The Basin Water

In stagnation periods, the properties of the basin water change only slowly due to vertical diffusion. A rough estimate of the mean rate of diapycnal mixing in the basin water may be obtained from eqn [14].

$$\frac{\mathrm{d}\rho}{\mathrm{d}t} = -\frac{CW}{gH_\mathrm{b}^2} \qquad [14]$$

Here the empirical constant C equals 2.0 and W may be obtained from eqn [5]. The vertical diffusivity κ at the level z in the basin water may be computed from the empirical expression in eqn [15].

$$\kappa(z) = \frac{W/H_\mathrm{b}}{\rho \bar{N}^2} c_\kappa \left(\frac{N(z)}{\bar{N}}\right)^{-1.5} \qquad [15]$$

Here $\bar{N}$ is the volume-weighted vertical average of the buoyancy frequency $N(z)$ and $c_\kappa\ (\approx 1)$ is an empirical constant.

The basin water may be expected to be completely exchanged during the period T_e defined as in eqn [16].

$$T_\mathrm{e} = \frac{R_\mathrm{e}}{\mathrm{d}\rho/\mathrm{d}t} \qquad [16]$$

Here R_e is the mean density reduction in the basin water needed to obtain a complete exchange. T_e is the residence time for basin water. Along the Norwegian West Coast, the value of R_e is about $4/3\,\mathrm{kg\,m^{-3}}$. The value of R_e should depend on the characteristics of density fluctuations in the coastal area, and may thus possibly attain different values in other regions. Combining eqns [14] and [16] shows that the residence time decreases as W increases.

Some fiords have very narrow mouths that will hamper exchange of new deep water. A measure of this is the filling time, which is the volume of the basin water divided by the flow rate of new basin water. If the filling time for a fiord is very long, the basin will be filled not only with the densest but also with less dense coastal water. The basin water in such a fiord will thus have lower density than the basin water in a neighboring fiord with similar conditions except for a much shorter filling time.

Conclusions

This essay on fiord circulation demonstrates that several oceanographic processes of general occurrence are involved in fiord circulation. Being sheltered from winds and waves, fiords are excellent large-scale laboratories for studying these processes. The mechanics of water exchange of surface and intermediary layers, as described here, should apply equally well to narrow bays lacking sills.

See also

Dispersion and Diffusion in the Deep Ocean. Estuarine Circulation. Flows in Straits and Channels. Internal Tidal Mixing. Internal Tides.

Further Reading

Aure J, Molvær J and Stigebrandt A (1997) Observations of inshore water exchange forced by fluctuating offshore density field. *Marine Pollution Bulletin* 33: 112–119.

Freeland HJ, Farmer DM and Levings CD (eds) (1980) *Fjord Oceanography*. New York: Plenum.

Farmer DM and Freeland HJ (1983) The physical oceanography of fiords. *Progress in Oceanography* 12: 147–220.

Stigebrandt A (1999) Resistance to barotropic tidal flow by baroclinic wave drag. *Journal of Physical Oceanography* 29: 191–197.

Stigebrandt A and Aure J (1989) Vertical mixing in the basin waters of fiords. *Journal of Physical Oceanography* 19: 917–926.

FIORDIC ECOSYSTEMS

K. S. Tande, Norwegian College of Fishery Science, Tromsø, Norway

doi:10.1006/rwos.2001.0092

Introduction

Fiords and semienclosed marine systems are characterized by distinct vertical gradients in environmental factors such as salinity, temperature, nutrients, and oxygen; sampling of biological variables is considerably less adversely influenced by currents and weather conditions than in offshore systems. Therefore, the fiords are particularly well-suited for detailed studies of the pelagic habitat and have traditionally attracted marine scientists, mainly as a site for curiosity-driven research. They are easily accessible and have therefore been used as experimental laboratories for testing new methodologies, exploring trophic relations, and building new theories.

Compared with the fisheries on the shelf outside or in open oceanic waters, the catch from the fiords does not seem proportionately great. Nevertheless, fiords play an important role in many local communities in productive coastal areas in Norway, Scotland, British Columbia, and Greenland. There are fisheries locally renowned for local herring stocks – Loch Fyne for example – and for early year classes of Atlantic–Scandian herring. The salmon fisheries of British Columbia, Scotland, and Norway, highly seasonal affairs catching the fish as they return from the open sea to spawn in fresh water, are also a prominent resource. In more recent time, fiords have become refuse pits of cities and highly populated areas. A growing awareness of the importance of these sites for the bordering societies has led to a more cautionary use of the fiords. This is in particular true for the development of salmon and mariculture production facilities, where future demand for area is being met in coastal developmental plans developed from our knowledge of the physical and the biological setting of the particular fiord habitats.

