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**STANDARD METHODS FOR SAMPLING RESOURCES AND
HABITATS IN COASTAL SUBTIDAL REGIONS OF BRITISH COLUMBIA:
PART 2 - REVIEW OF SAMPLING WITH PRELIMINARY RECOMMENDATIONS**

by

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This document reviews methods used to sample nearshore subtidal biota and physical/chemical resources. It provides the basis for the development of sampling standards applicable to marine waters of British Columbia. The discussion of methodologies is presented within a generalized framework that facilitates the development of sampling standards. The nearshore subtidal is a complex, inaccessible, three-dimensional environment with large temporal and spatial variability in biological and physical/chemical resources. These properties dictate that standard sampling methods be developed by considering the spatial scale of data collection, and by considering the specific resource to be sampled.

Several methods are discussed that allow for the sampling of nearshore subtidal habitats by considering the spatial scale of the data collection. Spatial scales identified represent mapping scales and include site, regional, local and Provincial categories. The advantage of identifying the required spatial sampling scale is that many suitable remote sensing methods can be used to sample large areas, within a small time frame. However, a difficulty with this approach is that not all flora and fauna are equally susceptible to the remote sensing methods at a given scale, and that different resource properties need to be sampled by different methods at different scales. The sampling methods described in this document are those that are frequently used to collect data for mapping initiatives. We recommend that readers concerned with mapping and classification issues refer to a companion document by Booth et al. (1996) that discusses issues concerning mapping and classifying nearshore subtidal resources and habitats.

In this document, sampling methods are also identified within the context of the specific biological or physical resources being sampled. Methods used to sample eight different biological resource groups, as well as sediments and physical/chemical properties of seawater are discussed. The advantage of identifying specific resources is that specialized methods can be used to collect detailed information. The disadvantage of this approach is that each resource group may require a suite of specialized sampling methods, and thus the time and cost of sampling subtidal habitats may become prohibitive. Also, detailed sampling is often complicated by factors such as seasonal migration patterns, or spatial variability.

We make two general recommendations for further development of sampling standards. This document is not the definitive statement about sampling methods. Rather it brings together existing information and existing protocols. From this it is apparent that the detail about some methods is greater than others, and there is a need to distinguish between proven and hypothetical uses of some methods. These deficiencies lead us to recommend that each Part in Appendix I be expanded into separate standard methods documents.

Standard sampling methods will evolve over time. The evolution of sampling standards will depend on the fundamental properties of a sampling programme, such as accurate location/position of sampling stations, precision and accuracy of data, knowing the bias of sampling method, and collecting statistically valid data. We recommend that investigators follow the sampling guidelines whenever possible. However, where the sampling methods are not suitable, specific information on the method should be recorded so that other investigators can critically assess the validity and accuracy of the collected data.

Overall, we believe that this document offers a starting point for the evolution of sampling standards for shallow nearshore subtidal resources and habitats of British Columbia.

RESUME

Robinson, C.L.K., D. E. Hay, J. Booth and J. Truscott. 1996. Standard Methods for Sampling Resources and Habitats in Coastal Subtidal Regions of British Columbia: Part 2 - Review of Sampling with Preliminary Recommendations. Can. Tech. Rep. Fish. Aquat. Sci. XXXX: xii+ ll9p.

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PREFACE

This report is submitted to the Resources Inventory Committee (RIC) by the Coastal Task Force. The Resource Inventory Committee members are specialists from a variety of professional disciplines and represent Provincial, Federal, Aboriginal and private sector agencies and other resource interests. RIC's objective is to develop a common set of standards and procedures for Provincial resource inventories.

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1.0 INTRODUCTION

There is a requirement by various agencies to collect information about biological resources (e.g., presence/absence or biomass of fish) and physical/chemical properties of nearshore subtidal habitats (datum to minus 30 m). This information is needed for coastal resource inventories, environmental effects monitoring, protected areas strategies, general planning, environmental impact and stock assessments, and so on (Table 1). In the past, a wide variety of sampling methods have been used uncritically in the nearshore subtidal which makes comparisons and interpretation of data among studies difficult. For instance, agencies cannot plan properly because of a lack of appropriate data, or because of low quality resource information.

One approach to ensuring that data are collected in a meaningful and useful way is to require that agencies conform to sampling standards. A standard may be defined operationally as a measure serving as a basis to which others conform or should conform and by which the accuracy or quality of data is assessed (Refer to Appendix 2 for other important definitions). The definition of a standard implies that the quality (reliability) and usability of the data will be determined by how it was collected, and that data which do not meet certain criteria should be rejected by users. The ultimate value of a set of sampling standards to resource managers or planners is that low quality data does not have to be discarded, and that data collected by various agencies will be directly comparable and integrated with existing data.

The criteria for establishing standards for sampling biological and physical/chemical resources of the nearshore subtidal in British Columbia are presently not defined. As a first step in defining standard methods, this document reviews methods used by habitat managers, biologists, planners, consultants, and applied research scientists to sample aquatic vegetation, invertebrates, fish, and physical/chemical properties. The sampling methods discussed in this document have the greatest likelihood of becoming standards, and were selected on the basis of professional judgement, consultations with sampling agencies, and in some cases, simply because they are the only available method.

The methods discussed in this document are presented within the framework of two possible generalized approaches used to sample nearshore subtidal areas of British Columbia. In general, there are widely different approaches to sampling biological and physical resources in the nearshore subtidal (Table 1). Some studies indicate that subtidal resources are sampled over large stretches of coastline for use in resource inventories (e.g., Emmett et al. 1994), while other studies concentrate on site specific environmental sampling (e.g., Seaconsult Marine Research Ltd. 1994), or specific biological resource sampling (e.g., Hay et al. 19933. We propose that standard sampling methods be developed by considering two general approaches.

First, investigators might select sampling methods based on the relevant spatial scale of their project. For example, agencies of the Province tend to sample (and map) intertidal and nearshore subtidal resources on a habitat-by-habitat basis at relatively large spatial scales, while the Federal government (primarily Department of Fisheries and Oceans; DFO) concentrates sampling on a resource-by-resource basis at relatively small spatial scales. Section 2 discusses

methods used to sample at spatial scales ranging from the local to Provincial scales. Note that the methods discussed for sampling at a particular spatial scale form a link with a second document discussing standard methods for mapping biological and physical resources of the nearshore subtidal (Booth et al. 1996). The importance of this link is that the value of the biological and physical resource maps depend on the quality of data collected.

Second, investigators might select sampling methods based on the specific biological and physical/chemical nearshore subtidal resource that they are interested in. This approach is frequently taken by DFO to assess commercial fish and shellfish stocks, and to evaluate environmental impacts (Table 1). Section 3 discusses methods used to sample one of 10 biological or physical/chemical resource groups in the nearshore subtidal.

This document describes sampling methods that may be used within the framework of the two generalized approaches for sampling the nearshore subtidal. The description and discussion of methods is meant to provide an extended framework for developing standards. In light of this objective, there are several points worth noting. First, several detailed documents exist that describe standard protocols for certain sampling methods (Table 2). These documents should be referred to in any sampling program, until detailed standards or protocols are developed for sampling methods discussed in this document. Second, the sections describing sampling methods for each biological or physical/chemical resource group are not definitive guides to protocols but rather provide a gateway to existing studies and information. Third, in the development of standard sampling methods it should be recognized that standards will need to be refined over time, as new methods are developed or as old methods are enhanced. That is, the standard sampling methods will evolve. Fourth, it is possible that departures from standard methods may be necessary at times to meet the specific requirements of individual projects. To be consistent with the concept of a standard however, specific information on the non-standard method should be recorded so that other investigators can critically assess the validity and accuracy of the collected data.

We now present a brief description of methods used to sample biological and physical/chemical resources in the nearshore subtidal within the framework of the two generalized approaches: 1) spatial scale, and 2) resource of concern.

2.0 SAMPLING BY SPATIAL SCALE

A set of standard sampling methods may be recommended by considering the required sampling resolution, or the effective mapping scale of a project. This generalized approach does not consider individual biological or physical resources, but focuses on the mapping or sampling requirements of scale. From an overview of selected studies (Table 1), there are four main spatial scales commonly used to describe, and sample, nearshore subtidal resources:

1) Provincial (> 1:250,000 map scale)
2) Regional (1:20,000 to 1:50,000 map scale)
3) Local (1:10,000 to 1:20,000 map scale)

4) Site (< 1:10,000 map scale)

These spatial scales and their names are taken from the terrestrial system of ecological classification for British Columbia, and are discussed in a companion document on nearshore subtidal classification and mapping standards by Booth et al (1996). Methods can be recommended on the basis of spatial frequency (or scale) of sampling. For instance, a map scale of 1 :10,000 (metric) indicates that 1 mm on a chart is equivalent to 10 m on the sea bed, or sea surface. Thus a sampling method is required that samples resources at least every 10 m. Conversely, at a scale of 1:250,000 sampling does not need to occur as frequently or a different type of sampling method is required. We now discuss several methods that are frequently used to sample resources at each of the main representative spatial scales (see Table 3).

2.1 SAMPLING AT THE PROVINCIAL SCALE

Studies conducted at a Provincial scale (> 1:250 000) generally require sampling methods that provide a broad overview. Provincial studies are generally used to assess qualitative properties such as distribution or presence and absence of resources or habitat types. Also characteristic of these studies is the need to sample or collect data from a large area over a short period (days to weeks). The main group of sampling methods that will give a rapid, overview of nearshore subtidal resources/habitats are the remote sensing devices. There is no one single remote sensing method that is consistently used for sampling nearshore subtidal resources and habitats because of the rapid changes in technology, resolution, and availability of remote sensing data. In this section we provide a brief description of most of the available remote sensing methods according to the appropriate data collection/mapping scale (i.e., Provincial, regional, local, site), maximum ground resolution, water column penetration, resource group or habitat property sampled, and major limitations. These considerations are summarized in Table 4.

Remote sensing methods rely on electromagnetic or acoustic radiation for transmitting qualitative and quantitative data from nearshore subtidal resources or habitats to an instrument located some distance away. There are several important issues to consider when using remote sensing methods. First, it is necessary to distinguish between proven and hypothetical uses of remote sensing methods. Readers are referred to Booth et al (1996) for a more complete discussion of what nearshore subtidal biological resources remote sensing devices can measure. It is also important to recognize that all remote sensing methods require "ground-truthing" to verify the accuracy of data collected, and that all sensors need to be frequently calibrated (e.g., daily).

There are two types of remote sensing instruments: 1) active devices which emit light or sound and deduce properties of the medium from changes in emitted and received signal, and 2) passive devices which only receive background radiation. The smallest unit sampled by a remote sensing device on the sea surface (or sea floor) is called a pixel. The width of a scan line (swath) is composed of a sequence of adjacent pixels. Pixel resolution (scale) ranges from as high as a few centimetres (e.g., CASI) to as low as several kilometres (e.g., microwave signals from

satellites). Generally there are four groups of remote sensing methods based on the platform on which the sensor is mounted, and hence the physical distance from the resource:

1) Satellites (100's of kilometers above the sea surface)
   a) satellite sensors
2) Airborne (< a few kilometers above the sea surface)
   a) aerial photography
   b) aerial video imagery
   c) airborne multispectral sensors (e.g., compact airborne spectrographic imager)
   d) Light detection and ranging (LIDAR)
3) Boat based (on sea surface)
   a) hydroacoustics and processors (e.g., RoxAnn, QT)
4) Submersibles (below sea surface)
   a) remotely operated vehicles (ROV) using video or photographs
   b) towing systems (for sensors or SCUBA divers)
   c) sidescan sonar

2.1.1 Satellites

Satellite mounted sensors can provide remote sensing information about nearshore subtidal resources/habitats from altitudes of greater than several thousands of kilometres above the earth's surface. The dozens of orbiting satellites primarily use passive remote sensing devices to record the intensity of reflected radiation over spectral bands ranging from the longwave ultraviolet to thermal infrared (electromagnetic radiation). Satellites can also contain active sensors that use microwave and radar. The swath width of satellite coverage ranges from 60 to 180 km. Ground resolutions are available for visible to infrared wavelengths at 2, 4, 10, 20, 30, 50, 80 m. Coarser resolutions are also possible ranging from 300 m to 5 km. Ground resolution depends primarily on the satellite, and the spectral bands that the investigator is interested in. For instance, the multispectral scanners (MSS) and thermal mapper on LANDSAT have resolutions of 56m X 79 m and 30 m by 30 m, respectively, while the MSS on the French SPOT satellite has a ground resolution of 20 X 20 m. An important consideration in selecting the scale is the cost per pixel. For instance, larger pixels gives wider coverage for the same cost but have lower resolution than small pixels. Because of the possible wide ranging ground resolutions, satellites can be used to sample across mapping scales from local to Provincial.

In the nearshore subtidal, satellite imagery can be used to assess surface water colour or fluorescence, both of which can be directly related to chlorophyll a and b concentrations. Additional information that can be collected using satellite imagery includes: wave height and direction, water currents, and suspended sediment concentrations in surface waters. Thermal infrared data are also collected from satellites (thermal mapper; TM) and are used as a measure of sea surface temperatures (+ 1K). The main limitations of satellite data are that most data is received from depths of a few 10's of centimetres below sea surface, visible spectral sensors can only relay information when there is no cloud cover, precise-ground truthing is required (which is

difficult with coarse resolution), and interpretation of images with phenomena experiencing short temporal dynamics is difficult (e.g., blurring of current boundaries). An additional limitation is that the frequency of passage of a particular satellite over a study area restricts the frequency of data collection. This may be an important consideration given the high temporal variability of many oceanographic features monitored by satellites. It is worth noting that the near future foreshadows substantial increases in the resolution and type of satellite imagery data that will be available. For instance it is expected that the United States, China, Russia, and France will provide greater access to operational satellite imagery, and the launching of Canada's Radarsat will provide all weather imaging for coastal regions.

