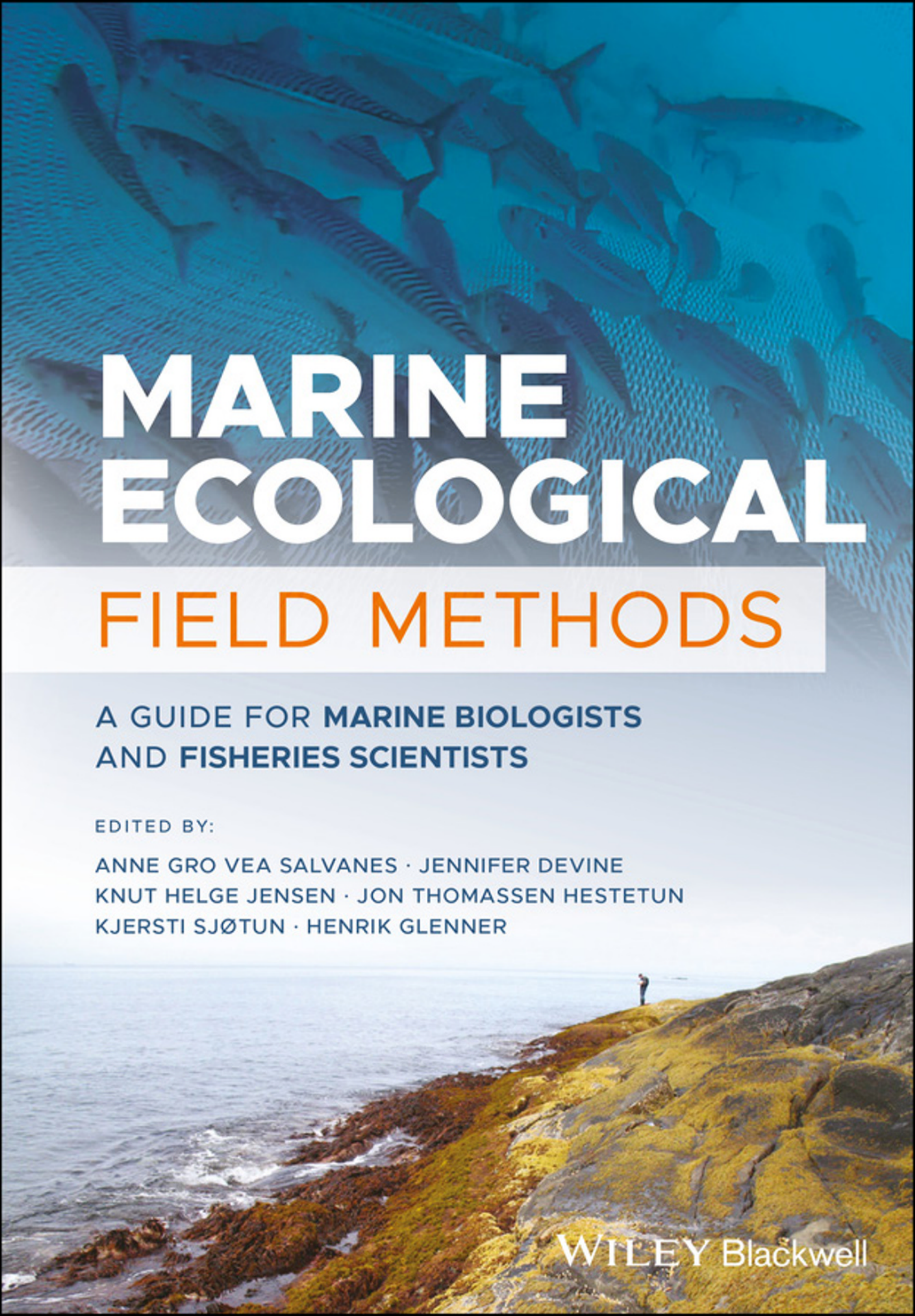

MARINE ECOLOGICAL FIELD METHODS

A GUIDE FOR MARINE BIOLOGISTS AND FISHERIES SCIENTISTS

EDITED BY:

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Foreword

Despite covering over 70% of the surface of the planet, the marine environment is less accessible, and thus less well-known than terrestrial habitats. A variety of technologies allow for marine field studies on environments ranging from the shallow nearshore to depths of thousands of meters, on individuals, populations, communities, and ecosystems. This book describes marine ecological sampling equipment, methods, and analysis, ranging from physical parameters to fish, microalgae, zooplankton, benthos, and macroalgae. It will be useful for graduate students and early-stage professionals in marine biology and fisheries, even those not directly involved in fieldwork, by giving an overview of marine biological data collection, handling and analysis.

