longer further to the north it may be anticipated that in the Bothnian Bay the need to grow big may be even larger before the winter period starts.

Along exposed coastlines and in the outer parts of archipelagos predictions indicated that, due to the relatively low temperatures, it should not be possi-

ble for 0+ perch to reach above about 0.6 gram or 42 mm. In more sheltered archipelagoes, bays and freshwaters, with warmer waters, a first-year growth of 1–5 grams seemed to be possible according to the simulations; the highest growth predicted in the most sheltered and shallow waters. Such habitats appeared over the whole geographical range. When compared with actual field data, predicted growth and abundance differences between habitats could in general be confirmed (Figs. 7 and 8). Thus, the model may be used to analyse recruitment potential of different Baltic waters.

Only if the 0+ perch can stay in very shallow waters during the whole first growth season in the exposed parts of the archipelago in the southern Gulf of Bothnia, will it be possible for them to grow to a size close to one gram (0.89 g or 48 mm according to the predictions). Since the larvae and juveniles have dispersal periods into deeper waters (Karås 1987, Urho *et al.* 1990) it is likely that first-year growth in this exposed area will be even slower, and that recruitment will not be possible.

In the growth simulations it was assumed that the fish consumed and grew at maximum rates. When compared with actual field data this generally seems to be close to the case. However, in most of the simulations growth was slightly overestimated. This was most pronounced for the well-protected bay at Gräsö. Also in earlier studies in the southwestern Gulf of Bothnia it was demonstrated that perch during their first growth season consumed and grew close to the potential maximum (Karås 1987, Karås & Thoresson 1992). However, in temperatures over 20–25°C consumption was submaximal. This temperature effect, thus, might explain the relatively low growth at Gräsö, especially in the most sheltered habitat, where the highest temperatures were experienced.

In the areas where recruit production was predicted to be difficult or impossible, very few or no 0+ perch were found. On the other hand, in areas where the model predicted substantial growth, large numbers appeared. In the archipelagos of the northern Bothnian Bay, predicted growth was fast enough

Table 3. Predicted weights and lengths of 0+ perch at the end of the growth season. Dates of hatching and metamorphosis (set at 38 mm in the model) were calculated from temperature data according to Karås (1987). The predictions were based on temperature recordings at different depths at sites representing more or less exposed habitats. — = a size large enough for metamorphosis was not attained before the end of the growth period. ( ) = on the field sampling date.

Area	Year	Depth (m)	Hatching	Metamorphosis	Weight (g)	Length (m)
N Bothnian Bay						
sheltered bay	1988	0.3	2 Jun.	17 Jul.	5.00	84
—	1988	2.0	4 Jun.	8 Aug.	0.90	47
exposed	1991	2.0	27 Jun.	—	0.26	31
sheltered bay		2.0	7 Jun.	7 Aug.	1.00	49
W Northern Quark						
sheltered bay	1991	0.5	3 Jun.	8 Aug.	1.00 (0.96)	49
		2.0	3 Jun.	8 Aug.	0.96 (0.84)	48
lake		2.0	3 Jun.	10 Aug.	0.87 (0.68)	47
E Northern Quark						
flada	1990	1.0	11 May	23 Jul.	2.73	68
sheltered bay		2.0	16 Jun.	3 Aug.	1.31	54
exposed		2.0	16 Jun.	—	0.25	31
W Gulf of Bothnia						
exposed island	1991	2.0	24 Jun.	13 Sep.	0.48	38
exposed bay		0.5	30 Jun.	—	0.37	35
exposed bay		2.0	5 Jul.	—	0.29	33
SW Gulf of Bothnia						
very sheltered	1992	0.5	19 May	7 Jul.	3.20	72
sheltered archipelago		2.0	27 May	15 Jul.	1.88	60
exposed		0.5	30 May	4 Aug.	0.89	47
		2.0	8 Jun.	25 Aug.	0.61	42