2.1.2 Airborne

Airborne remote sensing devices are operated from low flying aircraft at several hundreds of meters above the sea surface. There are four main applications of airborne remote sensing methods: Aerial photography (AP), aerial video imagery (AVI), airborne multispectral sensors, and light detection and ranging (LIDAR). Airborne systems provide more information from higher resolution pixels than satellite systems, but data are substantially more expensive to collect because of flying time. AP is the most cost effective airborne remote sensing methods, followed by AVI, CASI, and LIDAR. CASI is an order of magnitude higher in costs than AVI, while LIDAR is roughly another order of magnitude above CASI. All of the airborne systems are most effective at Provincial to regional spatial scales.

i) *Aerial photography*

Aerial photography is a remote sensing method best suited for sampling at the local to site scales. Fixed wing aircraft or helicopters are used to conduct AP surveys from elevations of a few to several hundred metres. Two main types of black and white or colour film are used that are sensitive to either the visible spectrum or the infrared. Infrared films can penetrate to depths of about 5 to 7 m depending on water clarity. Ground resolution on aerial photographs can be as high as 1 m. Generally however, the desired mapping scale will determine the ground resolution of aerial photographs, which in turn determines aircraft altitude and the number of photographs taken. Aerial photography has mainly been used to record presence/absence and distributions of canopy kelps and seagrasses. For instance Foreman (1975) used infrared photography to map distributions of kelp beds in coastal B.C.. Aerial photography is also used to record the presence of fish schools in shallow waters (e.g., spawning herring). The main constraint of AP is the cost of commissioning professional aerial photography and analysis (photo-interpretation). It is most cost-effective to determine the existing aerial coverage for the study area. Time of year and day are important considerations when conducting AP surveys because optical (and vegetative) characteristics vary. Interannual comparisons are also generally difficult unless all photographs are taken from same season and time of day.

ii) *Aerial video imagery (A VI)*

Video imagery is a visual technique that involves both video recordings and visual observations/comments from a helicopter or fixed winged aircraft at altitudes of a couple hundred metres. AVI surveys are coupled to differential global positioning systems. The video imagery is usually collected obliquely (i.e., the camera lens axis points at an angle to the ground or vertically. If the horizon is included, the imagery is defined as high oblique; if not, it is low oblique). Objects on the order of several centimetres can be resolved. AVI is supplemented by commentary and still photographs, and is coupled to a differential global positioning system. AVI is primarily used to sample coastal morphology, substrates, and biota in the intertidal zone (e.g., Harper et al. 1993). There are however recent initiatives to extrapolate intertidal information to nearshore subtidal habitats. Aerial video imagery has also been used to discern nearshore subtidal urchin barrens, and it has been used to map kelp distributions (presence or absence and spatial thickness of kelp bed). AVI likely has limited potential for sampling the nearshore subtidal.

iii) *Airborne multispectral sensors*

An example of an airborne multispectral sensor is the compact airborne spectrographic imager (CASI). CASI is a passive, high resolution multispectral imaging device that is operated from fixed wing aircraft at altitudes of 100 m to 10,000 m. Generally, digital data is collected from a scanning spectroradiometer that records the intensity of reflected radiation over fifteen spectral bands (418 to 927 nm coverage at 1.8 nm resolution). Up to 250 spectral bands can be measured but information for no more than 32 wavelengths can be stored and processed. The wavelengths selected will depend on the purpose of the study and the local conditions. A generalized CASI survey would have the aircraft use DGPS navigation, and fly north-south or east-west transects to reduce glare from the sun.

The ground resolution of CASI sensing will depend on altitude and ground resolution required, but generally, cross track resolution is proportional to 0.12% of altitude. Thus at 3000 m a cross track pixel size would be about 3.7 m. Long track resolution is determined by aircraft and instrument speed. Maximum long track resolutions are on the order of 1 to 2 m. An important consideration is that with increased pixel resolution there is increased cost associated with processing a larger number of pixels (i.e., more and bigger data files). The swath width of a CASI transect depends on altitude and pixel width, and can range up to 2 or 3 miles. For instance, water quality studies off England flown at 3,000 m had 5 km wide swaths and pixels of 10 to 15 m wide. Note that the English study used a wide-angle lens which changed the field of view. CASI can sense information in the water column down to about 2/3 of secchi depth in coastal areas.

Imagery data from a CASI survey is electronically stored, corrected for position, and can be incorporated into a geographical information system. Because the width of 'colour channels' can be programmed, an operator can alter the configuration of the instrument to match target objects. For instance, CASI can separate brown from green algae based on absorptive properties of the algae. CASI surveys have also been used for to quantify chlorophyll fluorescence of

phytoplankton, oil slicks, effluent from pulp mills, stock assessment of fish schools, multispectral classification of submerged vegetation down to 4-5 m, and mapping of kelp beds by distinguishing between floating canopy from submerged kelp. The main limitations of using CASI are the time of year or day when sampling is done, water clarity, and sun angle. See Borstad 1992 and Borstad et al. 1992 for more details about CASI.

iv) *Light Detection and Ranging (LIDAR)*

LIDAR is an active, remote sensing airborne system. It can be used to conduct day or night surveys, and requires sophisticated optics and involves a laser pulse as the excitation source. A telescope focuses on a 'spot' where the laser pulse enters the water and the light reflectance is collected through the telescope and re-focused on a light detector. Data points are gathered on a 30 m by 30 m grid. A single flight line covers a swath of 300 m wide. An optimal survey includes flying transects from the near shore (2 m minimum depth) to required depths; transects are spaced 200 m apart with 50 m overlap. About 50 km^2 can be surveyed per hour. LIDAR is mainly used for profiling the depth of the sea floor in shallow water to an accuracy of 0.3 m in 30 m of water (50 m in tropics).

LIDAR has been used to sense bottom substrates, bathymetry, and to determine fluorescence; algal patches can be resolved to a horizontal spatial resolution of less than 10 m. Any subsurface 'object' or particulate matter that reflects light can be sensed by LIDAR. For instance, subsurface vegetation, fish, and turbulence entrained bubbles/material each give their own reflective signatures. LIDAR is not influenced by temperature, salinity, or density changes. LIDAR surveys are relatively more costly than surveys conducted by surface vessels, but cost effective in isolated areas. LIDAR does not work well in fog, surface ice, or mirror flat ocean surface because of enhanced surface light reflectance. The reflected light signals are electronically stored for future processing and analysis. LIDAR is primarily used for hydropigment mapping in remote areas.

2.1.3 Boat Based

i) *Hydroacoustics*

An underwater sound source is produced in single or multiple frequency pulses by a single or duel beam transducer (15 to 250 KHz). The same instrument also contains a receiver. Echosounders are usually hull mounted on surface ships or towed behind the vessel. The angle of the beam is fixed and 'looks' downward. The choice of echo frequency depends on the application but in general there is a trade-off between low attenuation but high background noise at low frequencies and better target definition with lower background noise at higher frequencies. Lower frequencies are better for depth penetration but there is a loss of detail.

Echosounders for locating fish schools use high-frequencies to determine fish species and abundance. The important consideration in detecting fish is the presence/absence and size of the swim bladder. Fish without swim bladders provide weak hydroacoustic targets. Another

important consideration is the target strength, which depends on orientation of the fish and fish species. Potential acoustic scatters in the nearshore subtidal are fish, zooplankton, phytoplankton, and gas bubbles from sediments, among others. Echo-sounders can also be used to resolve physical features of the water column such as freshwater lenses, or pycuoclines. Generally, hydroacoustic devices are capable of resolving features on the order of a few metres. Ultimately the spatial resolution will depend on water depth, frequency, and the angle of acoustic beam. The main limitation of echosounders is they do not function well in water < 2 m.

Echosounders have been primarily used to determine depth, and to observe and detect fish in the water column, but recently applications have been developed for benthic biota and habitats. The signal from a single beam has up to 135 characteristics which can be post-processed using principal components analysis to differentiate substrates. For instance, a post-processing system called RoxAnn has been used to discriminate among sea bed types such as gravel, sand, mud, and rock. The system reads two characteristics of the echogram. The first characteristics can be related to the roughness, while the second characteristic can be related to the hardness. RoxAnn has also recently been used to distinguish between different shellfish on the east coast of Canada. Atlantic scallops, Icelandic scallops, quahogs, stimson clams and propellor clams all show a specific and precise hydroacoustic signature. The post processing system has also been used to distinguish between four different states of seagrass in the Mediterranean (new growth, mature, dead, and dying), but cannot distinguish among macroalgae. Sea state does not seem to affect data acquisition of RoxAnn, and sampling can be conducted at speeds of up to 15 knots.

The minimum water depth that RoxAnn can be operated in depends on pulse width of the echosounder but is typically 2 m at 200 KHz. The maximum depth is dependent on the power source, level of transmitter and beam width of the echosounder. The depth resolution in sediment depends on the frequency of the transducer. At high frequencies (e.g., 208 KHz) only the first few centimetres are penetrated, while at lower frequencies (e.g., 40 KHz) up to 3 decimetres penetration is possible. The width the of the acoustic swath depends on water depth and on the angle of the acoustic beam. The main benefits of RoxAnn are: acoustic data can be stored for later analysis, data can be outputted to most geographical information systems, and ground truthing can be conducted later. The main limitation with RoxAnn as with all remote sensing devices, data must be constantly be ground truthed. Other post-processing systems use more or different echo characteristics. Caubield Engineering can identify contaminants in soft bottom sediments, while Qestar Tangent (QTC) post-processing uses 3 more echo characteristics.

2.1.4 Submersibles

i) *Towing systems*

Towing systems include any platform towed behind a surface vessel. These remote sensing and sampling systems include hydroplanes, underwater tugs, automated water samplers, plankton samplers, and video or still cameras. Towed systems are used to sample a small area of water column around a sampling device over a large area of unbroken sea-bed. Systems are towed at rates ranging from 1 km of sea-bed covered in 30- minutes (hydroplanes) to systems

towed at several knots. In general, the horizontal sampling (spatial) resolution of towed systems ranges from about 1 m to less than 10 m around the device. The larger sampling scales (10 m) are obtained used hydroplanes or underwater tugs with SCUBA divers attached. Most towed plankton and water samplers sample only within a few metres of the device. Underwater video imagery is frequently used with a towed systems to map resources such as sea grass beds. In general, towed systems are used to qualitatively and quantitatively sample a wide variety of nearshore subtidal resources such as plankton, fish, substrate type, and physical or chemical water quality properties. The main limitation of using towed systems is the relatively small horizontal spatial scale sampled.

ii) *Underwater remotely operated vehicles (ROVs)*

ROV's are a vehicle for piggy-backing cameras or sampling devices. ROVs differ from towed systems (see above) in that they are not towed but rather are tethered to surface ships. In addition, ROVs are under their own power, and are directed from the surface ship by a "pilot". An advantage of the ROV over a towed system is that it can stop and look, however they cannot "fly" as straight a line or transect as a towed system. ROVs "sample" by collecting either video or still images of nearshore subtidal resources and habitats. For example, underwater video imagery systems mounted on ROVs can be used to map nearshore subtidal biota such as sea grass beds. Ultimately, the spatial sampling resolution depends on the resolution of the camera system. Some ROVs can also sample by collecting specimens using manipulator arms. Manipulator arms have wide ranging functions, including rotation, open/close, and bending. Bigger ROVS have more manipulator functions that are controlled by hydraulics or electric power.

In oceanographic sampling, ROVs are mainly used to sample benthos, and substrates. A comparison of estimates of species density obtained by trawl, dredge and camera indicate that ROVs typically underestimate quantitative properties, but provide reasonable qualitative estimates of larger epifauna. ROVs are frequently used to collect samples to ground-truth other remote sensing methods such as hydroacoustics. The main logistic constraints of ROVs is the distance it can work away from the ship (i.e., tether length), and shore approaches. The tether length of smaller ROVs suitable for nearshore subtidal work range from 500 m to 1500 m. The smaller ROVs are generally restricted to sampling in > 2 m of water. Most ROVs have a relatively high resolution (cms) but they are limited to viewing about 10 m from the ROV because of underwater turbidity.

iii) *Side-scan sonar*

A pair of hydroacoustic transducers (see above) are mounted on a 'fish' and towed behind a surface vessel at 3-4 kn. The acoustic instruments 'scan' each side of the fish. The two acoustic beams are narrow (1° vertical height) and they 'look' horizontally with a fan width of 50 to 60°. Signals can be pulsed on a regular basis, individually or simultaneously. The frequency range used varies from 100 to 400 KHz. At frequencies > 300 KHz swath width is 100 m on either side of the 'fish'. At 100 KHz swath width is about 500 m on either side. In 20 m of water, the fish would have to be towed close to the surface to get a maximum width of 200 m per side. The maximum resolution of the transducers depend on many factors. The resolution is generally

1/400th of the scan range. For instance, a 1 m object is resolved with a scan width of 400 m. This assumes that the target is 'reflective', there are no obstacles between the fish and the object, and the sea floor is flat. The greatest resolution expected is on the order of 1 m using a 50 m scan range in shallow waters. The minimum depth of operation is 2-3 m, but the side-scan sonar can 'look' into shallower water from safe boating depths.

Side-scan sonar has been used for bathometric mapping, vegetation surveys, and schooling fish. The amplitude of the return signal appears to be indicative of the substrate. This system has future potential to be used in the development of a bottom classification system incorporating both bathymetry and biota at higher resolution than RoxAnn. The main limitations of side-scan sonar are from working in shallow waters where depths restrict swath width, and possible surface noise from boat and/or waves interfere with signal reception.

2.2 SAMPLING AT REGIONAL AND LOCAL SCALES

Sampling subtidal resources/habitats at the regional to local scale will generally require a mixture of remote sensing and site sampling methods (Table 2). Site sampling methods can be divided into passive and active sampling gear. Passive methods such as traps/pots, gillnets, or angling are most appropriate for assessing qualitative properties of biological resources such as presence/absence. Active sampling methods are used to pursue and capture nearshore subtidal resources. These methods include seines, trawls, dredges, sleds, etc.. Most active methods are used to collect quantitative data from local to Provincial scales (Table 2). In general, the most appropriate methods to use at local or regional scales will be determined by assessing the spatial resolution required, and the biological resource to be sampled (see sections 4 and 5).

2.3 SAMPLING AT THE SITE SCALE

Projects conducted at site specific scale require that data be collected at high spatial resolution using direct or observational sampling methods. The most commonly used method for sampling nearshore subtidal at the site scale (< 1:10 000 map scale) is a SCUBA survey. The critical feature of a SCUBA survey is that data be collected from transects of known width and length. This type of survey is referred to as a strip census or area density survey, and allows for quantification of data among sites and studies (e.g., Walton 1979). For a good general discussion of SCUBA survey considerations in the nearshore subtidal see Gamble (1984). In general, SCUBA site surveys will be one of three types:

1) diver observations recorded on slates
2) diver observations using video/still cameras
3) diver collections made by hand, scrapers, and or by using remote samplers such as a corers or air lift suction sampler.

SCUBA site surveys are conducted on a nearshore subtidal habitat type by habitat type basis. The difficulty is identifying specific nearshore subtidal habitat types. Refer to Booth et al

(1996) for a general discussion about nearshore subtidal habitat classification, and Emmett et al. (1994) for a specific approach for identifying nearshore subtidal habitat types. When sampling any nearshore subtidal habitat type, SCUBA surveys should employ strip census methods. The following approach is commonly used.

A random SCUBA swim or snorkel of a nearshore subtidal habitat will usually help decide how many transects to use and their placement. For a site survey, at least 2 transects are placed from shore seaward along predetermined compass bearings. Additional transects may be required depending on the complexity of the nearshore subtidal habitat. Compass courses should ensure that transects are normal to the coastline or perpendicular to bottom contours. Most transects extend from chart datum to the maximum depth not exceeding diver decompression limits (about 15 m). If the maximum depth of 15 m results in an impractically long transect (e.g., a shallow bay), a minimum transect length of 100 m should be used. Maximum transect depth should be determined from the surface using an echosounder, corrected for tides, and marked with an anchored surface buoy.

The shoreward (O m) and seaward positions of each transect should be determined accurately using a hand-held differential GPS and dead-reckoning. The length of the transect should be determined to the nearest metre (m), and transect positions should be recorded on a chart. The alongshore spacing of transects will depend on habitat complexity but they should be at least 50 m apart and no further than 250 m apart. The width of a transect will depend on habitat complexity and visibility. A simple method to use is as follows: A diver swims along a measured transect (e.g., 100 m long) with a 1 or 2 m wide pole. The diver notes transition points along the transect line and counts larger organisms passed over by the pole. This results in a 100 m2 to 200 m2 belt transect.