This handbook provides a guide to the use of marine ecological sampling methods used for pure research and for fisheries management purposes. The book covers survey and sampling design, sample and data collection and processing, and data analysis. The research question and characteristics of the organisms and habitat dictate what sampling equipment is required. Information is included on sampling equipment, ranging from those that are useful in shallow nearshore areas, such as bottles, secchi discs, and gillnets or beach seines to those deployed from large research ships for studies offshore, such as remotely operated vehicles (ROVs), fishing trawls, and hydroacoustics, or remote observation using satellites.

The development of this book started at the Department of Biology at the University of Bergen in 2011; when due to lack of suitable literature, students attending a marine field course were provided with short handouts. The handouts became more and more advanced from year to year. In 2014 the publisher Wiley became aware of the initiative and invited us to write a textbook for broader use. The six editors of the book have, over several years, been involved in the writing and development of the book project. As we came across additional themes relevant for the handbook, and that we ourselves felt we did not know well enough, we invited experts from our network at the Institute of Marine Research and the Department of Biology at the University of Bergen to contribute as co-authors. The editors have produced text, and in addition taken the lead on the structure, contents, and in the editing of the entire manuscript. All editors have worked on the full text. A.G.V. Salvanes has had the main responsibility for coordinating the work, J. Devine has had the final edit on all chapters, J.T. Hestetun was mainly responsible for keeping references organized and for quality evaluation of figures.

All artwork was produced by R. Jakobsen. We hope the handbook will help reader to plan and execute fieldwork to answer research questions, and provide basic knowledge of the most common methods for collecting field data for modern marine research. We also hope the handbook will enable readers to explain and evaluate the principles of different sampling approaches, their strengths and weaknesses, and not least how to process, catalog, and interpret collected field samples and experimental data.

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Bergen, January 20, 2017

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1

The Marine Environment

Jon Thomassen Hestetun, Kjersti Sjøtun*, Dag L. Aksnes, Lars Asplin, Jennifer Devine, Tone Falkenhaug, Henrik Glenner, Knut Helge Jensen and Anne Gro Vea Salvanes*

The marine environment covers over 70% of the surface of the Earth, yet represents special challenges when it comes to scientific inquiry. When compared to terrestrial systems, the marine environment is much less easily accessible and, despite great effort, remains less well known. With the rise of the modern natural sciences, tools and methods have been continually developed to explore marine environments, from the littoral zone and nearshore environment to open waters and the shelf and abyssal seafloor. From tried and true collection equipment, often identical to or based on fishing gear, to new innovations in remotely controlled and autonomous vehicles, exploration of the underwater world is heavily dependent on the tools used.

Technological advancement now allows marine field studies to be conducted at all levels: from individuals to populations, to groups of populations, and to entire ecosystems. Habitats from the shallow nearshore to depths of thousands of meters are increasingly accessible; studies of interactions between specific organisms and physical and biological components are possible. The equipment used for sampling is dependent on the research questions asked and the characteristics and depth of the studied organisms and their habitat. Gears range from simple tools that are useful in shallow nearshore areas, such as bottles, secchi discs, and gillnets or beach seines to advanced equipment, such as remotely operated vehicles (ROVs), fishing trawls, and hydroacoustics deployed from large research ships for studies offshore and at greater depths. Even remote observation from space can be performed using satellites.

A characteristic transect from a continental landmass to the deep ocean includes nearshore environments that, depending on local geology, may consist of sandy beaches, cliffs or fjord systems. The continental shelf may stretch out some distance from the continental landmasses, gradually giving way to the continental slope, which descends down to the abyssal plains of the world's major

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oceans. As an example, the western coast of Norway contains an elaborate fjord system with numerous deep basins divided by shallower sills, giving way to the Norwegian Channel and then the shallower continental shelf. To the southwest, the North Sea is a shallow sea on top of a continental shelf only, while to the northwest, the Norwegian Sea descends into a deep-sea basin which also contains the Mid-Arctic Ridge, separating the Eurasian and North American continental plates. Banks, seamounts and submarine canyons are features that add to the topographical complexity of this general system (Figure 1.1).