The trophic relationships play an essential role in shaping the pattern of species interactions. Delineating their existence in the form of food chains and webs provides important knowledge of ecosystem functioning and dynamics. This basic knowledge is essential for the understanding that has to form the basis for ecosystem and management models for the marine biota; this article presents some of this generic knowledge for fiordic ecosystems.

General Features

Globally, most of the fiords are found in high latitudes: in the Northern Hemisphere north of 50°N in Canada, the United States, Greenland, Scandinavia, Scotland and Svalbard; and south of 40°S in Peru, Chile, and New Zealand. They are subjected to temperate, boreal, or arctic climates, and have many oceanographic processes that occur over a wide range of space and timescales. At the high-frequency end of the spectrum, tidal flows can generate turbulence, internal waves, and eddies, while processes such as renewal of oxygen in deep enclosed basins may in extreme cases have timescales of tens of years. Another property of fiords is the presence of strong gradients in a number of abiotic factors, which may affect organisms. The gradients may exist in the horizontal or vertical plane and may be permanent or variable.

Topography and Estuarine Circulation

The fiord systems of the world are all quite young in evolutionary time, yet they offer opportunities that are quite unique among coastal systems. Their common origin as glaciated coastal U-shaped valleys and the common hydrographic conditions give them a number of characteristic features. They are generally long, narrow, and often deeper than the continental shelf outside. A deep basin connects directly or indirectly with the open sea at one end over a relatively shallow sill, typically one-half to one-tenth the basin depth (**Figure 1**). The sill, formed by moraine material as it accumulated at the ice edge, limits the exchange of water between the fiord and the coastal region outside. Most fiords have large rivers that often enter at the head of the fiord, but a substantial amount of fresh water is drained into the fiord from the bordering mainland.

The water masses can be separated into three vertical layers: brackish surface, intermediate, and basin water. The brackish surface layer varies in time and space, dictated by the fresh water runoff, wind, and tide. At the river outlet, a local elevation of the surface generates a density-driven fresh water current out of the fiord, which is gradually being mixed with saline water from below. This vertical mixing process is called entrainment and leads to an overall increase in salinity in the surface brackish water. Entrainment leads to a compensation current below that is going in the opposite direction. This pattern of water transport is called estuarine circulation and is a prominent feature in most fiords. Owing to the Coriolis force there is a tendency for water currents to be deflected to the right (in the Northern Hemisphere), which will generate a larger outflow of surface water on the right side of the fiords compared to the left side.

The tides vary locally, but will in general add only little to the net water transport. Therefore the wind-generated and estuarine circulations, are important for the exchange of water between fiords

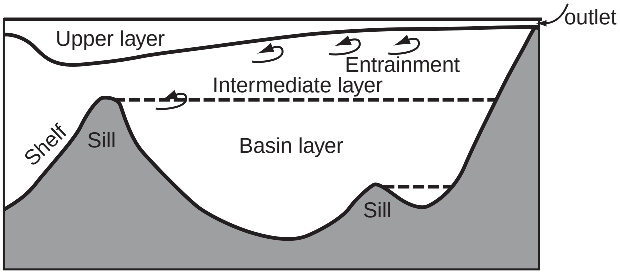

Figure 1 Basic topography and water layers of a fiord with estuarine circulation.

and the outside shelf. The wind-driven circulation is dictated by the wind stress on the surface and the vertical density gradient. The effect of the wind decreases vertically with increasing density gradient. Since the wind blows in or out the fiord, the wind-driven circulation sets up the estuarine circulation, as either an inward or an outward flowing surface layer depending on the magnitude, duration, and direction of the wind.

The main reason for water exchange in the intermediate layer is the existence of density gradients of water between the fiord and the shelf outside, which follow wind driven upwelling and downwelling at the shelf (**Figure 2**). Characteristically, this exchange occurs mainly as a two-layer circulation with inflow in the surface layer and a compensating outflow at the lower intermediate layer. This happens when the prevailing wind is northward along the western side of the continent (downwelling), and an oppositely directed circulation occurs when the wind is coming from the north (upwelling).