The amount of time divers will spend conducting an observational or camera survey along a transect will vary with diver experience, habitat conditions, and information being collected. To assess qualitative properties such as presence/absence, a minimum of 15 minutes is required for each 100 m transect. More detailed quantitative collections will require between 30 to 45 minutes. If the transect is to be sampled by a diver, samples should be collected from 5 m depth intervals from datum to minus 15 m along each transect (i.e., 4 stations per transect at 0 m, 5 m, 10 m and 15 m). Also, centre a 5 m by 5 m boundary around the station depth. Sample quadrats should then be placed randomly within the 5 m by 5 m bounded area. The number and size of quadrats used will ultimately depend on study objectives, habitat complexity, and biological resource being sampled. During any SCUBA survey, record as many features of the nearshore subtidal habitat as possible. This includes vegetation type and extent, substrate type and extent, slope, aspect, and other major physical/chemical features.

Although SCUBA surveys are the most appropriate method for assessing shallow nearshore subtidal habitats/resources on a site-specific scale, there are several limitations to be aware of. A major limitation of SCUBA is the restriction to depths not requiring decompression (< 15 m). This may be a critical factor given the deeper ranging capabilities of most nearshore subtidal fauna. In addition, determining an accurate position of underwater sampling sites is difficult (Gamble 1984), but absolutely critical for repetitive (e.g., compliance) monitoring.

Finally, SCUBA is limited because it is a slow process that requires highly trained and experienced divers, and an enormous level of effort for collecting data at anything beyond the site scale.

2.4 SUMMARY

This section has described commonly used methods for sampling nearshore subtidal resources on the basis of the spatial scale of the project. This general approach to sampling is complicated by the fact that some methods can be used to sample across a wide variety of spatial scales (e.g., satellites), while other methods do not effectively sample all biological resources or habitats equally well at the same scale (e.g., remote samplers). In addition, some methods are more suited for sampling qualitative properties such as presence/absence, while other methods can give quantitative information such as biomass estimates (see below). The best strategy would be to employ several remote sampling methods that encompass several spatial scales.

3.0 SAMPLING BY RESOURCE(S) OF CONCERN

A second possible generalized approach, identified from project overviews, for developing sampling standards is to sample nearshore subtidal resources on a resource-by resource basis. This approach is most frequently taken by DFO to assess commercial fish and shellfish stocks, and to evaluate environmental impacts (Table 1). These studies generally require that sampling occur from site to regional scales, and thus they use a variety of sampling methods.
Recommending standard methods for sampling individual resources will be a complicated task because the methods used will be highly dependent on project objectives, complexity of habitat, and the resource being assessed. However, as a first step in developing standards, this section discusses methods used to sample vegetation, invertebrates, fishes, physical/chemical properties of seawater, and sediments in the nearshore subtidal. It is necessary to begin with a discussion of two important issues that should be considered before selecting a sampling method and sampling the resource: (i) sample design and (ii) methods of analysis.

3.1 SAMPLE DESIGN

The design of the sampling program is probably the most important consideration for studies conducted in the nearshore subtidal because of the large spatial and temporal variability in resources. The primary design questions that need to be addressed before sampling commences are: what resource is to be sampled, how, when and where is sampling to commence, how many samples are needed, and what statistical tests should be used in the analysis of any data collected. When addressing these questions there are two main considerations. First, the investigator must choose a sampling method that is not selective, and that is efficient at sampling the resource. For example, not all members of a biological resource group, such as fish, are equally vulnerable or susceptible to a given sampling method. We recommend that the

investigator assess the selectivity of the proposed sampling method by consulting the appropriate literature or by conducting in situ selectivity tests. Second, the investigator must consider the horizontal and vertical distribution of the resource, and subsequently the spatial design of the sampling program. There are four general spatial designs for sampling populations (Greeson et al. 1977). Simple random sampling results in every sample having an equal chance of selection, and each unit is representative of the entire population. Stratified random sampling increases sampling efficiency because it divides the population into strata, whereby the strata are more homogeneous than the population as a whole. Stratified sampling is most useful where the study area contains many different habitat types, such as the nearshore subtidal. Systematic sampling occurs when the first sample site is selected randomly, and additional sample sites are spaced a fixed distance from the first site. Two disadvantages of systematic sampling are samples may be biased (see below), and there is no may of estimating the standard error of the mean. Two-stage sampling is used when it is difficult or expensive to measure a parameter precisely, and includes using an imprecise method to select a large sample of sites and then applying a more precise sampling method to a subset of the sites.

3.1.1 Accuracy and Precision

Fundamental to sample design is the concept that it is virtually impossible to measure attributes of the whole population in an area, and thus a subset of measurements, or samples, must be collected. Two important issues surrounding the collection of samples are accuracy and precision. Accuracy (or bias) refers to how close sample values are to population values, while precision (variance) is the closeness of repeated measurements (Sokal and Rohlf 1981). In sampling the subtidal, accuracy is an important consideration because it is difficult to detect and correct. For example, bias can result from the sampling method used, its selectivity or inefficiency, and/or the design of the sampling program over space and time. The level of precision obtained for a collection of samples is influenced by natural population variability, design of sampling program, and the amount of sampling conducted. Samples are precise if there is low variability and they are imprecise if there is large scatter around the mean. Because precision refers to repeatability, it can be improved by increasing the number of samples (replication), or by decreasing the size or dimension of the samples (e.g., volume). It is generally agreed that more samples of smaller size are preferable to few samples of large size, because of reduced statistical error and provision of more representative coverage.

3.1.2 Reducing Bias and Variability

The concepts of accuracy and precision should be used to assess the potential success of any sampling program. There are two general sampling design strategies for reducing bias and variability. First, sampling design should allow for a distinction between explained and unexplained variation. To avoid confounding of different "types" of variability, the investigator should consider using design approaches such as fixed plots over time, stratification by subtidal habitat type, pre and post impact sampling, and using standard sampling methods. For example, stratification of samples by habitat "type" or along known environmental gradients helps to

reduce sample variance as well reduce bias by partitioning a potentially large and heterogeneous nearshore subtidal habitat into smaller strata. Samples should be taken and analysed for each strata separately.

Second, sampling design should allow for replicate samples to be taken over space and time. Accurately knowing the location of a nearshore subtidal sampling site is important for being able to return to that site for time series sampling, to verify original data, and to accurately plot the sample data on maps. The method used to determine location in the shallow nearshore subtidal will depend on project scale and on the type of sampling method used. For instance, herring spawn surveys need to be repeated within +/- 10s of metres, and thus require methods that accurately measure location (D. Hay, pers. comm., Fisheries and Oceans, Nanaimo). Some sampling methods such as a SCUBA survey make it inherently difficult to accurately determine station position underwater. In this instance, it is best to accurately determine the starting and finishing positions of a SCUBA transect survey using surface markers. Several documents have been written on standard methods for determining position in the subtidal, including simple piloting or navigational techniques (e.g., Tetra Tech Ltd. 1986), and differential global position systems (DGPS; Wells et al. 1992).

In summary, survey design will depend upon many factors including, project objectives, behaviours of the resource group, nearshore subtidal habitat, statistical analyses to perform, and so on. It is highly recommended that users become familiar with sample design issues by referring to good discussions found in Pielou (1977), Green (1979), Stuart (1984), Simenstad et al. (1991).

3.2 METHODS OF ANALYSIS

Once a sampling program has been properly designed and conducted, it will be necessary to analyse the data statistically. The choice of statistical test will depend on several properties of the data. If sample data meet the standard requirements of normality, such as independence, normal error distribution, homogeneity of variance, and additivity of effects (Stuart 1984), then parametric statistical analyses can be used. See Sokal and Rolf (1981), Zar (1984), and James and McCulloch (1990) for appropriate analyses. The foundation of choosing a statistical analysis is to evaluate the primary question that was defined before sampling begins. The null hypothesis states that there is no real difference between the value of a parameter from the sample and the true population value. A statistical analysis examines the sample data on the basis of an expected normal distribution, and a significance level is established that corresponds to a probability of rejecting the null hypothesis if it is true. For example, a significance level of 0.05 means that if the null hypothesis is rejected, there is 95% confidence that the rejection is correct.

If the null hypothesis is accepted when it is true or rejected when it is false then the correct decision is made. However, if a true null hypothesis is rejected it is called a Type I error, or if the null hypothesis is accepted when it is false, it is called a Type II error. When analyses are conducted to test hypotheses, most studies report the cases in which the null hypothesis is rejected, at some level of statistical significance. Relatively few studies report the cases in which

there is failure to reject the null hypothesis. It is possible that a real effect existed in the data but that no significant relationship was found due to small sample size or to large variability in samples taken. Peterman (1990) indicates that the assertion that the null hypothesis is true, even though results show only that it has not been falsified, is a logical jump that scientists and resource managers often make. The consideration that the null hypothesis is true is not justified unless the probability of making a Type II error is low (e.g., ß < 0.2).

Peterman (1990) suggests that proper resource management requires two steps. First, statistical analyses should be used to reject (or not reject) the null hypothesis. Second, if the null hypothesis is not rejected then ,B or the detectable effect size must be calculated. Decisions should be made based on the assumption that the null hypothesis is true only if the probability of making a Type II error is low. Ideally, field sampling designs should have a high probability of detecting an effect, if an effect exists. Important in this process of hypothesis testing is determining the power of a statistical test. Power is defined as 1 - ß, and it is the probability of rejecting the null hypothesis when it is false and an alternative hypothesis is true. Ultimately, power is influenced by: 1) the calculated probability below which the null hypothesis is rejected (oc); 2) the magnitude of the true effect one is testing for (effect size); 3) sample size; and 4) sample variance which includes natural and measurement variability. Power is positively related to oc, and larger effect sizes have higher power than smaller effect sizes. That is, the closer the parameter value is to the null hypothesis the lower the power and the harder it will be to find statistically significant results. To improve the power of a test while keeping oc constant for a given null hypothesis, the sample size should be increased. Power is also positively related to reliability of samples. For example, changing to a more precise sampling device, or increasing the number of samples collected will reduce sample variation and increase power.

There are two main approaches to using power analysis. A priori analyses can be conducted before sampling is started. For example, power analysis can be used to determine how large an effect size is, or how many samples are needed to give acceptable power. Power analysis can also be performed after sampling, but it is relevant only when interpreting a statistical analysis that has failed to reject the null hypothesis. For example, one may want to know if there was no effect, or if the study design had a low probability of detecting an effect even if one was present. Peterman (1990) discusses several specific published examples of using power analysis.

In sum, we recommend that investigators use the concepts of statistical power to assist in interpreting results, and to improve the design of sampling programs. Refer to Peterman (1990) and references therein for a good discussion on the use of power analyses in the aquatic sciences.

3.3 METHODS FOR SAMPLING BIOLOGICAL AND PHYSICAL RESOURCES

In Appendix I we provide a summary of methods commonly used to sample nearshore subtidal resources. These descriptions provide a starting point for the development of sampling standards. If the samples are collected using the methods described in Appendix I are accurate, precise, and statistically valid, then the nearshore subtidal resource data can be used confidently in mapping initiatives for planning and management purposes. However, if investigators use

alternative sampling methods they should record criteria that allow for an evaluation and assessment of their method by others. We have provided guidelines for the type of information to be recorded in the form of critical assessment criteria (Table 5). These criteria were developed for each of the resource groups discussed below and were adapted from criteria used in the Arctic Data Compilation and Appraisal Program (ADCAP; e.g., Ratyuski and de March, 1988). To assist with the collection of critical assessment criteria refer to Table 6.

Overall, we have discussed 15 methods for sampling nearshore subtidal biological and physical resources at the local or site scale (Table 7). The appropriate method to use depends on the resource being considered, and on the qualitative or quantitative data required. We also indicate the appropriateness of 10 remote sensing methods for sampling nearshore subtidal biological and physical resources at the regional and Provincial scales (Table 8). Refer to Section 2.1 on remote sensing methods. We have not discussed sampling methods for groups of highly motile fauna such as marine mammals and sea birds because their movements and behaviours are generally a response to factors external to the immediate habitat. Appendix 1 consists of 10 Parts that describe methods and protocols used in sampling biological, physical/chemical, and sediment resources of the pelagic shallow nearshore subtidal. Refer to Table 2 for existing protocols for methods used in the shallow marine.

> Part A. Aquatic vegetation: Surface algae, subsurface algae, rooted macrophytes
> Part B. Infauna: shallow and deep burrowing species
> Part C. Epifauna: sessile, motile, and evasive species
> Part D. Demersal fish eggs
> Part E. Phytoplankton
> Part F. Zooplankton
> Part G. Pelagic fish larvae/eggs
> Part H. Fish: pelagic, suprabenthic, demersal species
> Part I. Chemical and physical properties of seawater
> Part J. Sediments/substrates

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Table 1. A selected overview of projects conducted in nearshore subtidal areas of British Columbia. Included is a brief description of the project, sampling agency, horizontal and vertical sampling scale, sampling method and mapping scale used.

Project Description	Example Study and Reference	Sampling Agency	Horizontal and Vertical Sampling Scales	Mapping Scale Used	Resources Assessed	Sampling Method
Fish Habitat Inventory	Sooke Harbour and Basin fish habitat inventory; Feakins 1991	DFO	62 units 50 to 1750 m wide over 41 km; datum to minus 20 m	1:12,000	Vegetation, benthic fauna, fish	SCUBA survey, benthic sled
Stock Assessment	Spawning areas of British Columbia herring: a review, geographical analysis and classification ; Hay et al. 1989.	DFO	100m long transects	None mentioned	Herring spawn, vegetation, substrates	SCUBA survey
Habitat Inventory	Burrard Inlet Environmental Action Program; Casher et al. 1993	DFO	2 transects/ 100 m/ 30 shore units; datum to minus 20 m	1: 20,000	Vegetation, benthic fauna, fish, substrates	SCUBA transect survey
Environmental Impact Assessments	Environmental effects of harbour construction activities at Steveston, British Columbia Part 1. Main Report; Anderson et al. 1981	DFO	12 point stations over 5 km; intertidal to minus 8 m	None mentioned	Vegetation, benthic fauna, fish, sediments, water quality	Niskin bottles, Ponar grab, beach seine
Marine Park Inventory	Princess Margaret Provincial Park Foreshore nearshore subtidal habitat classification; Swanston and Shaughnessy 1993	BC Parks	24 stations over 8 km; datum to minus 20 m	None mentioned	Vegetation, benthic fauna, fish	SCUBA survey - random swim
Shore Zone Mapping	British Columbia physical shore-zone mapping system; Howes et al. 1994	MELP	0.5 - 35 km; mainly intertidal	1:40,000 to 1:50,000	exposure, slope, substrates	video imagery, aerial photographs
Environmental Effects Monitoring	Environmental effects monitoring: pre-design study for the Alberni Pulp and Paper Mill at Port Alberni, British Columbia. Part 1. Baseline information; Seaconsult Marine Research Ltd. 1994	for EC/DFO	13 stations over 25 km; intertidal to minus 30 m	None mentioned	vegetation, benthic fauna, fish, substrates	SCUBA survey with video
Biophysical Inventory	A biophysical inventory of the coastal resources in the Gwaii Hanass/South Moresby National Park Reserve; Harper et al. 1994	Canadian Parks Service	10s of km alongshore; mainly intertidal	None mentioned	vegetation, benthic fauna, substrates	Aerial video imagery with ground truthing

Table 1 (Cont'd.)