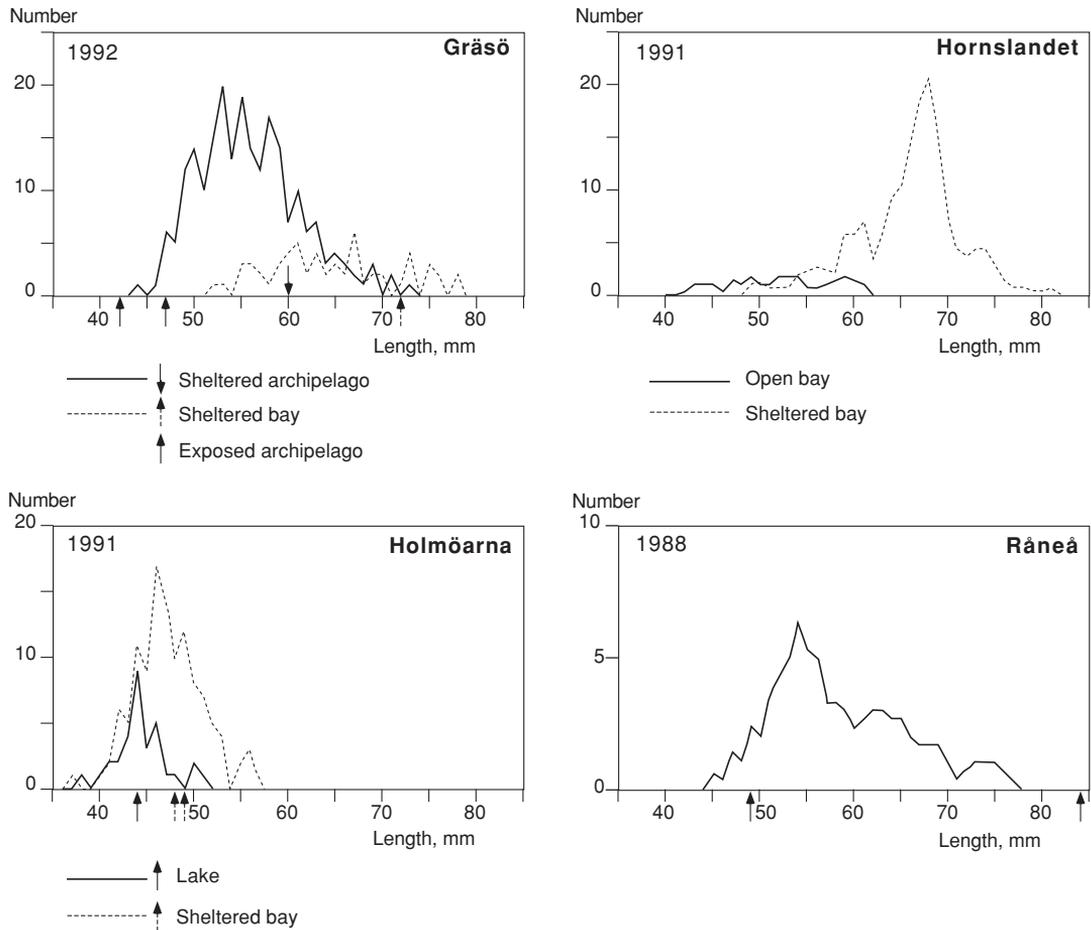


Fig. 7. Length distributions of perch young-of-the-year in different areas and habitats. Growth simulations, when available, are illustrated by arrows. Two arrows for a habitat indicates simulations for both the 0.3 or 0.5 and 2.0-m depth.

for successful recruitment only in the innermost parts. In the Northern Quark area it was predicted that sheltered bays and fresh-waters have the greatest potential for recruitment. Field studies of the distribution of spawning grounds and different nursery areas confirm this (Karås & Hudd 1993). In the year studied, some size-related mortality during the winter period may, however, be anticipated as some juveniles were unable to achieve a weight over 1 g by the end of the growth season.

At the exposed coasts, such as the Hornslandet area, recruitment seems to be limited to the few sheltered bays. The 0+ perch produced in the open bays of this area may, due to slow growth, suffer size-related mortality during winter. In exposed habitats of the area, and in the exposed archipelago of the northern Bothnian Bay, sharp temperature drops

Table 4. Percentage of samples with different numbers of perch young-of-the-year within categories.