The sill creates a natural barrier that prevents water exchange between the basin and the corresponding depth outside. Partial or total renewal of the basin water takes place when water of higher density than the deep basin water is found above the sill. The major periods of deep-water renewals are found in late winter during upwelling conditions on the shelf outside. Total renewal of the deep water in the fiords happens occasionally, with a frequency of 5–10 years. The basin water in most fiords is being renewed at a rate that prevents anoxia. Nevertheless, in some fiords with very shallow sills, the renewal of the basin water is low and takes place through vertical diffusion. Here one can find anoxic conditions with high levels of hydrogen sulfide, due to the organic drain-off from land and sedimentation from the surface plankton production.

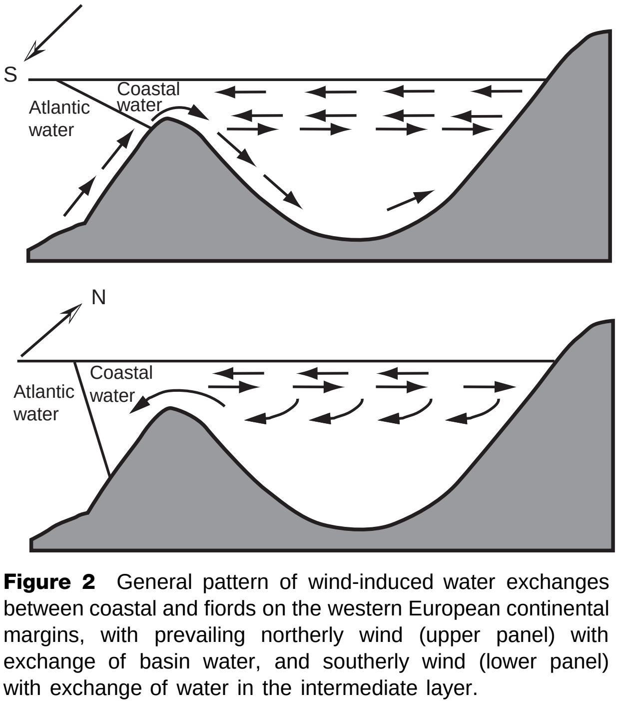

Figure 2 General pattern of wind-induced water exchanges between coastal and fiords on the western European continental margins, with prevailing northerly wind (upper panel) with exchange of basin water, and southerly wind (lower panel) with exchange of water in the intermediate layer.

The above outline of the basic physical functioning of fiords underlines the open-ended nature of fiord communities, which nevertheless seem to maintain individual and group characteristics in terms of their biology. There may be a useful distinction between fiords *sensu stricto* and smaller, more shallow enclosed systems (i.e., 'polls'). The basic distinction between these two systems is that fiords have a sill depth greater than the depth of the pycnocline, while shallow enclosed systems normally have a sill depth less than the depth of the pycnocline. In biological terms, the latter are in general an ultraplankton–microzooplankton community, whereas the fiord community is chiefly a net phytoplankton–macro/megazooplankton community.

Fresh Water Runoff and Nutrient Cycling

The fresh water runoff plays a major modifying role in the dynamics of the lower trophic organisms in a fiord. The magnitude of this fresh water runoff varies depending on the extent of the surrounding landmass. Fiords can be classified as high-runoff and low-runoff, arbitrarily separated at an annual mean river runoff of $150\,\mathrm{m^3\,s^{-1}}$. On the other hand, peak values of a few weeks' duration are found in the range from 500 to $20\,000\,\mathrm{m^3\,s^{-1}}$. There is a strong seasonal variation in fresh water runoff, with annual maximum around April in southern fiords and around June in subarctic regions. Low runoff in the beginning of the season will enhance the stabilization of the water masses, facilitating the onset of the spring bloom. Later, increased runoff enhances the washout of the surface water layer, and modifies the phytoplankton biomass and species composition.