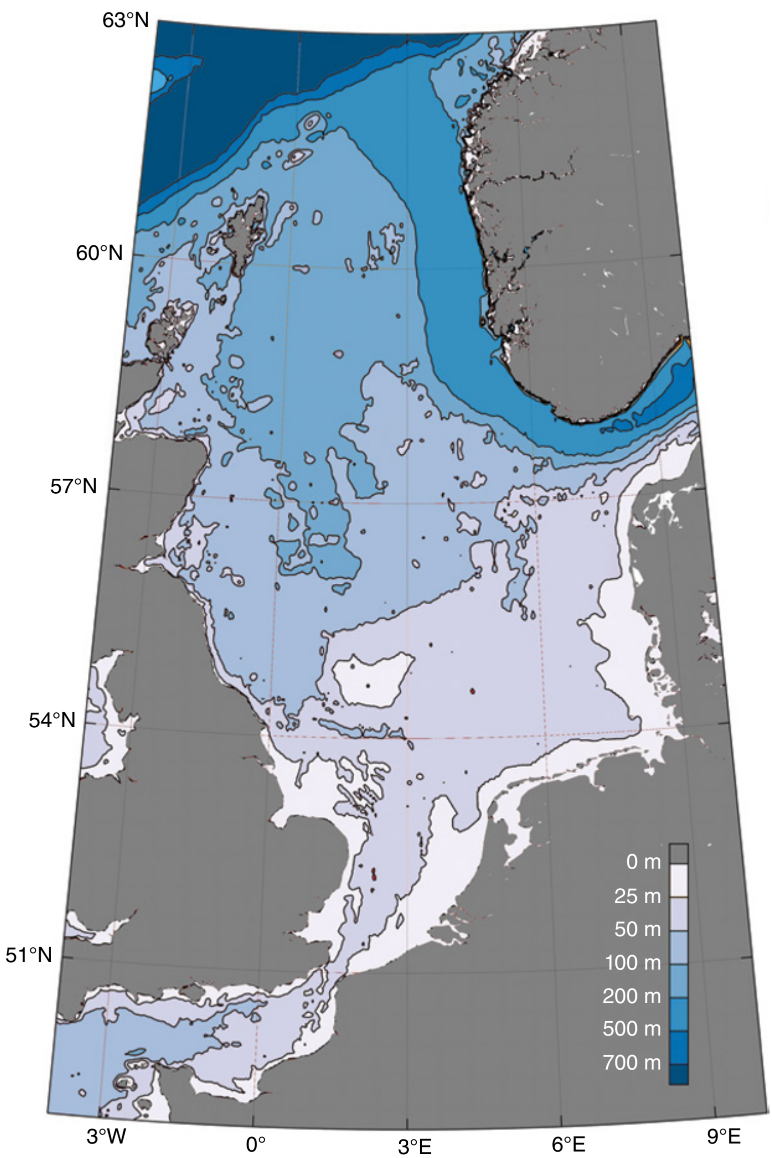

Figure 1.1 Topographic chart of the North Sea. *Source:* G. Macaulay, Institute of Marine Research, Norway.

Species composition changes with depth and distance from the coast, both for pelagic species and for organisms associated with the seafloor. Organisms are morphologically, physiologically, and behaviorally adapted to their environment through natural selection. Individuals with favorable genetic traits have increased breeding success than those lacking these traits (genetic adaptation). Some species are able to shift between environments and habitats, for instance benthic species with a pelagic egg and larval phase, or species that shift diurnally between different water depths (diel vertical migration, DVM). Diel vertical migration typically occurs between water masses with different properties in terms of light, temperature, oxygen, and salinity, requiring a physiological response from the organism. In general, effects of abiotic and biotic factors influence morphology, physiology, and behavior and thus how animals adapt to their habitat.

Examples of **abiotic factors** are the optical properties of the water column and include: light and the amount of suspended particles, which are important for visual predation; temperature, which regulates physiology, metabolic processes, and swimming activity; salinity, which affects physiology and osmoregulation; oxygen levels, which regulate respiration and metabolism and can limit reproduction or growth at low levels; and depth, which regulates pressure and affects buoyancy of fish that use swim bladders to obtain neutral buoyancy. Stratification of water masses, which often is seasonally dependent, limits nutrient availability in upper strata (the photic zone, as well as oxygen concentration in the lower strata or in isolated basins. Eutrophication and closeness to urbanized regions will also affect the level of primary production and the depth range where visual feeding is possible.

Biotic factors influencing the structure of marine communities and ecosystems include prey availability, predation, competition, and parasitism, and are regulated by direct or indirect access to production from lower trophic levels. Trophic communities in shallow waters benefit from readily available photosynthetic primary production, however, such production may be limited by nutrient availability. Organisms in deeper layers usually depend on energy and biomass from above either through migrating animals, transporting nutrients from surface waters to depths, or through the downward transport of debris, dead organisms, and particulate organic matter (POM). Because lower systems are dependent upon the upper regions, total biomass often decreases with depth. Population and individual growth potential will be further regulated through food access and competition. Access to reproduction (mates and spawning grounds) and reproductive behavior (nest spawning, demersal spawning, or pelagic spawning) will affect recruitment to populations. Presence of suitable nursery environments (e.g., coral reefs and kelp zone habitats) regulates survival of early life stages (larval stages of benthos and juvenile fish). Mortality risk (predator density, visibility, and size) in the habitats also changes with depth and distance from the coast.