Project Description	Example Study and Reference	Sampling Agency	Horizontal and Vertical Sampling Scales	Mapping Scale Used	Resources Assessed	Sampling Method
Biophysical Inventory	An inventory and mapping of nearshore subtidal biophysical features of the Goose Islands, Hakai recreational area, British Columbia; Emmett et al. 1994	BC Parks	39 transects 0.2 to 2.5 km apart in 25 shore units; datum to minus 20 m	1:20,000	vegetation, benthic epifauna, fish, substrates	SCUBA transect survey with video
Fish Habitat Inventory	Vegetation, invertebrate distribution and fish utilization of the Campbell River Estuary British Columbia; Raymond et al. 1985	DFO	5 to 15 sites over several km; intertidal to minus 5 m	1:4,000	vegetation, water quality, benthos, zooplankton, fish	plankton net, beach seine,
Stock Assessment	Bottom trawl survey of young of the year lingcod in the Strait of Georgia by the R/V Caligus, June 15 - August 3, 1991; Workman et al. 1992	DFO	66 trawls over 200 km of coastline; 15 m to 35 m	1:50,000	juvenile lingcod, substrate type, depth, tide	substrate type, depth, tide
Fish Inventory	A description of the fish community of the Squamish River estuary, British Columbia: Relative abundance, seasonal changes and feeding habits of salmonids; Levy and Levings 1978	DFO	6 stations sampled over several km; intertidal to minus	1:5,000	fish presence/absence, salinity, temperature, depth	salinity, temperature, depth
Habitat Inventory	Vancouver Harbour and Burrard Inlet benthic infaunal sampling program October 1987; Burd and Brinkhurst 1990	DFO	28 stations sampled over 15 km; minus 9 to 60 m.	Not used	Benthic infauna, depth, substrate	Ponar grab and 100 ml corer
Stock Assessment	1985 research catch and effort data on nearshore reef-fish in the Strait of Georgia; Richards and Cass 1985	DFO	50 sites over 200 km; minus 5 m to 100 m	Not used	fish species, depth, conductivity, temperature	Angling, CTD
Habitat Inventory	Plankton samples in Campbell River and Discovery Passage in relation to juvenile Chinook diets; Brown et al. 1987	DFO	10 stations over 3 km; intertidal to minus 5 m	Not used	zooplankton, temperature, salinity, depth, tide	Miller net, CTD

Overview of Subtidal Sampling Methods

Table 2. A summary of selected documents discussing sampling protocols for marine resources.

Title	Author	Year
Oceanographic sampling manual for the long-term cooperative plankton research monitoring program (COPRA) Can. Tech. Rep. Fish. Aquat. Sci. 1976: 45 p.	Shaw, W.	1994
Biological sampling manual for salmonids - A standardized approach for the Pacific region. Can. Tech. Rep. Fish. Aquat. Sci. 1998: xiii + 167 p.	Shaw, W.	1994
Global positioning system bibliography. Tech. Rep. DRP-90-2. Dredging Research Program, U.S. Army Corps of Engineers, Waterways Experimental Station, Vicksburg, MS.	Wells, W., D.E. Wells, and A. Kleusberg	1992
Estuarine Habitat Assessment Protocol. Puget Sound Estuary Program. Environmental Protection Agency Report 910/9-91-037. 201 p.	Simenstad, CA., C.D. Tanner, R.M. Thom, and L. L. Conquest	1991
Physical Measurement, p. 139-146. *In* Phillips, R.C. and C.P. McRoy [eds]. Seagrass Research Methods. UNESCO Monographs on Oceanographic methodology No. 9. Paris, France.	Fonseca, M.S.	1990
Recommended protocols for measuring conventional water quality variables and metals in fresh water of the Puget Sound region. Report submitted to the U.S. Environmental Protection Agency, Office of Puget Sound, Seattle, Washington. 5 p.	Tetra Tech	1990
Procedures for collecting and processing British Columbia herring samples. Can. MS Rep. Fish. Aquat. Sci. No. 2030.	Hamer, L.	1989
Recommended protocols for sampling and analyzing subtidal benthic macroinvertebrate assemblages in Puget Sound. US EPA Report TC-3391-04. 31 p.	Tetra Tech	1987
Plankton, p. 280-334. *In* J.M. Baker and W.J. Wolff [eds]. Biological surveys of estuaries and coasts. Estuarine and brack-water sciences association handbook. University of Cambridge Press.	Tett, P.B.	1987
Subtidal techniques, p. 199-225. *In* Littler ,M. and D.S. Littler [eds]. Handbook of phycological methods – Ecological field methods for macroalgae. Cambridge University Press.	Foster, M.S., T.A. Dean, and L.E. Deysher	1985
Methods for Study of Marine Benthos. Blackwell Scientific Publ. 387 p.	Holme, N.A. and A.D. McIntyre	1984
Phytoplankton manual. Monograph on oceanographic methodology No. 6. UNESCO Press, France, 337 p.	Sournia, A.	1978
Methods for collection and analysis of aquatic biological or microbiological samples. U.S. Geological Survey. Techniques of Water Resource Investigations of the United States Geological Survey, Book 5, Chapter 4, Washington, DC. 332 p.	Greeson, P.E., T.A. Ehlke, G.A. Irwin, B.W. Lium and K.V. Slack	1977

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Table 2 (Cont'd.)

Title	Author	Year
Standard techniques for pelagic fish eggs and larva surveys. FAO Fisheries Technical Paper No. 175: 100 p.	Smith, P.E. and S.L. Richardson	1977
Zooplankton sampling. Monograph on oceanographic methodology No. 2. UNESCO Press, France, 174 p.	UNESCO	1974
A guide to measurement of marine primary production under some special conditions. Monograph on oceanographic methodology No. 3. UNESCO Press, France, 73 p.	UNESCO	1973
A practical handbook of sea water analysis. Fish. Res. Bd. Canada Bulletin 167: 311 p.	Strickland, J.D. and T.R. Parsons	1972

Table 3. List of direct and remote sampling, and remote sensing methods and the four spatial scales that are typically sampled. This may also be thought of as the alongshore coast line sampling interval. Note that some methods only sample a particular spatial scale (e.g., SCUBA), while other methods sample across spatial scales (e.g., remote sensing methods).

Sampling Methods			Nearshore Subtidal Sampling/Mapping Scale			
General	Subgroup	Specific	Provincial (> 1:50,000)	Regional (1:20,000 to 1:50,000)	Local (1:10,000 to 1:50,000)	Site (< 10,000)
Direct Sampling Methods	Observational methods	SCUBA - visual/camera survey				Yes
		SCUBA - removals (e.g., airlift suction sampler)				Yes
Remote Sampling Methods	Passive sampling gear	Water sampling - bucket/tube/bottle/sensor				Yes
		Traps/pots		Yes	Yes	
		Gillnet		Yes	Yes	
		Angling		Yes	Yes	Yes
	Active sampling gear	Beach seine	Yes	Yes	Yes	
		Purse seine	Yes	Yes		
		Neuston net	Yes	Yes		
		Bongo net	Yes	Yes	Yes	
		Plankton net			Yes	
		van Veen grab	Yes	Yes	Yes	
		Staff beam trawl	Yes	Yes	Yes	
		Otter (bottom) trawl	Yes	Yes		
		Dredge/sled	Yes	Yes	Yes	
Remote Sensing	Satellite	Satellite imagery	Yes	Yes		
	Airborne	Aerial photography	Yes	Yes	Yes	
		Aerial video imagery	Yes	Yes	Yes	
		CASI	Yes	Yes		
		LIDAR	Yes	Yes		
	Water surface	Echosounder	Yes	Yes		
		Bottom classification systems	Yes	Yes		
	Underwater	Remotely operated vehicle	Yes	Yes		
		Towed platforms	Yes	Yes	Yes	
		Side-scan sonar	Yes	Yes		

Table 4. Overview of properties of remote sensing devices used to sample nearshore subtidal habitats and biological resources. Relative spatial map scales are: Provincial, 1:50,000 to 1: 250,000; regional, 1:20,000 to 1:50,000; local, 1:10,000 to 1:20,000; site < 1:10,000.

Remote Sensing Method	Scale of Data Collection	Max Spatial Resolution	Depth Penetration	Resources Commonly Sampled	Habitat Properties Commonly Sampled	Main Limitations
Satellites	Provincial to site	2 m	to 30 m	phytoplankton, surface kelps	temperature, currents, salinity, depth, TSS	weather dependent, interpretation
Aerial Photography (infrared)	local to site	< 1 m	5 to 7m	kelp, some schooling fish	N/A	cost, weather dependent, low depth resolution
Aerial Video Imagery	regional to local	< 1 m	< few m	surface algae, urchin, kelp, some epifauna	N/A	low depth resolution, weather dependent
CASI	regional to local	10 cm X 1 m	2/3 secchi	kelp, seagrass, schooling fish, phytoplankton	water colour, substrates	cost, time of sampling
LIDAR	regional to local	30 X 30 m	30 m	algae, schooling fish	depth, sediment/substrate	cost, low surface resolution, low depth resolution
Echosounder	regional to local	< 1 m	100s of m	fish, zooplankton	depth, density, sediment/substrate	ineffective in shallow water, interpretation
Bottom Classification Systems	regional to site	< 1 m	100s of m	algae, seagrass, fish, epifauna, some infauna	depth, sediment/substrate	cost
ROV	local to site	< 1 m	< 50 m	algae, epifauna, some infauna, benthic fish	sediment/substrate	visibility
Towing systems	local to site	< 1 m	< 50 m	phytoplankton, zooplankton, benthos, fish	water temperature, salinity, depth,	visibility, continuous sampling
Side-scan Sonar	regional to site	< 1 m	100s of m	algae, schooling fish, zooplankton	depth, pycnoclines, sediment/substrate	low resolution, echogram interpretation

Table 5. Critical assessment criteria that should be reported to allow for an evaluation of the reliability and accuracy of data collected, and to assist in the development of standard sampling methods. Critical assessment criteria to collect when using non-standard sampling methods

Resource Group	Critical Assessment Criteria
All groups	- Date (day, month, year) - Time of day sampling done (PST) - Survey design (stations, quadrats, transects, or grids and stratified random, random) - Accurate position of sampling unit (quadrat, tow, set, haul, grab; as longitude and latitude in ° ' ") - Number of sampling units taken per station or habitat type - Depth of sampling unit (in m from chart datum) - Collecting agency/individual - Location of voucher specimens and identification keys used - Method of sample preservation (% formaldehyde, freezing, fresh)
Aquatic Vegetation - surface, subsurface, rooted vascular	- Type of SCUBA survey performed (random swim, transect, video/still camera, removals) - SCUBA survey duration (min), number and experience of divers - Number, length (m), width (m), spacing (m), and orientation (parallel or perpendicular to shoreline) of transects - Number and size (m^2) of quadrats - Depth (m) of sampling units (quadrats, transects)
Phytoplankton	- Water collecting device (bucket, tube, water bottle, automatic sampler, sensor) - Depth (m) and volume of samples (ml) - Number and volume (ml) of subsamples - Number of stations and samples collected
Zooplankton	- Type of plankton net or pump used - Mesh size (mm) or pump tube diameter (mm) - Number of samples collected and their depth - Duration of plankton net haul (min) and orientation (vertical, horizontal, oblique) - Volume of water filtered by net or pump (m^3) - Rate of ascent/descent of sampling device (m sec^{-1})

Table 5 (Cont'd.)

Resource Group	Critical Assessment Criteria
Infauna - shallow and deep burrowers	- Survey design (grid, transect, random) and number of stations - Properties of sampling device used (SCUBA survey, dredge type, grab type) - Number, length (m), width, spacing (m), and orientation or transects - Number, size (m^2), depth of quadrats - Sediment depth sampled to (cm) - Sieve mesh size (mm) - Location of voucher specimens
Epifauna	- Type of SCUBA survey performed (random swim, transect, video/still camera, removals) - SCUBA survey duration (min), number and experience of divers - Number, length (m), width (m), spacing (m), and orientation (parallel or perpendicular to shoreline) of transects - Number and size (m^2) of quadrats - Depth (m) of sampling units (quadrats, transects) - Type and dimensions of trawl/net, dredge, or trap used (height, width and length in m) - Mesh size (mm) - Duration of tow (min) or soak time of traps (h), and depth sampled (m)
Benthic fish eggs	- Type of SCUBA survey performed (random swim, transect, video/still camera, removals) - SCUBA survey duration (min), number and experience of divers - Number, length (m), width (m), spacing (m), and orientation (parallel or perpendicular to shoreline) of transects - Number and size (m^2) of quadrats - Depth (m) of sampling units (quadrats, transects)
Larval fish	- Type of net used and dimension (mouth diameter in cm) - Mesh size (mm) - Duration of net haul (min) and orientation (vertical, horizontal, oblique) - Volume of water filtered by net (m^3) - Rate of ascent/descent of net (m sec^{-1}) - Number of net hauls per station and per habitat type

Table 5 (Cont'd.)

Resource Group	Critical Assessment Criteria
Pelagic fish	- Type of SCUBA survey performed (random swim, transect, video/still camera, removals) - SCUBA survey duration (min), number and experience of divers - Type of fishing gear used and dimensions (length, width and height in m) - Mesh size (mm) - Duration of tow (min) or soak time (h) - Number of sampling units (tows, sets) per station and habitat type
Suprabenthic fish	- Type of SCUBA survey performed (random swim, transect, video/still camera, removals) - SCUBA survey duration (min), number and experience of divers - Number, length (m), width (m), spacing (m), and orientation (parallel or perpendicular to shoreline) of transects - Number and size (m^2) of quadrats - Depth (m) of sampling units (quadrats, transects)
Benthic fish	- Type of SCUBA survey performed (random swim, transect, video/still camera, removals) - SCUBA survey duration (min), number and experience of divers - Number, length (m), width (m), spacing (m), and orientation (parallel or perpendicular to shoreline) of transects - Number and size (m^2) of quadrats - Depth (m) of sampling units (quadrats, transects) - Type of fishing gear and dimensions (length, width, and height (m)) - Mesh size (mm) - Duration of tow (min) and depth (m)

Table 6. Habitat information that should be routinely collected when sampling biological resources. For position, X refers to along-shore scale, y to across-shore scale, and z to depth. Abbreviations: DO: dissolved oxygen.

Resource Group	Water Temp	Salinity	Inorganic Nutrients	Tidal Currents	Shoreline Exposure	Position (X,Y,Z)	Substrates Sediments	Geomorphology	DO	Light
Macroalgae-canopy			Yes	Yes	Yes	Yes	Yes	Yes		
Macroalgae-subsurface			Yes	Yes	Yes	Yes	Yes	Yes		Yes
Rooted vascular plants		Yes	Yes	Yes	Yes	Yes	Yes	Yes		Yes
Phytoplankton	Yes	Yes	Yes	Yes		Yes			Yes	Yes
Zooplankton	Yes	Yes	Yes	Yes		Yes			Yes	Yes
Infauna - shallow burrower						Yes	Yes	Yes		
Infauna - deep burrower						Yes	Yes	Yes		
Epifauna - sessile					Yes	Yes	Yes	Yes		
Epifauna - motile					Yes	Yes	Yes	Yes		
Epifauna - evasive					Yes	Yes	Yes	Yes		
Benthic fish eggs	Yes	Yes			Yes	Yes	Yes	Yes	Yes	
Fish larvae	Yes	Yes		Yes		Yes			Yes	
Pelagic fish	Yes	Yes		Yes		Yes			Yes	
Suprabenthic fish	Yes			Yes	Yes	Yes	Yes	Yes	Yes	
Benthic fish	Yes			Yes		Yes	Yes	Yes	Yes	

Table 7. Overview of remote and direct observational methods for sampling qualitative (e.g., presence/absence) and quantitative (e.g., biomass) properties of each main biological resource group listed in section 4.0. Abbreviations: SO: SCUBA observations; SR: SCUBA removals; WS: water sampling methods; TP: traps or pots; GL: gillnet; AN: angling; BS: beach seine; PS: Purse seine; NN: neuston net; BN: bongo net; PN: plankton net; GB: van Veen grab; ST: staff beam trawl; OT: otter trawl; SD: dredge/sled.