Fresh water runoff plays a minor direct role in the nutrient cycle of fiords, where the nitrate supplied has been found to account for a maximum of 10–20% of the potential uptake by phytoplankton in June in western Norwegian fiords. Indirect factors influencing the transport of new nutrients into the photic zone from below are therefore of major importance for the new production within the fiord. Although most of the nitrate loss out of fiords takes place below the euphotic zone, such losses may affect the future vertical transport of nitrate from the nonphotic to the photic zone. Hence, advective nutrient loss in the layer close to the photic zone may lead to reduced new production within the fiord. Since loss rates of nutrient appears to exceed loss rates from phytoplankton, an advective nutrient exchange, even below the euphotic zone, may therefore be of greater importance to the primary production than the exchange of the phytoplankton itself. The above picture prevails under specific wind conditions on the coast, and in case of reversed winds a nutrient loss may be turned into net nutrient supply to the fiord.

Seasonality in Energy Input to the System

Primary Production

Year-round measurements of primary production exist for a number of fiords and demonstrate that they are in the range of the general level of production in coastal waters of 100–150 g C m^{-2} y^{-1} (**Table 1**). Some of the data indicate that remarkably high levels of primary production can exist where boundary conditions or land runoff enhance the nutrient load to the fiord. Vertical stability can also generate off-seasonal blooms, even in November and December in fiords at lower latitudes, but it is unlikely that these blooms effectively stimulate secondary production.

Table 1 Estimates of primary production in representative fiords on the Northern Hemisphere

Region	*Year*	*Primary production (g C m^{-2} y^{-1})*
Norway		
Balsfjorden	1977	110
Lindåspolls	1976	90–100
Sweden		
Kungsbackafjord	1970	100
Greenland		
Godthaabfjord	1953–56	98
Canada		
How Sound		
entrance	1973	300
entrance	1974	516
inner stations	1973	118
inner stations	1974	163
Port Moody Arm	1975–76	532
Indian Arm and the Narrows regions	1975–76	260
Strait of Georgia	1965–68	120
River Plume	1975–77	149
USA		
Puget Sound	1966–67	465
Port Valdez	1971–72	150
Valdez Arm	1971–72	200

A significant proportion of the annual phytoplankton production occurs before the macrozooplankton grazing population becomes established. The estimated annual flux of phytoplankton based carbon to the bottom of fiords is $\sim 10\%$ of the total particulate material sedimentation. This means the majority of the particulate material reaching the bottoms of the fiord is inorganic. Although there is a strong component of copepods in fiord communities, krill, when present, are the major pellets producers contributing to the recognizable organic matter reaching the fiord bottom. Surface sediments show negligible seasonal variation in total organic matter, organic carbon and nitrogen, amino acids, and lipids. This may be due to a rapid conversion of sediment material into a pool of sediment microorganisms. The macrobenthos in the deep basin can be dominated by specialized deposit-eaters, such as the echinoderm (*Ctenodiscus crispatus*), which accumulates fatty acids indicative of an extensive microbial input.

Variability in Time and Space

Scaling of Exchange Processes

The pelagic community in fiords is often found to have a higher variability in time and space than that in oceanic water. This is mostly related to differences in advection between the habitats, where the strongest flushing is usually found in fiords.

As the physical scale of fiords varies, the balance between internal and external forcing is also likely to vary. The cross-sectional area above the sill is therefore an important boundary property, and the ratio between the cross-sectional area and the total fiord volume may indicate the impact of the sill boundary conditions on the fiord. This ratio varies considerably from one fiord to another (**Table 2**). In

Table 2 Examples of ratios of cross-sectional area (*A*) to total fiord volume (*V*) in Norwegian fiords

Fiord	*A/V*	*Advective influence*
Lindåspolls	10^{-7}	Advective influence of *Calanus* population < internal processes
Ryfylke fjord	2×10^{-6}	Advective exchange of zooplankton < internal production
Masfjord	8×10^{-6}	Advective exchange of zooplankton = internal production
Malangen	4×10^{-5}	Advective exchange of zooplankton biomass > internal production
Korsfjorden	10^{-4}	*Calanus* heavily influenced by advective processes

a sill fiord, the cross-sectional area of the fiord mouth (A) is believed to constrain the water exchange over the sill. The advective impact has been found to be larger in fiords with a high ratio of cross-sectional area to total fiord volume (see A/V in **Table 2**).