Chapter 1 begins with a brief description of zonation in the pelagic and benthic realms, followed by a description of the topographies of coastal and fjord biotopes, the continental shelf and slope, and the deep ocean. These biotopes shape the habitats for bottom associated marine organisms. This is followed by a description of the physical characteristics of the pelagic ecosystem, including circulation of water masses in fjord ecosystems and a description of the light environment in marine waters. The chapter ends with an overview of temperate organisms (benthos and fish) that inhabit the littoral, sublittoral, continental shelf and slope, deep fjords, and the deep sea.

1.1 Marine Habitats

1.1.1 The Pelagic and Benthic Realms

The oceans are commonly divided into the pelagic and benthic realms. The pelagic realm refers to the body of water from above the seabed to the surface of the water. The organisms swimming or floating in this water column are termed pelagic and can be roughly divided into nekton, able to control their position in the water masses, and plankton. Traditionally the pelagic realm is subdivided into five zones:

1) The epipelagic: from the surface to about 200 meters and where the amount of UV light from the sun still allows photosynthesis.
2) The mesopelagic zone: from about 200 to approximately 1000 meters. The twilight zone where the organism still might be able to detect sunlight, but at which depth the energy from UV light is too limited for photosynthesis.
3) The bathypelagic zone: from 1000 to about 4000 meters, where no sunlight remains.
4) The abyssopelagic zone: from about 4000 to 6000 meters. The average depth of the largest oceans in the world is largely contained in this zone – between the 3300 meters of the Atlantic Ocean to the 4300 meter average depth in the Pacific.
5) The hadopelagic zones: between 5000 to 6000 meters. These zones are found in relatively restricted areas like deep trenches to the deepest trench, the Mariana trench, which is about 11 000 meters deep.

The benthic realm is defined as the bottom sediment or seabed of the ocean and the organisms in or on it are defined as the benthos. Organisms living in the benthic realm are living in close a relationship with the sediment, often permanently attached to it (epibenthos) or burrowing in it (endobenthos), while others, although they can swim, are never found far away from the seafloor, on which they are totally dependent (hyperbenthos or, in the case of fishes, demersal).

About 80% of the ocean floor consists of soft sediment, which can be designated as marine sediments of particle size ranging from mud to coarse sand (0.05 mm to about 1 mm in diameter). This entails that this soft-bottom substrate type defines the vast majority of habitats, from the high subtidal zone to the deepest part of the abyssal zone. Obviously, the term is very broadly defined, and soft sediments can be divided into a number of subhabitats, which are dependent on latitude, temperature and other local environmental factors, including a wide size range and a high diversity of associated organisms.

Ocean hard bottom areas, while less extensive, represent important habitats distinguished by differences in biota composition and dominating life strategies compared to soft-bottom counterparts. Hard bottom seafloor is often associated with specific topographical features such as for instance submarine canyons, seamounts or mid-ocean ridges, or other areas with stronger currents. It can provide substrate for large number of immobile organisms, and current activity can form the basis of filter-feeding communities.

The benthic realm is zoned by depth in a way that generally corresponds to the zones in the pelagic realm:

1) The intertidal zone: where land meets the sea. This has no parallel in the pelagic realm.
2) The sublittoral zone: defined as the area of the coast that, even at lowest tide, is always submersed to the extent of the continental shelves. The continental shelves extend to approximate depths of 200 meters. This corresponds to the epipelagic zone.
3) The bathyal zone: extends from 200 meters to approximately 4000 meters. This also includes the continental slope and corresponds to the mesopelagic and the bathypelagic zone.
4) The abyssal and hadal zones includes most of the ocean seafloor from 4000 meters to the deepest trench at 11 000 meters. These zones correspond, respectively, to the abyssopelagic and the hadopelagic zones in the pelagic realm.