Resource Group	Resource Group Property	SO	SR	WS	TP	GL	AN	BS	PS	NN	BN	PN	GB	ST	OT	SD
Macroalgae-surface	Qualitative	X														
	Quantitative		X													
Macroalgae - subsurface	Qualitative	X														
	Quantitative		X													
Rooted macrophytes	Qualitative	X														
	Quantitative		X													
Phytoplankton	Qualitative			X												
	Quantitative			X												
Zooplankton	Qualitative			X							X	X				
	Quantitative										X	X				
Infauna -shallow	Qualitative	X														X
	Quantitative		X										X			
Infauna - deep	Qualitative	X														X
	Quantitative		X										X			
Epifauna - sessile	Qualitative	X														
	Quantitative		X													
Epifauna - motile	Qualitative	X														
	Quantitative		X													
Epifauna - evasive	Qualitative	X													X	
	Quantitative		X		X											
Benthic fish eggs	Qualitative	X														

Direct and Remote Sampling Methods

Table 7 (Cont'd.)

		Direct and Remote Sampling Methods														
Resource Group	Resource Group Property	SO	SR	WS	TP	GL	AN	BS	PS	NN	BN	PN	GB	ST	OT	SD
	Quantitative		X													
Fish larvae	Qualitative							X		X	X	X				
	Quantitative							X		X	X	X				
Pelagic fish	Qualitative	X				x	X	X	X					X	X	
	Quantitative							X	X					X		
Suprabenthic fish	Qualitative	X		X			X	X							X	
	Quantitative		X			x		X							X	
Benthic fish	Qualitative	X						X							X	
	Quantitative		X					X							X	

Overview of Subtidal Sampling Methods

Table 8. Overview of remote sensing methods used for sampling qualitative (e.g., presence/absence) and quantitative (e.g., biomass) properties of each main biological resource group listed in section 4.0. Abbreviations: SAT IMG: satellite imagery; AVI: aerial video imagery; CASI: compact airborne spectrographic imager LIDAR: light detection and ranging ROV: remotely operated vehicles.

Resource Group	Resource Group Property	Remote Sensing Methods									
		SAT IMG	Air Photo	AVI	CASI	LIDAR	Echo Sounder	Bottom Classification Systems	ROV	Towed Platform	Side-Scan Sonar
Macroalgae- surface	Qualitative	X	X	X	X	X					
	Quantitative		X	X	X	X					
Macroalgae - subsurface	Qualitative		X					X	X		X
	Quantitative							X			X
Rooted macrophytes	Qualitative	X	X	X	X	X		X			X
	Quantitative	X	X	X	X	X					
Phytoplankton	Qualitative	X	X		X	X		X		X	
	Quantitative	X			X					X	
Zooplankton	Qualitative						X		X	X	X
	Quantitative						X			X	X
Infauna -shallow	Qualitative						X	X	X		X
	Quantitative							X			
Infauna – deep	Qualitative							X			
	Quantitative										
Epifauna - sessile	Qualitative		X			X		X	X		X
	Quantitative							X			
Epifauna - motile	Qualitative		X	X				X	X		
	Quantitative							X			
Epifauna - evasive	Qualitative								X		
	Quantitative										

Table 8 (Cont'd.)

Resource Group	Resource Group Property	Remote Sensing Methods									
		SAT IMG	Air Photo	AVI	CASI	LIDAR	Echo Sounder	Bottom Classification Systems	ROV	Towed Platform	Side-Scan Sonar
Benthic fish eggs	Qualitative		X	X	X	X		X	X		
	Quantitative				X	X		X			
Fish larvae	Qualitative						X				
	Quantitative						X				
Pelagic fish	Qualitative						X		X		X
	Quantitative						X				X
Suprabenthic fish	Qualitative								X		X
	Quantitative										X
Benthic fish	Qualitative						X	X			
	Quantitative										

Overview of Subtidal Sampling Methods

**APPENDIX I. OVERVIEW OF METHODS USED TO
SAMPLE SHALLOW SUBTIDAL RESOURCES**

This appendix discusses methods that are used to sample the following resources in the shallow nearshore subtidal (chart datum to minus 30 m):

Part A	Aquatic vegetation: Surface algae, subsurface algae, rooted macrophytes
Part B	Infauna: shallow and deep burrowing species
Part C	Epifauna: sessile, motile, and evasive
Part D	Demersal fish eggs
Part E	Phytoplankton
Part F	Zooplankton
Part G	Fish larvae/eggs
Part H	Fish: pelagic, suprabenthic, demersal species
Part I	Chemical and physical properties of seawater
Part J	Sediments/substrates

To facilitate the presentation of the methods, we have used the following outline for each resource group:

1. Identify common species and the general characteristics of the resource group, and the nearshore subtidal habitats that they are typically associated with.
2. Discuss methods for sampling qualitative properties such as presence or absence.
3. Discuss methods for sampling quantitative properties such as abundance or biomass.
4. Discuss alternative sampling methods. These methods may be used commercially, or they may offer promise as a new sampling approach.
5. Discuss information to be collected by the investigator to help others determine the compatibility and accuracy of the data. This information is called critical assessment criteria.
6. Refer to studies conducted on the resource group in British Columbia, that discuss specific sampling methods, or databases that contain resource group data.

PART A. AQUATIC VEGETATION

Aquatic vegetation in shallow nearshore subtidal habitats can be divided into three main groups based on its location in the water column. 1) Surface algae: The surface algae are algae that have large fronds extending over, or just below, the water surface. This group includes the large brown algae that grow to depths in excess of 10 m and include the annual kelps (e.g., Nereocystis luelkeana) and the perennial kelps (e.g., Macrocystis integrifolia). These algae occur in "kelp forests" which grow parallel to the shoreline, and that are attached via holdfasts to hard, rocky substrates. The surface algae are conspicuous from the air, and thus can be readily sampled using remote sensing methods. 2) Subsurface algae: The subsurface algae grow below the water surface, and do not form a floating canopy. This group is quite diverse consisting of brown algae such as Agarum or Laminaria, red algae such as Gigartinz, Iridea, and Porphyra that grow close to the substrate (i.e., < 0.25 m high), and the green algae which are typically found in the upper nearshore subtidal to depths of 3 m from LLW, and include genera such as Ulva and Enteromorpha. 3) Rooted vascular plants: This group grows rooted in sediments in the shallow nearshore subtidal, and area commonly known as seagrass or eelgrass. The most common seagrass genera is Zostera, with Zostera marina dominating in the shallow nearshore subtidal British Columbia habitats. Zostera marina has grass-like leaves to 1.5 cm wide and 3 m long. Seagrasses prefer low wave exposures and range in depths from 2 m to 5 m below LLW. Nearshore subtidal distributions are controlled by light availability, tidal exposure, and substrate properties. Seagrasses grow over a wide range of salinities (10-30°/oo), and temperatures (1020°C), and are found in sandy or muddy substrates. The lower intertidal and shallow nearshore subtidal is also inhabited by dense stands of the hardy, vascular "surfgrass" Phyllospadix spp. Surfgrass prefer moderately high wave energy or exposed sites, and are substantially less common than the seagrasses (Emmett et al. 1994).

A1. GENERAL SAMPLING CONSIDERATIONS

- For any particular nearshore subtidal habitat the algae form a complex mosaic of both perennial and annual species which varies over space and time. Some of this variability is related to the disturbance history of the nearshore subtidal habitat. For instance, the annual kelp Nereocystis luerkeana thrives following a disturbance but over time will be replaced by perennial brown algae such as Laminaria spp. or Agarum spp. or member of the red algae. The disturbance history of the nearshore subtidal habitat should be determined or sampling be conducted over several years (See Lindstrom and Foreman 1978).
- Temporal variability in macroalgae and seagrass communities must be considered. For instance, the most complex and variable component of the nearshore subtidal macroalgae community is found in the upper intertidal through the mid-nearshore subtidal depths (+ 1 m to -8 m from LLW). These algae exhibit large seasonal changes in biomass. In contrast, properties of macroalgae below 8 m are relatively constant over time. To account for seasonal changes in shallow nearshore subtidal macroalgae, sampling is usually conducted at least monthly between March and October. The temporal frequency of sampling sea grass

communities should be related to the annual peak in biomass, which generally corresponds to late summer.

- Algal communities also exhibit variability over longer periods (as yet undefined by in 10's of years). Thus, sampling at one point in time does not mean the algal community will be the same in 5, 10 or 20 years.
- The survey design for aquatic vegetation in general should include stratified random sampling across the nearshore subtidal habitat unit because of the likelihood of changes in the community with changes in habitat characteristics such as depth, substrate and slope.
- A key concern when conducting SCUBA surveys is who is going to do the sampling. Divers should be very experienced or trained for conducting in situ taxonomic determinations. Because of the difficulty in identifying algal species in situ most investigators should use destructive sampling methods, prepare voucher specimens for each sample, develop and use a practical field guide, and train field staff.
- Because communities of aquatic vegetation are mainly influenced by environmental conditions substrate type and extent, slope, current exposure, and water temperature should be measured simultaneously.

A2. SAMPLING QUALITATIVE PROPERTIES

Common qualitative properties of aquatic vegetation measured are presence/absence, percent cover, or distribution. Sampling for qualitative properties is most easily accomplished on a site scale using a SCUBA transect survey. SCUBA transect surveys were discussed in section 2.3. Note that for SCUBA transect surveys of seagrass beds, the placement of transects will depend on the patchiness of the bed. Generally, if beds are patchy and occur over a large nearshore subtidal area then stratified cluster sampling will be most appropriate. If sea grass beds are distributed in a clearly defined area parallel to shore then transects should be placed in the centre of the population parallel to shore. Finally, if populations are distributed in a small area fairly uniform along the shore but changing with depth, the transects should be placed perpendicular to the shore (Philips and McRoy 1990).

Ultimately, qualitative data collected using SCUBA surveys are limited because they rely heavily on the experience of the diver in identifying species, and the thoroughness of each diver. In general, qualitative surveys simply say what may be there (untestable) and do not provide meaningful information. To enhance a qualitative SCUBA survey, video\still cameras are frequently used. These images however, represent 2-d observations which provide lirnited information about a 3-d environment.

For sampling qualitative properties of surface vegetation and rooted vascular plants at small scales, hydroacoustic techniques such as Bottom classification systems can be used (See section 2.1).

A3. SAMPLING QUANTITATIVE PROPERTIES

Detailed quantitative sampling of aquatic vegetation is used to determine biological associations, biomass, seasonal components, and disturbance history. Detailed surveys offer a foundation for the more frequently conducted qualitative, observational surveys (see above). The quantitative survey allows one to develop vegetation-environment relationships, and to identify 'key' species. In general, quantitative assessments of aquatic vegetation should use SCUBA transect surveys as discussed in section 2.3, in conjunction with quadrats and destructive sampling. We now discuss specific considerations of SCUBA surveys for each main group of aquatic vegetation.

i) Surface Algae

Larger surface algae such as the kelps, are best sampled quantitatively using non-quadrat methods such as point sampling. Ultimately, canopy kelps may best by sampled using remote sensing methods such as aerial video imagery or aerial infrared photography (see section 2. 1).

ii) Subsurface Algae

A stratified random survey design is frequently used to quantitatively sample subsurface algae. Quadrats are randomly placed in different cross shore zones extending along a 100 m transect. Zones will be determined from observations of substrate type and extent, slope, obvious changes in algal communities, and so on.

The quadrat size used depends on the "size" and patchiness of the macroalgae. For sampling understorey kelps and smaller benthic algae 0.25 m2 quadrats are typically used. Larger canopy kelps can be sampled using non-quadrat methods such as SCUBA transect surveys and point sampling or aerial surveys.

Destructive sampling consists of cropping the larger algae within a quadrat flush with substrate. Smaller algae can be collected from quadrats in each zone using an airlift suction sampler. At the same time percent cover and main species distribution can be estimated, and voucher specimens should be prepared for each sample collected.

All algal material should be placed in a 0.5 mm mesh bag. At the surface, samples collected from quadrats should be preserved in 3-4% formaldehyde for later analysis. Freezing of algal samples modifies weight, and is not recommended.

iii) Rooted Vascular Plants

Quadrat size will depend on shoot density and distribution of the sea grasses. Quadrats of 0.1 m2 should be used for densely packed beds, while 0.5 m2 quadrats should be used for sparsely spaced seagrass. In general, several smaller quadrats will give more precise estimates of

quantitative properties than a few large quadrats. At least one quadrat should be sampled every 5 m along a 100 m transect.

Samples of sea grass should be removed from within quadrats. Seagrass stems should be first removed into a net bag which has been pulled over them. Divers can sample subsurface sediments and seagrass parts using a suction sampling device. The area enclosed by a quadrat should be suction sampled to a depth of at least 15 cm. All subsurface samples should be sieved through a 0.5 mm mesh, and contents washed with seawater, sorted, and weighed (Philips and McRoy 1990).

Once quantitative samples have been collected for aquatic vegetation, the following methods are used:

- Standing stock (biomass) is usually measured and reported as g wet weight per unit area (g wet weight m~2). Wet weight can be estimated by first quickly removing all visible water by blotting. Weights should then be determined on an electronic scale and reported to the nearest 0.01 g for smaller algae and 1.0 gram for larger browns.
- Seagrass shoot density can be estimated by divers counting the number of stems within a quadrat. Simenstad et al. (1991) suggest that standing live shoots (green leaves) should be distinguished from standing dead shoot counts. Density is reported as the number of stems per 1 m2.
- Because of the variability in measuring moisture content dry weight is also determined. Dry weight can be determined by drying fresh plant/algal material at 60-70°C for 24-48 h, or until a constant weight is achieved. Algal dry weight should then be measured to nearest 0.01 g (reds, greens) or 1.0 g (browns) on a calibrated electronic balance or scale, respectively.
- Ash-free dry weight is the material remaining after organic matter has been combusted at a high temperature. To estimate ash-free dry weight place the dried plant tissue sample or subsample in a muffle furnace set at > 500°C and leave until a constant weight is achieved (typically < 24h). The burnt material is cooled in a desiccator before weighing on an electronic balance.
- In situ productivity of nearshore subtidal macroalgae is determined by measuring oxygen evolution and uptake in chambers, by ^{14}C experiments, and by using standard light-dark bottle techniques. Refer to Foster et al. (1985) and Naito and Russell (1989) for references and standard procedures. Kentula and McIntire (1986) discuss a standard procedure for estimating seagrass net productivity from samples collected in the field. Productivity measures should be reported in grams dry weight tissue per m2 of habitat per unit time.