The extent to which the planktonic part of a fiord system is controlled by internal biological processes rather than advective processes depends on the physical scale of the fiord versus the timescale of these processes. As a general simplification we may write eqns [1] and [2].

$$\frac{\delta B}{\delta t} = rB + 0.5vR(B_{\mathrm{B}} - B) \qquad [1]$$

$$R = \frac{A}{V} \qquad [2]$$

Here B = biomass concentration within the system (mg m^{-3}); t = time (s); r = local instantaneous growth rage of B (s^{-1}); v = mean absolute current above the sill (m s^{-1}); B_{B} = biomass concentration in incoming current (mg m^{-3}); A = cross-sectional area above the sill (m^2); and V = fiord volume (m^3).

As B approaches B_{B}, the net advective effect becomes zero. This does not mean, however, that the advective effect has ceased, since the biomass renewal within the system may still be dominated by advection rather than local growth. The growth rate (r) and the advective rate ($\beta = 0.5\,vR$) have the same dimension (s^{-1}) and the ratio r/β decides which of the two processes dominates the biomass formation within the system. If $r/\beta > 1$, growth is the dominating process, while $r/\beta < 1$ indicates advective dominance.

The importance of advection relative to the growth of phytoplankton and zooplankton is given in **Figure 3**. The much lower growth rate of zooplankton compared with that of phytoplankton implies that the transport influences primarily the zooplankton biomass. Phytoplankton is, however, constrained to the upper, photic, zone where transport processes are most prominent. Zooplankton may utilize the entire water column and the advective influence may thereby be diminished. The zooplankton confined to the advective layer (dotted line) in **Figure 3** is influenced three times more strongly by advection than is zooplankton distributed in the entire fiord volume (solid line). Similarly, vertical migration (diel and seasonal) may also reduce the influence of advection for populations depending on the food availability in the advective layer.

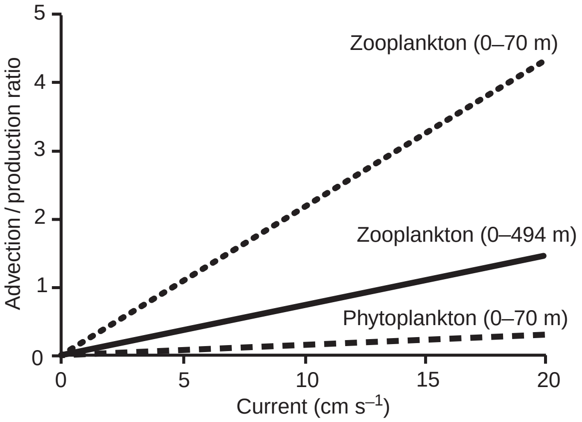

Figure 3 The relation between the ratio advection/production and current velocity for phytoplankton and zooplankton in a fiord. Modified from Aksnes *et al.* (1989).

From eqns [1] and [2] we see that the value of R (ratio between the cross-sectional area above the sill and the fiord volume) gives the order of magnitude of the advective influence in a particular system. This ratio varies considerably from one fiord to another (**Table 2**), and it may serve as an index indicating the potential advective influence on a system.

Impact of Tidal Currents

The tidal amplitude varies by approximately a factor of 2 within the regions where fiords are found. Tidal currents result in no net water exchange when averaged over a tidal period (12.42 h). On the other hand, there is a significant vertical difference in tidal currents, where the highest flow rates are found in surface layer, with concurrent flow in the opposite direction close to the bottom. Therefore, total exchange of organisms is not necessarily proportional to the net exchange of water, and the vertical position of the organisms plays a major role for the advection rate.

The renewal rate of water and zooplankton can be calculated as a percentage of the total water and zooplankton biomass volume in a fiord with moderate to high tidal amplitudes (**Table 3**). Comparing contrasting periods in spring and autumn, the total renewal rate of the water is ~6% and 14% per day in spring and autumn, respectively. The numbers for the two given size categories of zooplankton are 6% in spring, 3.5% for zooplankton > 500 μm and 12% for zooplankton between 180 and 500 μm in size. The importance of the tidal current for water and zooplankton transport can be estimated by comparing the residual current (i.e.,

Table 3 Advective daily transport of water and zooplankton biomass in Malangen, expressed as percentage of the entire volume inside the fiord

	Spring (%)		*Autumn* (%)	
	Total	*Residual*	*Total*	*Residual*
Water	6.1	3.6	14.6	8.1
Zooplankton > 500 μm	6.6	5.1	3.5	1.2
Zooplankton 180–500 μm	6.4	5.2	12.0	7.4

the current velocity after the removal of the tidal component) and the total current. For example, the tidal water is responsible for 23% and 66% of the renewal of zooplankton > 500 μm during spring and autumn, respectively. Equivalent numbers for the smallest size fraction of zooplankton are 19% and 39%. This demonstrates that the tide can play an important role in the transport of zooplankton in fiords.