Number of fish	Sheltered	Half-sheltered	Exposed
W Gulf of Bothnia			
Hornslandet			
0	40	70	100
1–10	20	20	0
11–100	30	10	0
> 100	10	0	0
<i>n</i>	10	20	20
SW Gulf of Bothnia			
Gräsö			
0	60	27	80
1–10	25	27	13
11–100	15	42	8
> 100	0	5	0
<i>n</i>	40	60	20

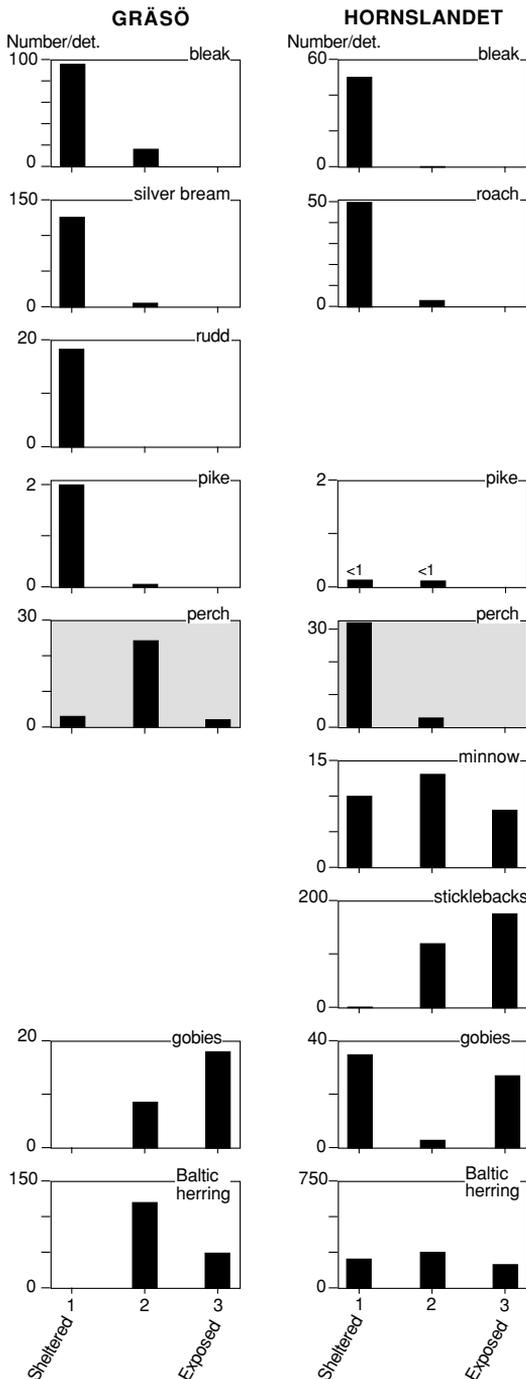


Fig. 8. Abundances of young-of-the-year of different species on a scale of different exposure at Gräsö and Hornslandet.

down to and below 10°C additionally have the potential to dramatically increase larval mortality, since this temperature is close to the lower limit for their survival (Hokansson 1977, Karås 1987).

In the well-protected bay in the Gräsö area in southern Gulf of Bothnia growth was high, but the abundance of 0+ perch was low. Additional quality factors to the basic influence of temperature thus may influence recruitment in this case. Among these are vegetation as shelter, the oxygen situation, level of predation and access of food. The food-limiting effects mentioned, occurring during high temperatures, might also be one reason for these young fish to move out of this habitat.

According to the recruitment model, variations in the temperature conditions between years in a certain habitat will lead to fluctuations in year-class strength. The model, however, also predicts that the extension of the areas possible for recruitment will change in a similar manner. Thus, in a warmer year in, e.g. archipelagos, the areas producing recruits will be extended. The large fluctuations in perch year-class strength (Kipling 1976, Neuman 1976, Willemssen 1977, Buijse 1992) may, thus, be explained by cooperating factors.

Comparisons with other species showed that all typical warm-water species represented (bleak, silver bream, roach, rudd and pike) had distribution patterns similar to perch (Fig. 8). They were, however, even more concentrated to the most shallow and sheltered parts of the coastal area. Thus, the recruitment model for perch may to some extent also be used to predict distribution of recruits in these species. Young-of-the-year of other species like minnow, sticklebacks, gobies and Baltic herring, however, have wider distribution areas (Fig. 8).

In conclusion, perch recruitment areas at exposed coasts in the Gulf of Bothnia seem to be limited to the most sheltered bays and adjacent fresh-waters. Exposed areas of the archipelagos are other habitats where recruitment production is restricted. Sheltered archipelagos, however, have this potential all over the Gulf. In the southern parts recruitment is possible further out from the mainland than in the north. In some of the areas in the north of the Gulf of Bothnia, only very sheltered bays and fresh-waters have the potential to produce perch recruits. In gen-

eral, the hypothesis that a temperature-based recruitment model could be used to describe the basic quality of potential recruitment areas in the Gulf of Bothnia was verified.

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