A4. ALTERNATIVE SAMPLING METHODS

Over large sections of the coast, qualitative properties of macroalgae such as kelp have been estimated by recording observations from fixed-wing aircraft or helicopter surveys. These data are collected using inflight commentary and/or video and still camera records made by observers, with analysis conducted later in the laboratory. Aerial video imagery has also been

used to rapidly and qualitatively assess the presence and distribution of sea grass beds (Frith et al. 1994). The utility of this method for assessing qualitative properties of sea grass beds is ultimately limited by water clarity and depth. For the most part, remote sensing observations have generally shown to be highly erratic and unusable for estimating kelp beds (R. Foreman, UBC, person. comm.). Observations from video or still camera observations are also of limited value because they assume accurate taxonomy. This assumption is generally untestable and data are unusable unless extensive dive truthing is conducted. A remote sensing method that has been frequently used is infra-red photography (IRP). This method gives a reasonable estimate of kelp properties. Foreman (1975) provides a comparison of various IRP methods. IRP can be used to depths of about 7 m.

It is also possible that once site-specific nearshore subtidal communities have been surveyed, longer stretches of coastline may be sampled by towing a SCUBA diver on a hydroplane. About 1 km of alongshore habitat can be covered in 30 minutes (Hiscock in Baker and Wolff 1987).

Investigators should also note that a large amount of data on nearshore subtidal macroalgae can be obtained from the herring spawn surveys conducted by the Department of Fisheries and Oceans (See Part G); Some of the herring spawn literature is included below.

Other remote sensing methods such as hydroacoustics (See section 3.1.3) can also be used to assess broad scale distributions of aquatic vegetation such as seagrasses, and may provide more detailed population property information. For instance, the RoxAnn system has been used to survey Mediterranean sea-grass beds, and was able to discriminate between four different states of sea-grass: new growth, mature, dead, and dying (Williamson 1994).

A5. CRITICAL ASSESSMENT CRITERIA

The following information should be collected and recorded when sampling aquatic vegetation to determine the comparability and accuracy of data among studies:

- transect length (m) and width (m)
- SCUBA assessment time per transect (minutes)
- number of transects and total number samples taken
- quadrat size (m^2) and number
- depth of sampling stations (m)
- substrate type, extent, slope
- water temperature (°C)
- location of voucher specimens collected

A6. GENERAL REFERENCES AND DATA SOURCES

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Table A1. Summary of common methods used to sample surface algae, subsurface algae, and rooted vascular plants.

Property	Sampling Method
Qualitative properties (e.g., Presence/absence)	Surface algae: Aerial photography; Aerial video imagery Subsurface algae: SCUBA survey Rooted vascular plants: SCUBA survey; Aerial photography; Aerial video imagery
Quantitative properties (e.g., standing stock)	Surface algae: Aerial photography or Aerial video imagery Subsurface algae: SCUBA survey with removals Rooted vascular plants: SCUBA survey with removals
Alternative sampling methods	Surface algae: LIDAR Subsurface algae: Bottom classification systems, CASI Rooted vascular plants: Bottom classification systems, CASI

PART B. INFAUNA

Benthic infauna are a diverse group of organisms that include polychaete worms, asteroids, crustaceans, echinoids, gastropods, bivalves, among others. The most important commercial resource of this group are the nearshore subtidal clams or bivalves. These relatively immotile animals live in a variety of substrates buried to 1 m below the surface, and are found throughout the intertidal to nearshore subtidal depths of 120 m (Table B1). Some commercially important bivalves such as manila clams are not considered in this document because they occur primarily in intertidal habitats (Quayle and Bourne 1972; Williams 1989).

Defining a common set of sampling standards will be difficult for benthic infauna because there are considerable differences in physical and biological characteristics of nearshore subtidal habitats even in close proximity, and thus considerable differences in resource species, population sizes, and distributions. Ultimately the type of sampling regime used will depend on the size and shape of the study area, nearshore subtidal substrate type and extent, the resources available for sampling, the resource, and the objectives of the project. The most useful approach may be to use SCUBA hand excavations or air lift suction samplers to sample benthic infauna. In habitats where SCUBA is not feasible dredges can be used to assess qualitative properties of infauna, and a van Veen grab to assess quantitative properties.

B1. GENERAL SAMPLING CONSIDERATIONS

- Spatial distributions of infauna are often complex (i.e., widely distributed populations, low densities) and depend upon a number of factors including habitat properties, time of the year, and biological interactions. Surveys that use grid sampling will show animal distributions and the locations of infaunal beds, particularity if the sampling interval is small. However, these surveys are time consuming. Surveys that conduct random sampling of infaunal beds are faster and probably adequate for most purposes but one must be certain of the location and extent of the infaunal bed and insure that sampling is truly random.
- Sample replication will be determined by study objectives. However, there is minimal sample replication needed for statistical reliability of parameter estimates. Most infauna surveys use quadrats. Between 5-25 quadrats are usually sampled depending on the shape and size of the study area, and the confidence interval desired for a parameter.
- Quadrat size will depend on the heterogeneity of the nearshore subtidal habitat. Quadrats typically used to sample shallow nearshore subtidal infauna range from 0.1 m2 to 1.0 m2, depending on density, species, and distribution. Larger quadrats are more appropriate for larger infauna, or if sampling time is limited, or if a larger area needs sampling. Smaller quadrats reduce the statistical errors and provide more representative coverage of habitat. Protocols for the Puget Sound Estuary program require that benthic macroinvertebrates be sampled using 0.1 m2 (Tetra Tech 1987).
- Investigators should be aware that some infauna (e.g., geoduck) extend well below the 30 m depth limit imposed in this study. Sampling should include some transects that run perpendicular to the shore to 30 m. This will show the distribution of infauna with depth.

- The location of grids or transects should be accurately determined and documented. The most common method is to record sampling sites on maps, but we recommend using more accurate methods such as a differential global positioning systems.
- There are three stages of infauna to consider: larvae, juveniles, and adults. Larval stages of infauna are pelagic and thus are dispersed with water currents and therefore should be sampled as pelagic zooplankton (See Part G). Sampling juvenile bivalves may require sieving sediment samples. There is a trade-off between retention of macroinvertebrates and the cost of sorting and taxonomic identification. Generally, a sieve mesh size of 60-pm is appropriate for most resource inventory studies (Tetra Tech 1987). Larger adult infauna can be sampled with methods discussed below.
- The method used to sample infauna may be partly determined on the basis of how deep they bury. A few infauna such as horse clams and geoduck bury to > 1 m, while the majority of other clam species are found < 50 cm from the surface. Some remote sampling methods such as grabs simply cannot sample infauna deeper than 20 cm.
- Where possible investigators should simultaneously collect habitat information such as substrate type and extent, depth, slope, water temperature, and vegetation.

B2. SAMPLING QUALITATIVE PROPERTIES

The qualitative properties (e.g., presence/absence) of some larger bivalve species such as geoduck may be determined using SCUBA surveys. A SCUBA survey should be timed and include a random swim where the diver determines the presence/absence of geoduck clams from observations of the substrate type, or from observing siphon holes. The siphon tip called a 'show' is the only part visible when a clam is buried. Show factors are used to estimate presence/absence and densities of geoduck (Harbo and Peacock 1983). Investigators must be aware that the ability to detect siphon holes varies with season. In spring and summer geoduck and horse clams are more active, and thus siphon holes are more easily seen. SCUBA surveys should consider using still/video cameras to record the substrate type and siphon shows, and thus provide permanent records of changes in infauna.

Dredges are used to sample the majority of benthic infauna qualitatively. Dredges collect infauna over large and variable nearshore subtidal habitats and thus are used to quickly assess the relative distribution and occurrence of infauna (Hartley and Dicks 1987). Many types of dredges can be used depending on substrate type (see Eleftheriou and Holme 1984). The authors recommend that mesh size of the dredge be 10-12 mm knot-to-knot, the dredge be towed slowly (1-2 knots) for at least 5-10 minutes, and that the dredge be bowed, oval or circular in shape to dig into the substrate. Dredges typically sample < 25 cm substrate depth. Dredges are limited because they are relatively awkward to handle and use, and generally require a larger boat. Dredging of sand/mud substrates is also a non-selective sampling method compared to diver excavations, and thus requires longer sorting and lab analysis.

B3. SAMPLING QUANTITATIVE PROPERTIES

Quantitative sampling implies that infauna will be collected and analyzed for various properties such as density, biomass, length, age, growth, reproductive status, and so on. To quantitatively assess infauna populations investigators use SCUBA surveys in conjunction with excavation devices such as diver controlled airlift samplers. Divers use the airlift suction sampler within a predefined quadrat (0.25 to 1.0 m^{-2}). Suction samplers are capable of removing substrates down to 50 cm. The main limitation of suction samplers is that they draw animals from surrounding substrates thus inflating abundance estimates within the quadrat, and they abrade animals as they are drawn in with the sediments (Simenstad et al. 1991). Because suction sampler tubes are typically < 10 cm, sample collections are limited to smaller infauna. Thus divers will have to collect larger specimens by hand. For bivalves that bury deep in substrates (e.g., geoduck) commercial harvesting methods may be required. This involves locating and holding siphons while the diver uses a hand-held high pressure water jet that displaces substrate surrounding the geoduck (Harbo and Peacock 1983).

In nearshore subtidal habitats where SCUBA is not feasible, remote sampling devices such as benthic grabs are used to sample infauna quantitatively. The most commonly used benthic grab is the modified van Veen bottom grab (Tetra Tech 1987; Simenstad et al. 1989). The minimum area sampled with the grab should be 0.1 m2. Most grabs will only be able to sample to 15-20 cm depth. The main advantages of the van Veen grab are ease of deployment from small boats, consistency in area sampled, minimum surface disturbance caused by pressure waves, and minimum disturbance due to leakage. The main disadvantages are penetration depth can vary widely from sample to sample, loss of information on vertical structure of sediments, and inability to capture larger, deeply buried infauna (Wood 1977; Tetra Tech 1987).

For all quantitative samples collected, the following methods are used:

- Density of infauna is reported as number of animals m^{-2}.
- Shell length of infauna is measured as the straight line distance between the anterior and posterior margin of the shell. Lengths are taken using vernier calipers and measured to the nearest mm.
- Wet weights of infauna is obtained for the total body and shell, shell only, whole soft body and siphon. Wet weights are recorded to the nearest 0.1 g on an electronic balance (e.g., Mettler), and biomass is reported in grams weight m 2
- Growth is estimated by measuring shell length at each annulus (mm).
- Depending on species of bivalve, age can be determined by trained personnel counting the number of annuli, or by analyzing thin sections of the shell (Quayle and Bourne 1972).
- Reproductive condition or stage of gonad development is determined by removing the central portion of the gonad and preserving the tissue in Davidson's solution. Histological work should be performed following standards discussed in references listed in Campbell et al. (1990).

- For properties such as length, age, weight, the sample size should be large enough to be representative of the population and should be random. Usually a minimum of 50 randomly selected animals be measured to increase the precision of estimated parameters.

B4. ALTERNATIVE SAMPLING METHODS

Hydroacoustic methods can provide information about the extent and distribution of nearshore subtidal substrates. In turn, this information may be combined with knowledge of presence/absence of infauna and thus used as a primary nearshore subtidal classification tool of bivalve assemblages. Refer to section 2.1.3 for discussion on hydroacoustic processors.

B5. CRITICAL ASSESSMENT CRITERIA

The following information (and appropriate units) should be collected and recorded when sampling epifauna to determine the compatibility and accuracy of data among studies:

- Survey design (grid, transect, random) and number of stations
- Properties of sampling device used (SCUBA survey, dredge type, grab type)
- Number, length (m), width, spacing (m), and orientation of transects
- Number, size (m^2), depth of quadrats
- Sediment depth sampled to (cm)
- Sieve mesh size (mm)
- Location of voucher specimens

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Table B1. Common clam species found in nearshore subtidal habitats of British Columbia. Included is information about maximum depth found in nearshore subtidal, commmonly associated substrates, and maximum depths of burial in substrates. Information from Quayle and Bourne (1972); Jamieson and Francis (1986); Williams (1989).

Common Nearshore Subtidal Clam Species	Depth in Nearshore Subtidal	Nearshore Subtidal Substrate	Burrowing Depth
Soft-shell clam (*Mya arenaria*)	to 10 m	mud	to 20 cm
Littleneck clam (*Protothaca staminea*)	to 10 m	firm gravel	to 15 cm
Butter clam (*Saxidomus giganteus*)	to 15 m	porous mixtures of sand, broken shell, gravel	to 25 cm
Razor clam (*Siliqua patula*)	to 20 m	sand	to 50 cm
Cockle (*Clinocardium nuttallii*)	to 30 m	soft sand, mud	< 5 cm
Horse clam (*Tresus nuttallii and capax*)	to 50 m	mud, gravel, shell or sand	to 1 m
Geoduck (*Panope abrupta*)	to 120 m	fine mud to sand-gravel	to 1.5 m

Table B2. Summary of methods used to sample nearshore subtidal infauna.

Infauna Property	Sampling Method
Qualitative properties (e.g., Presence/absence)	SCUBA observations (large infauna) and hand excavations (small infauna);
	Where SCUBA not feasible use a benthic dredge
Quantitative properties (e.g., density)	SCUBA using quadrats/transects and an airlift suction sampler;
	Where SCUBA not feasible use a modified van Veen grab
Alternative methods	Bottom classification systems (hydroacoustics)

PART C. EPIFAUNA

The nearshore subtidal epifauna include invertebrates that remain on, or near the surface of, substrates. The epifauna are very diverse and contain at least 8 important groups of species (Table C1). To facilitate the presentation of recommended standard sampling methods, the epifauna have been divided according to their ability to avoid sampling gear. Sessile epifauna are defined as those animals that remain firmly attached to substrates and that do not avoid sampling gear. Motile epifauna are slow moving animals that do not actively avoid sampling gear but their distributions can change dramatically from one sampling period to the next because of daily or seasonal migrations. The evasive epifauna can move quickly or are cryptic animals, and thus can avoid some types of sampling gear.

It will be difficult to define standard methods for epifauna because sampling will depend not only on the avoidance abilities of the species but also on the specific objectives of the study, what nearshore subtidal habitats are to be sampled, and what time of day or season is sampling to commence. The methods discussed here are generalized and are used primarily by the Department of Fisheries and Oceans (DFO) to assess stock properties of epifauna. However, most of these methods are also suitable for qualitative assessments, and for collecting quantitative data about other epifauna. Users are strongly urged to contact DFO for guidance as to the sampling protocol appropriate for species, nearshore subtidal habitat, and project objectives.