Impact of Vertical Behavior

The zooplankton community structure in fiords appears to be determined primarily by the species–environment relationship, rather than species–species relationships as in the central oceanic gyres. Different spatial distribution patterns are often observed along the length of the fiord, where populations decrease as they are moved away from their population centers. This along-fiord difference in abundance usually evolves from homogenous low stocks of overwintering populations early the same year.

Neritic species prevail at the inner regions, with a downstream decline in the abundance. Most oceanic species have been unable to establish viable populations even in the deepest part of the fiords. However, some, mesopelagic oceanic species have succeeded and the species-specific along-fiord differences in abundance vary and are linked to their differences in vertical behavior.

Most zooplankton migrates on different timescales, and by diel vertical migration (DVM) the population tends to move from deep waters during daytime to surface during night. The residence time during day and night is normally much longer than the transition time between upper and deep waters. Combining the residence time of the animals with the total current in the same depth strata of the water column, a simple prediction of the displacement over time can be estimated. For a species with wide and regular vertical migration, for instance, *Chiridius armatus*, there is a strong tendency to reside in the same geographical region over time (**Figure 4**). This species does best at deeper and more oceanic sites, and has been found to reduce its population size by a factor of 4 over a distance of 3–4 km, with an overall decline in abundance toward the head of the fiord.

Other species have very low migration amplitude, where ontogenetic migration tends to keep the recruits in surface water for a long time, with an induction of a slow downward migration at older life stages. This is the case for the oceanic species *Calanus finmarchicus*, which has its population center in the North Atlantic and the Nordic Seas but is a very widely distributed and quantitative species in the fiords of the Northern Hemisphere. *C. finmarchicus* spends as much as 8–9 months in the deep waters > 500 m while reproduction and growth takes place at the surface from April to July.

C. finmarchicus is a very prominent species on the shelves and in the fiords during the productive season but descends during summer and early autumn, being drained off from the shallower areas toward overwintering depths in deep basins in the fiords and the continental shelves. In some fiords the biomass build-up can reach 10–20% per day, and the high biomass, in particular in the basins during the autumn, clearly indicates that physical/biological aggregation mechanisms overrule the local produc-

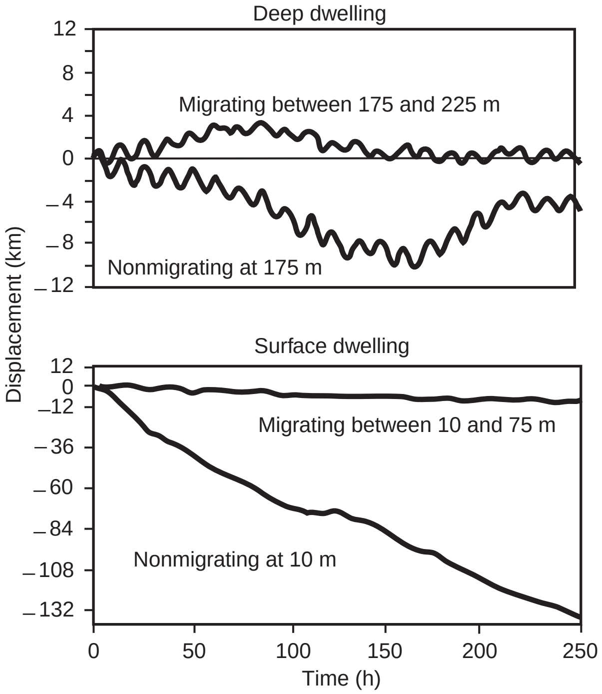

Figure 4 The travel distance for copepods migrating between 175 and 225 m and residing at 175 m during a 24 h cycle (upper panel), and for copepods migrating between 10 and 75 m and residing at 10 m during a 24 h cycle (lower panel).

tion. The mechanisms can be explained by the same simple model given above (**Figure 4**), where a declining flush rate with depth tends to retain older stages as they initiate the downward migration during the summer. The biomass aggregation will thus continue for several months, draining older stages from the upper and intermediate water layers in the fiord.