1.2 The Coastal and Fjord Biotopes

Fjord systems are found in many areas of the world including Alaska, Chile, Greenland, Norway, and New Zealand. They have a complex topography that can include numerous narrow passages, and are often divided into basins divided by shallower sills, which are shallow ridges situated at the mouth of the fjord and are normally old moraines. The outer part of the coast consists of a number of islands and thus the sheltered inland fjords give way to a coastal archipelago with a more wave-exposed and open coast on the outside (Figure 1.2). The topography of the coast of southwestern Norway represents typical characteristics of fjord biotopes, consisting predominantly of rock, with a few areas with sand beaches. The landscape and seascape was formed mainly by the activity of the large ice sheets during the glacial periods. As a result of glacial activity, the coast is divided by a number of large fjords. Many fjords are deeper than adjacent sea areas. For example, the Norwegian Sognefjord reaches a depth of 1308 m, significantly deeper than the offshore continental shelf.

This complex topography creates barriers to the passage of water as well as organisms, meaning that a fjord system can contain several distinct habitats or even ecosystems. Fjords are situated in the cold temperate parts of the world, meaning that they are subjected to strong seasonality, with seasonal differences in light and temperature conditions between winter and summer. Seasonal differences in water temperature are strongest in the surface layers. During winter, increased mixing of surface and deeper water layers creates a uniform water column, while in the summer, increased temperature and freshwater runoff create a distinct surface layer with different water properties than the deeper layer. In periods with high freshwater runoff, such as during the snowmelt period in spring and early summer, a clear salinity gradient from the outer to the inner part of the fjord is often apparent. Surface waters, the uppermost 10–15 m, in the

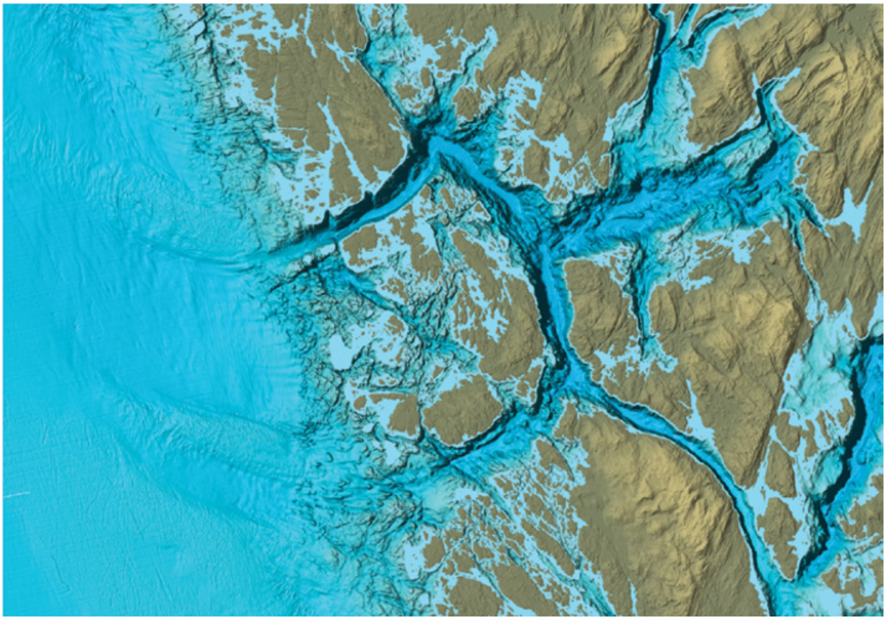

Figure 1.2 Part of the coastline of Western Norway, showing the complex bathymetry characteristic of fjords and many other coastal systems. *Source:* Gavin Macaulay, Institute of Marine Research, Norway, with permission from The Norwegian Mapping Authority.

inner parts of the fjord will have the lowest salinity. The bottom waters will often have low to zero oxygen concentrations because of the limitations sills and inlet passages set on water passage in the deeper layers; effects may be seasonal or year round. Nutrient runoff from adjacent land areas will also contribute to decreased oxygen concentrations in deep water.

The high variability in physical factors and barriers to propagation mean that fjord systems are typically home to many different communities and have an overall high biodiversity. In many cases, isolated relict populations of species can survive in fjord basins long after they have disappeared from adjacent sea areas.

1.2.1 The Littoral and Sublittoral Habitats

The **littoral zone** is used as a somewhat arbitrary term which normally refers to the intertidal and the very shallowest parts of the sea (*litus*, *litoris* (Latin) means "shore"). It is most commonly used for marine habitats and covers the **intertidal zone** (the area alternately covered with water or exposed to air during a tidal cycle) and the **splash zone** above the intertidal zone.

The different parts of the littoral zone can be defined by the upper and lower limits of specific zone-forming organisms (Figure 1.3). In temperate areas, the limit between the littoral and the sublittoral zone can be defined by the upper limit of kelp beds. Sometimes the shallowest part below the intertidal zone (the sublittoral zone) is also included in an expanded definition of the littoral zone. The lower extension of the sublittoral zone is arbitrary, but it is common to