C1. GENERAL SAMPLING CONSIDERATIONS

- Survey design and sampling methods will greatly depend on the spatial distributions of the epifauna, and the complexity of the nearshore subtidal habitat. For example, some sessile epifauna are randomly distributed (e.g., rock scallops), while other sessile epifauna (e.g., mussels) are found in clumps. It is useful to conduct a brief timed diver swim (5-10 minutes) of a proposed sampling site to assess the type and extent of the nearshore subtidal habitat, and to asses the vertical and horizontal distribution of the epifauna.
- Investigators should be aware that most motile and evasive epifauna populations extend well below the 30 m depth limit imposed in this study. In addition, many motile and evasive epifauna exhibit daily and seasonal inshore/offshore migrations through the shallow nearshore subtidal. Some evasive epifauna such as crabs also exhibit large depth variations by size and sex over time.
- Some epifauna are difficult to sample because they hide in crevices or under rocks (e*g., crabs, abalone, octopus). SCUBA surveys may be the only reliable sampling method to assess quantitative properties of these animals.
- The number of transects, number of quadrats, and quadrat size used to sample epifauna will depend on nearshore subtidal habitat complexity, on the species, and on the property sampled. A 1.0 m2 metal quadrat is most commonly used to sample epifauna.

- The location of transects, traps, or trawls should be accurately determined and documented. The most common method is to record sample site locations on maps, but more accurate methods such as differential global positioning systems should be used.
- Soak time of sampling gear such as traps or pots, or the length of trawl tows can greatly influence the epifauna caught. Traps or pots are usually left to soak for at least 24 h, while tows are conducted for at least 10-20 minutes.
- There are three stages of epifauna to consider: larvae, juveniles, and adults. Larval stages of epifauna are pelagic and thus are dispersed with water currents and therefore should be sampled as pelagic zooplankton (See Part G). This section discusses methods that can be used to sample juvenile and adult stages. Note that the method used should be appropriate for the animal stage being sampled. For instance, juvenile crabs (< 140 mm) should be sampled using trawls, while adult crabs should be sampled using passive gear such as traps.
- Seasonal events such as spawn timing may need to be considered in surveys. Recruitment events can range from every week to a few weeks. However, because of time and personnel constraints sampling for recruitment events will generally only be conducted once per year, and thus investigators should be aware of non-representative sampling (bias).
- Where possible investigators should simultaneously collect habitat information such as substrate type and extent, depth, water temperature, and vegetation.

C2. SESSILE EPIFAUNA

Sessile epifauna include organisms which are found attached to, or on top of, soft/sand/mud flats, rocky shores, and man made surfaces in and around the shallow nearshore subtidal. Nearshore subtidal sessile epifauna include the mussels which attach themselves to various substrates such as rocks, gravel, compact mud, and man-made surfaces by secreting byssal threads. The common blue and sea mussels (Mytilus spp) are found from heads of inlets to exposed shorelines, and they tolerate a wide range of temperatures and salinities. These mussels are found in the shallow nearshore subtidal to 45 m, while two species of horse mussels are found on substrates of deeper nearshore subtidal (> 50 m). Rock scallops (Crassadoma gigantea) are another common sessile epifauna found in nearshore subtidal B.C. Rock scallops attach primarily to rocks and are found from the low intertidal to 80 m (Jamieson and Francis 1986; Williams 1989). Note that several commercially important sessile epifauna (e.g., oysters, goose barnacle) are not considered in this document because they are primarily found in the intertidal zone.

C2.1. Sampling Qualitative and Quantitative Properties

To sample qualitative properties (e.g., presence/absence), investigators typically use SCUBA surveys. Refer to section 2.3 for a discussion concerning SCUBA surveys. The SCUBA survey should include observations of sessile epifauna, associated depth, substrate type and dominant vegetation. SCUBA surveys can be enhanced using still/video cameras which provides an accurate and permanent account of changes in qualitative properties of sessile epifauna in a given study area.

Because sessile epifauna are firmly attached to rocks and other hard substrata they do not lend themselves to being sampled with remote, active methods such as trawls. Rather, quantitative sampling of sessile epifauna is best accomplished with SCUBA surveys using removal methods. Removal methods include divers using a knife to scrape animals off substrates or using an airlift venturi suction sampler to remove specimens from the surface of the substrate. In either case divers remove animals from within a pre-defined quadrat of 1.0 m2. Samples collected are kept in a labelled mesh bag so that specimens can be later sorted and counted (see Benson, 1989; Ojeda, 1989; Kenelly, 1985). The number of quadrats and quadrat placement will depend on the complexity of the habitat, the species sampled, and the spatial distribution of the species. Refer to Part C7 for example studies.

For all quantitative samples collected, the following methods are used:

- Sessile epifauna density are reported in numbers of animals per m^2.
- Shell length of epifauna such as mussels is measured as the straight line distance between the anterior and posterior margin of the shell. Shell height is also measured for scallops. All lengths or heights are taken using vernier calipers and measured to the nearest millimetre.
- Standing stock or biomass is reported in grams wet weight per m^{-2}. Wet weights of sessile epifauna are usually obtained for the total body and shell, shell only, and whole soft body. Wet weights are recorded to the nearest 0.1 g on an electronic balance (e.g., Mettler), and biomass is reported in grams weight m^{-2}.
- Growth can be estimated by measuring shell length at each annulus (mm).
- Depending on species of bivalve, age can be determined by counting the number of annuli, or by analyzing thin sections of the shell (Quayle and Bourne 1972).
- Reproductive condition or stage of gonad development should be determined by removing the central portion of the gonad and preserving the tissue in Davidsonts solution. Histological work should be performed following standards discussed in references listed in Campbell et al. (1990).
- For properties such as length, age, weight, the sample size should be large enough to be representative of the population and be random. A minimum of 50 randomly selected animals are usually measured to increase the precision of estimated parameters.

C3. MOTILE EPIFAUNA

Motile epifauna are relatively slow moving animals that cannot actively avoid sampling gears but they can exhibit large daily and seasonal movements. Motile epifauna graze algae and are associated with rocky nearshore subtidal areas, and are frequently found in kelp beds. An important member of this resource group is the northern abalone (*Haliotis kamtschatLana*), which colonizes rocky substrates in high salinity waters with some wave or current action. Abalone are mainly found at depths < 20 m. Williams 1989). Another important motile epifauna is the sea urchin (*Strongylocentrotus francisciana* and *S. droebachiensis*). Urchins inhabit rocky

substrates in association with bull or giant kelp beds and other brown algae in moderate to high wave exposed areas. They occur from the extreme low tide to 60 m nearshore subtidal, however most urchins are concentrated in the 5 to 10 m nearshore subtidal range (Jamieson and Francis 1986). Little is known of the biology, distribution and abundances of the nearshore subtidal urchins, most sampling has been conducted in the intertidal and shallow nearshore subtidal (Campbell 1990). Another motile epifauna is the California sea cucumber (Parastichopus californicus) which is found on most substrates from rock to sand at densities of < 1.0 m~2, from O to 90 m nearshore subtidal where there is little or no current and detritus accumulates.

C3.1. Sampling Qualitative and Quantitative Properties

SCUBA survey methods are used to assess the qualitative and quantitative properties of motile epifauna. DFO uses standard SCUBA survey methods for assessing abalone and sea urchins, and these survey methods should be used to sample other similar motile epifauna. When sampling motile epifauna additional information about substrate type, site exposure, tidal flow, dominant algal vegetation and percent cover be determined for each study area.

i) *Abalone*

The standard SCUBA survey technique used by DFO to assess abalone populations is the 16-quadrat method (Breen and Adkins 1979). A preliminary dive survey is conducted to determine the top of the abalone zone. Four transects are then placed parallel to each other about 4.0 m apart, extending from the top of the abalone zone seaward from the coast. Along each transect four 1 m2 metal quadrats are spaced every 2 m (e.g., 1 m, 3 m, 5 m and 7 m), for a total of 16 quadrats. Divers must carefully turn over rocks and check between crevices for juveniles. All animals encountered by divers in a quadrat are removed, and later counted and measured. Ten surveys using the 16-quadrat method in British Columbia coastal waters are listed in Sloan and Breen (1988). The authors have discussed the inherent weaknesses of this standard survey method to assess abalone abundances.

- Densities should be reported as number of abalone m^{-2}.
- Maximum shell length of the abalone is determined using calipers and measured to the nearest millimetre.

ii) *Sea urchins*

The qualitative and quantitative properties of sea urchins are also sampled using SCUBA surveys. The following is an overview of the method used for purple sea urchins (e.g., Adkins et al. 1981). A series of contiguous 1 m^2 metal quadrats are placed along a transect. Transects should begin at the seaward edge of the dense kelp zone and continue for a minimum of 25 m or to the lower edge of the sea urchin zone (densities < 0.5 m^{-2}), which ever comes first. Habitat complexity and urchin densities determines the number of transects and their spacing which varies from 2 m to 5 m apart. All urchins encountered in quadrats along the transect should be removed, counted, and measured.

- Densities should be reported as number of urchins per m^2.
- Sea urchins should be measured for test diameters with vernier calipers to the nearest millimetre. Juvenile urchins are considered to have a test diameter of < 60 mm.
- The purple sea urchins are taken commercially for their gonads. If measured, gonad drained wet weights should be determined to the nearest 0.1 g on an electronic balance (Campbell 1990).
- For all of the above, at least 50 randomly individual epifauna should be collected and analyzed to increase the precision of estimated parameters.

C4. EVASIVE EPIFAUNA

This resource group is characterised by animals that can actively avoid most sampling gears. Most species in this group inhabit the shallow nearshore subtidal region for only a portion of their life cycle or part of the year. Resource species are diverse and include the Pacific octopus (Octopus dofleini), found in rocky nearshore subtidal areas (O to >100 m nearshore subtidal) where dens are established in caves, rocky areas, or sometimes in sand-shell substrates. The coonstripe shrimp (Pandalus danae) and prawn (P. platyceros), are common in areas with sand, gravel or rocky substrates with crevices. Humpback shrimp (P. hypsinotus) prefer muddy bottoms. All three shrimp species remain in shallow water bays and inlets during their first year due to an abundant food supply, but move to deeper areas later in life (>200 m nearshore subtidal). Dungeness crab (Cancer magister) prefer sand or mud substrate and occupy the intertidal to 180 m nearshore subtidal. They are often found buried slightly below the surface in sand or vegetated habitats. Red rock crab (C. productus) are common in rock, gravel or kelp beds from the intertidal to 80 m nearshore subtidal in areas that are slightly protected from wave action. They do not bury down into the sand or mud like Dungeness crabs. Pink scallop (Chlamys rubida) and Weathervane scallop (Patinopectin caurinus) are most commonly found in sand or mud substrates, while the Spiny scallop (C. hastata) and Rock scallop (C. gigantea) are associated with rocky substrates. Scallops prefer areas with strong currents for larval dispersal. Populations are found along the B.C. coast in small, high density groups from the low intertidal to 200 m nearshore subtidal (Jamieson and Francis 1986; Williams 1989).

C4.1. Sampling Qualitative Properties

For the evasive epifauna, qualitative properties (e.g., presence/absence) be assessed using SCUBA surveys. The most frequently used approach is to have a diver conduct a timed random swim, or have a diver towed behind a boat. The timed assessment should last a minimum of 15 minutes. Divers record observations of substrate type, depth, and counts of different species of epifauna. SCUBA surveys can be enhanced using still/video cameras which provides an accurate and permanent account of changes in qualitative properties of epifauna at a given study site.

C4.2. Sampling Quantitative Properties

The method used to sample quantitative properties of evasive epifauna depends primarily on the species of interest. To facilitate the presentation of sampling methods we discuss four main groups of evasive epifauna: crabs, octopus, shrimp and scallops.

i) *Crabs*

The method used to sample quantitative properties of crabs (e.g., density) is highly dependent on the size and sex of the animal. The most frequently used method for sampling crab larvae (< 140 mm) is the 2 or 3 m wide staff beam-trawl (Gunderson 1986; Smith and Jamieson 1990). The staff trawl is more effective than the otter trawl because it uses a rigid beam system that results in a mouth opening of fixed size. In addition the beam trawl is designed and rigged to follow the contours of the seabed closely, while tickler chains "scrub" the bottom in advance of the net. For a complete description of trawl design and use see Gunderson (1986). The date, tow depth, bottom type, area swept by the trawl, tow distance, and mesh size should all be recorded. Larger adult crabs (> 140 mm) are cryptic (e.g., hide in substrates) and thus should be sampled using crab traps (Smith and Jamieson 1990). The type of crab trap, mesh size, and deployment pattern will depend on the complexity of the nearshore subtidal habitat, time of year, and species of crab. The soak time and effectiveness of the bait are two important factors influencing the number and size of crabs caught.

- Densities are reported as number of crabs per m^2.
- Crab size is determined by measuring the carapace width, which is the distance between the notches after the tenth anterolateral spine (Smith and Jamieson 1990). Measurements are recorded to the nearest millimetre.

ii) *Octopus*

Octopus most commonly occur in boulder/rubble habitats between 3- 11 m nearshore subtidal. When sampling octopus it is important to be aware that they undergo two seasonal migrations per year. Thus nearshore abundances fluctuate, with peaks in summer and winter. Also note that larval octopus are planktonic for several weeks to months, and should be sampled as pelagic plankton (see Part G). Adult octopus can be sampled using SCUBA, hook and line, trapping and trawling. We recommend using a combined approach of SCUBA surveys and traps for quantitative sampling. A random timed SCUBA survey can initially be used to enumerate octopus and their dens. Because of frequent poor diving conditions, scare response, and activity level, octopus should also be sampled using pots. The type, size, and number of pots will depend on a variety of factors. Refer to Hartwick et al. (1984) and Rathjen (1991) for details as to appropriate sampling protocols.

- Octopus densities are reported as the number of octopus per m^2.
- The length of octopus is difficult to measure, so they should be weighed. Octopus can be weighed by removing excess water from the mantle cavity and weighing individuals in a mesh bag on a spring scale, correcting for bag weight. Weights are reported to the nearest gram.

iii) *Shrimp*

Several species of shrimp use the shallow nearshore subtidal at some time in their life cycle. However, the adults of all species are primarily found in waters deeper than 20 m. Sampling shrimp for quantitative properties in the shallow nearshore will best be accomplished using baited traps. The type and number of traps will depend on the species and habitat complexity. Factors that need consideration when using traps include design, bait, single versus strings of traps, soak time, size and sex influence on vulnerability to capture (Boutillier 1986). If sampling in deeper nearshore subtidal habitats, shrimp can be trawled for using the standard National Marine Fisheries Service high-rising shrimp sampling trawl (See Boutillier et al. 1977 for details). Since trawls are towed, boat speed, winch speed and pay, out must be carefully regulated and measured as these factors will also influence net depth. Optimally between 3-5 net tows of 10-20 minutes duration each should be conducted in each sample region. The volume of water filtered by the trawl can be determined from flow meters attached to the trawl net, or calculated from tow time and net dimensions.

- Report shrimp densities as number shrimp per m2.
- The carapace is measured to the nearest 0.1 mm (from the orbit of the eye to the mid-dorsal posterior margin).
- Shrimp weights are reported to the nearest 0.1 gram.
- For all of the above, at least 50 randomly individual shrimp should be collected and analyzed to increase the precision of estimated parameters.

iv) *Scallops*

Qualitative properties of scallops should be sampled by SCUBA divers removing all individuals from within 1 m^{-2} quadrats placed randomly in the nearshore subtidal habitat (e.g., see Orensanz 1986). Alternatively, SCUBA divers can swim in random search patterns, or along transects. A swim should be timed, and last a minimum of 15 minutes. Scallop abundance should be recorded as number of scallops collected per dive duration. Observations on depth and substrate should be noted for each dive survey. The number of quadrats and transects will depend on habitat complexity and scallop densities. Sampling for scallops in nearshore subtidal habitats not suitable for SCUBA should be conducted using a scallop dredge. A standard dredge survey employed by DFO uses a 2.4 m New Bedford scallop dredge with 75 mm rings, a 38 mm mesh liner, and a tow length of 800 m (see Robert and Jamieson 1986).