Food Web Structure and Functioning

The Zooplankton Community

The community structure varies extensively between fiords but reflects mostly the shelf habitats found at similar latitudes (**Figure 5**). In subarctic waters, the zooplankton is composed of few species, but with high biomass. Small copepods may be abundant, especially during summer and autumn, and are not major pathways to the juvenile and adult fish. The larger copepods forms (i.e., *Calanus finmarchicus* and *Metridia longa*), the chaetognath *Sagitta elegans*, and the two krill species (*Thysanoessa* spp.) form easily identifiable trophic links in the transfer of materials to higher trophic levels. They all spawn during spring, matching the spring bloom to variable degrees, and each has a restricted growth period within the time-window from April to October. During the long overwintering period a marked decrease in organic lipid-based reserves takes place in both copepods and krill, accounting for 40–70% of that present at the end of the primary production season. Copepods and krill are often found as sound-scattering layers (SSLs) in the basin water of the fiord, and are heavily preyed upon both by demersal and pelagic fish.

The Higher Trophic Animals

In fiords there may be around 30 species that have a commercial potential, although only half of these are exploited regularly by man. Some pelagic and demersal fishes are separated into ocean and coastal stocks, where the former spends their time mostly in the ocean and visit the coast during spawning or overwintering. The latter are more confined to the fiords and coastal zones during their entire lifetime.

The communities in fiords may have from one to several apex predators. In some fiords cod plays this role, and as many as 70 taxa have been found in cod stomachs from Balsfiorden, northern Norway. Although as many as 15 fish species were identified, krill, capelin, and herring are considered its dominant prey. This emphasizes that cod is weakly

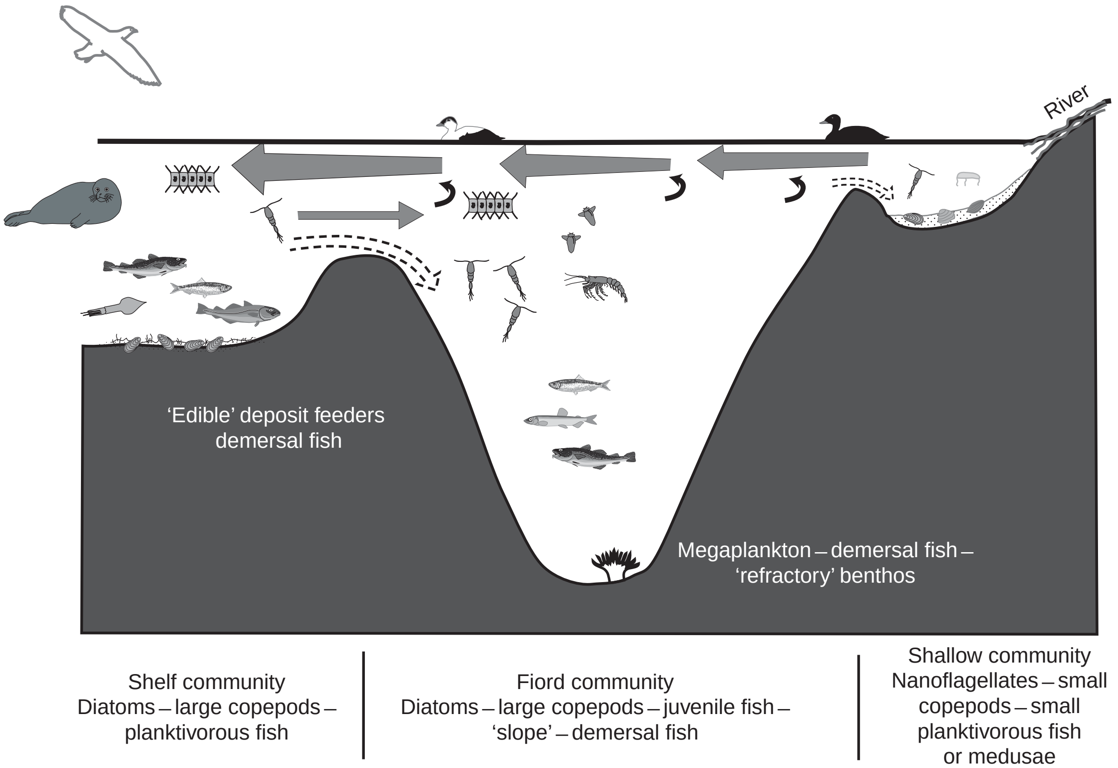

Figure 5 A generalized structure of the biological community from the shelf to the inner part of the fiord. Modified from Matthews and Heimdal (1980).

linked with the benethic community. Prawns, also, may be more trophically dependent on the pelagial, a feature contrary to the general tendency in the literature to classify them as part of the benthic food chain. The cod stocks in fiords are mostly coastal cod and undertake very little migration. Tagging experiments have documented that individuals are confined to an area from 5 to 8 km in extent during their entire lifetime. Artificially released cod tend to migrate over longer distance and are more easily trapped by fishing gears and other predators, and are thereby subjected to a higher risk of predation. Cod stocks in fiords may have lower growth rate, length, and age at maturity than oceanic stocks, which indicates that they may be subjected to different management strategies in future.

Consumption of cod by mammals other than man is substantial, although it varies extensively between fiords. Species such as sea otter, harbor seals, and porpoises do visit fiords for short time-windows, having a more limited affect as predators on the local fish fauna. Cormorants have a less varied diet and are known to roost and feed in fiords from late September to early April, within 8 km of their night roost. Although their toll on local cod stocks may be low, around 1/20 in terms of numbers, compared to cannibalism within the cod population, their local impact is still important since they prefer juvenile cod in the length range 4–50 cm.

Other Structural Forces of the Pelagic Community in Fiordic Ecosystems

Light is an important limiting factor for the visual foraging process in fishes, and the light regime may potentially affect the competition between visual and tactile predators. Food demand and risk of mortality are regulated by balance between catching and avoidance between predator and prey, which ultimately may be regulated by visibility in the water column. The seasonal variation in the light may therefore be an important structural force for vertical distributions of important components in the community in fiords. Zooplankton size and density increase with depth; the most visible forms are found only in deep waters. At night, macroplankton and mesopelagic fishes are dispersed in the water column, with a tendency for dispersion of the SSL. All components of the SSL respond to changes in light intensity during day, in order to balance vision versus visibility. The pelagic juvenile fishes in the upper part of the SSL migrate to the surface to maximize their feeding period. The more visible fishes stay in the deeper part of the SSL. At dawn, euphausiids (*Meganyctiphanes norvegica*) descend from surface waters to midwater depths, and the larger mesopelagic fishes (*Benthosema glaciale*) and the pelagic prawns (*Sergestes arcticus* and *Pasiphaea multidentata*) migrate to even darker water. Large pelagic fishes are found in the entire water column, feeding with the highest densities mainly below and at the deepest end of the SSL.

A strong faunal difference is often found between adjacent fiords. This has been linked to the differences in the light climate, fiords with low visibility tending to have a higher component of jellyfish, with the jellyfish being replaced by fish in fiords with higher visibility. This has prompted the hypothesis that the visibility regime may affect the distribution of tactile and visual predators such as jellyfish and fish. The implication is that light is a forcing factor on the marine ecosystem dynamics through the visual feeding process, with potential secondary links to eutrophication. The mechanistic relationship between differences in sea water absorbance and the biological components is not established, but fiords with different visibility regimes will still play an important basis for research needed for ecologically based future management of these important marine biotopes.

See also

Beaches, Physical Processes Affecting. Coastal Circulation Models. Copepods. Fish Larvae. Fish Migration, Vertical. Fish Predation and Mortality. Krill. Macrobenthos. Marine Mammal Trophic Levels and Interactions. Meiobenthos. Mesopelagic Fishes. Patch Dynamics. Pelagic Fishes. Phytoplankton Blooms. Primary Production Processes.

Further Reading

Aksnes DL, Aure J, Kaartved S, Magnesen T and Richard J (1989) Significance of advection for the carrying capacities of fiord populations. *Marine Ecology Progress Series* 50: 263–274.

Howell B, Moksness E and Svåsand T (eds) (1999) *Stock Enhancement and Sea Ranching*. Oxford: Fishing News Books.

Falkenhaug T (1997) *Studies of Spatio-temporal Variations in a Zooplankton Community. Interactions between Vertical Behaviour and Physical Processes*. Dr Scient thesis, University of Tromsø; ISBN 82-91086-12-5.

Matthews JBL and Heimdal BR (1980) Pelagic productivity and food chains in fiord systems. In: Freeland HJ, Farmer DM and Levings CD (eds) *Fiord Oceanography*. New York: Plenum.