- Scallop densities are reported per m2
- Scallops are measured for shell height, which is the distance from the centre of the hinge to maximum projection point on the rim perpendicular to the hinge. Juvenile scallops are considered to have shell heights < 60 mm. Shell height is measured with calipers to the nearest 0.1 mm.
- Refer to Orensanz (1986) for standard ageing methods.

C5. ALTERNATIVE SAMPLING METHODS FOR EPIFAUNA

In nearshore subtidal habitats where SCUBA is not feasible, or if data need to be collected over a large spatial scale or over little time, hydroacoustic sampling methods may be appropriate. Hydroacoustics can be used to "sample" and map shallow nearshore subtidal habitats to provide qualitative information concerning presence/absence or relative distributions. For instance, Dealteris (1988) used a side-scan sonar system to economically sense bottom type and topographic features of shallow oyster reefs. It may be possible to use hydroacoustic processors to develop relationships between physical properties of nearshore subtidal habitats and sessile epifauna (See section 2.1.3). Aerial video imagery may also be used to rapidly and qualitatively assess the presence and distribution of kelp beds and sea urchin barrens (Frith et al. 1994). This utility of this method for assessing qualitative properties of sea urchins, is however, ultimately limited by water clarity and depth.

C6. CRITICAL ASSESSMENT CRITERIA

The following information (and appropriate units) should be collected and recorded when sampling epifauna to determine the compatibility and accuracy of data among studies:

- Type of SCUBA survey performed (random swim, transect, video/still camera, removals)
- SCUBA survey duration (min), number and experience of divers
- Number, length (m), width (m), spacing (m), and orientation (parallel or perpendicular to shoreline) of transects
- Number and size (m^2) of quadrats
- Depth of sampling units (quadrats, transects)
- Type and dimensions of trawl/net, dredge, or trap used (height, width and length in m)
- Mesh size (mm)
- Duration of tow (min) or soak time of traps (h), and depth sampled (m)

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Table C1. Summary of methods used to sample qualitative (e.g., presence/absence) and quantitative (e.g., biomass) properties of three main groups of nearshore subtidal epifauna.

Epifauna Group	Example spp.	Qualitative Sampling Method	Quantitative Sampling Method
Sessile	Mussel	SCUBA survey	SCUBA survey with removals
Motile	Abalone	SCUBA survey (16-quadrat method)	SCUBA survey with removals (16 quadrat method)
	Urchins	SCUBA survey	SCUBA survey with removals
	Cucumbers	SCUBA survey	SCUBA survey with removals
Evasive	Crabs	Staff beam trawl and crab trap	Staff beam trawl and crab trap
	Shrimp	Staff beam trawl and trap	Staff beam trawl and trap
	Octopus	SCUBA survey	SCUBA survey and pot-trap
	Scallops	SCUBA survey	SCUBA survey or scallop dredge

PART D. BENTHIC FISH EGGS

There are several fish species that lay adhesive egg masses on hard substrates or on macroalgae in the shallow nearshore subtidal. For instance, the lingcod (Ophiodon elongatus) lays large masses of adhesive eggs in areas with rock crevices, exposed to strong currents. The surf smelt (Hypomesus pretiosus pretiosus) spawns on pea-sized gravel of protected beaches. The adhesive egg masses found most frequently in the shallow nearshore subtidal belong to the Pacific herring (Clupea pallasi). The herring lay masses of adhesive eggs primarily on macroalgae (Hart 1980).

To assess the qualitative and quantitative properties of benthic fish eggs, investigators use survey methods developed by the Canadian Department of Fisheries and Oceans (DFO). These methods are routinely used to sample herring spawn and can be adapted to assess other fish species that lay eggs on substrates. DFO assesses herring spawn deposition in nearshore habitats because it provides a convenient indicator of abundance of spawning herring biomass. Further, DFO regularly assesses herring spawn along sections of the B.C. coast. Investigators interested in assessing herring spawn should thus consult with DFO before any herring spawn sampling is conducted. This section summarizes the important considerations for sampling herring spawn, and they can be applied to sampling other fish species that lay eggs on substrates.

D1. GENERAL SAMPLING CONSIDERATIONS

- An important consideration when sampling benthic fish eggs is spatial patchiness and the scales on which it varies. For instance, herring spawn is found throughout the B.C. coast with average cumulative annual deposition of about 400 km. Herring spawn is usually restricted to sheltered inlets, sounds, bays, and estuaries. Most herring spawn is deposited within 10 m of the mean tide level, and > 90% occurs within 150 m of the inshore edge of spawning. Some herring spawn patches however, can be up to 400 m wide. The greatest sampling effort is concentrated in areas that historically contains the most spawn (e.g., Hay et al. 1989).
- When sampling benthic fish eggs, investigators should be familiar with the spawning period and its duration. For instance, the total spawning period of herring in southern B.C. is from January to May, with major activity from mid-February to mid-April, and peak spawning in March. In northern B.C., total spawning period lasts from mid-February to mid-June, with majority activity from mid march to end of April, and peak spawning from mid-March to mid-April. In most geographical locales, spawning occurs in several major 'waves' and generally lasts 3-8 weeks.
- Most species of fish that lay benthic eggs are quite selective of appropriate nearshore subtidal habitat. Herring however, do not necessarily use one type of vegetation over another. Roughly 30% of herring eggs are laid on seagrasses (Zostera spp), 10% on Fucus, 20% on brown algae (kelps), and about 40% on red filamentous algae. The giant kelps are more important as spawning substrate in the Queen Charlotte Islands. Egg density in the vegetation can range from 1×10^5 to 1×10^6 eggs/m^{-2}. Eggs are deposited on surfaces of vegetation in 1-5 layers, on average, with up to 20 layers.

- In detailed site studies of adhesive fish eggs, investigators should collect concurrent information on water temperature, salinity, dissolved oxygen (see Part I), and macroalgae (see Part A).

D2. SAMPLING QUALITATIVE PROPERTIES

The most commonly assessed qualitative property of benthic fish eggs is presence/absence. The simplest method used for assessing herring spawn distribution is to use a grapple rake from a small boat and bring vegetation to the surface. Other methods used to assess the distribution of adhesive fish eggs is to conduct a timed random SCUBA survey or snorkel survey of the shallow nearshore subtidal habitat.

D3. SAMPLING QUANTITATIVE PROPERTIES

The quantitative properties of benthic fish eggs such as egg density or biomass can be sampled using a SCUBA transect survey as discussed in section 2.3. DFO has outlined survey protocols for sampling herring spawn (Schweigert et al. 1990), and a similar approach can be used to sample other species. The following methods are used:

- A minimum of 3 transects/km of coast with a minimum of 4 samples per 100 m of transect length are sampled per DFO statistical area. Transects are laid normal to the coast to assess the width of herring spawn.
- The general considerations for the SCUBA survey are survey speed, accuracy and precision, and degree of habitat coverage required. For instance, it is important to emphasize the speed of the survey because herring eggs hatch about 15 d after being laid.
- Several quadrats of a minimum 0.25 m^2 are randomly laid along each transect.
- Egg density can be determined directly by counting the number of eggs from sub-samples obtained from each quadrat. Alternatively, DFO has outlined and evaluated 2 predictive mathematical equations for indirectly estimating herring spawn density (Schweigert et al. 1990). These predictive equations require that the following information be collected from each quadrat: the average number of egg layers on vegetation, type of predominant vegetation, the proportion of quadrat covered with vegetation, and the wet weight of vegetation and attached eggs determined.
- The biomass of herring spawn can be determined by weighing eggs that have been stripped off the macroalgae. Wet weights are measured to nearest 0.1 g on an electronic balance.
- Simenstad et al. (1991) recommend and discuss two methods for assessing egg survival and viability. On the spawning ground, discrete egg masses can be isolated in mesh cages and monitored. Discrete egg masses can also be removed to the laboratory and placed in a flow through seawater system and evaluated for hatching success (see also Aneer and Nellbring 1982).

D4. ALTERNATIVE SAMPLING METHODS

Some remote sensing methods such as hydroacoustic processors offer promise for assessing herring spawn deposition. See section 2.1.3 for more discussion of hydroacoustic processors and other remote sensing methods that may hold promise for sampling benthic fish eggs.

D5. CRITICAL ASSESSMENT CRITERIA

The following information should be collected and recorded when sampling benthic fish eggs to determine how comparable and compatible data are among studies:

- quadrat size (m^2) and transect length (m), sample depth (m)
- type and extent of substrate and macroalgae
- water temperature, salinity, water current

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Table D1. Summary of methods used to sample benthic fish eggs.

Benthic Fish Eggs	Sampling Method
Qualitative properties (e.g., presence/absence)	SCUBA transect survey
Quantitative properties (e.g., density)	SCUBA transect survey using quadrats with observations and removals
Alternative sampling methods	Remote sensing methods such as bottom classification systems

PART E. PHYTOPLANKTON

The marine phytoplankton include at least 8 classes of algae that are distinguished on the basis of photosynthetic pigment and fine structure. Most phytoplankton are small in size (< 100 pm) and they obtain their energy supply from light through photosynthesis mediated by chlorophyll a. The marine phytoplankton either float singly or they are held together in small chains or colonies by threads, spines, and jelly. The phytoplankton reproduce rapidly on the order of hours to days when light and nutrient conditions are favourable. Common groups of coastal phytoplankton include the diatoms, dinoflagellates, small flagellates, and the blue-green algae.

The methods discussed for sampling phytoplankton have been used for decades. Perhaps the biggest consideration in sampling phytoplankton is where in the water column they are located. Sampling can be conducted at the surface, in the mixed layer, at discrete depths, or for the whole water column. The type of sampling will depend on study objectives. The methods discussed in this section are used primarily by the Department of Fisheries and Oceans, Institute of Ocean Sciences (IOS), Sidney for coastal oceanographic sampling programs.

E1. GENERAL SAMPLING CONSIDERATIONS

- Physical and chemical water properties vary daily, seasonally, and yearly because of natural seasonal cycles, daily fluctuations in the nearshore physical environment (e.g., tides), and biological processes (e.g., excretion). All of these processes significantly affect nearshore distributions and concentrations of phytoplankton. Phytoplankton should be sampled over several consecutive days because they can double their biomass on the order of days. To fully characterize the possible range of values, phytoplankton sampling should also occur at least twice monthly, and preferably weekly, during the most productive season (March to September).
- Sampling for phytoplankton takes place at point stations along transects, or at a grid of stations. The survey method used will depend primarily on tidal and current features of the nearshore subtidal habitat, and on study objectives. A transect of stations is appropriate if an alongshore or across shore gradient in phytoplankton is suspected. A grid of stations should be used if there is large spatial homogeneity in habitat unit. Stratified random sampling should be considered for studies over local and regional scales.
- When sampling phytoplankton it is critical that the location of point stations, transects, and grids be accurately determined and recorded. Station position in the nearshore nearshore subtidal can be determined using navigational fixes with land-bearings, but differential global positioning systems should be used when available.
- It is also critical to accurately determine and record the sample depth. Sample depth can be determined from calibrated pressure sensor on automated samplers (e.g., CTD), or from metre markings on the hydrocast line, or from an echo sounder. Depths are reported to the nearest 0.1. During hydrocasts, the wire angle should be measured and depths corrected accordingly.
- There are two steps in assessing phytoplankton: field sampling and laboratory analyses. In this document we discuss methods for field sampling. Refer to Strickland and Parsons (1972),

Parsons et al. (1993), and Forbes and Waters (1993) for accepted standard laboratory methods for analyzing phytoplankton properties such as fluorescence, or productivity. Strickland and Parsons (1972) and Parsons et al. (1993) discuss various methods including their capability (e.g., precision), special apparatus and equipment required, sampling procedures, sample storage protocols, specific reagents required, and necessary calculations for parameters.

- Phytoplankton can be sampled using remote sensing methods such as satellites, compact airborne spectral imagery (CASI), and light and range detection (LIDAR). Remote sensing methods are appropriate for sampling phytoplankton at the Provincial and regional scales. No single remote sensing method can be recommended because all are undergoing rapid advances in technology, resolution, and data processing. Refer to Section 2.1 for further discussion.

Phytoplankton can also be sampled using field sampling methods such as water bottles or pumps. Field sampling methods are required to calibrate remote sensing data, and to provide quantitative data on phytoplankton. In general, phytoplankton samples are not collected using plankton nets because these devices become clogged easily and result in contamination and misrepresentation of phytoplankton properties. Phytoplankton properties in shallow nearshore areas are sampled primarily by collecting water samples. Water samples can be collected from four general areas of the water column: surface, integrated mixed layer, discrete depth, water column profile using the following methods:

i) **Surface Water Samples**

Surface water samples are usually collected by dipping a well-rinsed bucket over the side of the boat. The required volume of sub-samples (see below) can be taken from within the bucket.

ii) **Integrated Water Samples**

The segmented integrating pipe sampler (Sutherland et al. 1992) is particularly useful for inshore sampling of water properties, combining advantages of both integrated and discrete depth samples. Integrated samples are usually taken from the surface to 10 m.

iii) **Discrete Depth (Grab) Samples**

Sea water samples from specific depths can be collected using diaphragm pumps or water bottles such as 1.7 L Niskin bottles. Pumps will quickly sample water from depth but may bias samples by introducing water from surrounding depths, or by introducing oxygen into samples. Water bottle casts (hydro-cast) can be conducted in shallow nearshore subtidal habitats. It is important to release the weighted 'messenger' only after the bottle has been lowered to the desired depth. In addition, water should be drawn immediately after each cast by ensuring that bottle tubing is placed directly in to the sample container before water is released.

iv) **Water Column Profile**

It is possible to obtain a water column profile from many hydro-casts, but automated samplers are more frequently used. Some conductivity-temperature-depth sounds (CTD) permit easy attachment of transmissometers or fluorometers to obtain data on the profile of chlorophyll in the water column. The transmissometer is preferred except in water subject to strong turbidity from inorganic sources (e.g., run-off), as it is not affected by variability in fluorescence yield due to differing phytoplankton species composition or light history. When using automated samplers there are several important considerations:

a) The automated sensor should generally be lowered at a rate of 0.5-1.0 m sec^{-1} until 1-2 m from the sea floor. The exact speed of lowering the CTD is dependent on the type used and manufacturer's specifications should be consulted. Determine maximum depth before lowering the sensor.
b) Data should be collected from the automated sampler at every metre on ascent and descent.
c) The sensors should be accurate to within + 0.03°C, +0.05 ‰, and + 1% pressure (depth).
d) All automated samplers must be calibrated with manually collected samples (see above). Larger CTDs usually have a rosette sampler attached from which water samples at discrete depths can be taken.

When water samples are collected, the following methods are used:

a) Sample replication will depend on project objects and property measured, but at least two replicate water samples be collected (i.e., two hydro-casts) at each station depth. In addition, it is important to collect replicate water sub-samples from each hydro-cast for laboratory analyses.
b) b) All water sample containers be labelled with at least the following information: date, time of day collection was made, station name and location, depth, method used to collect sample, replicate number, water property to be analyzed for, name of collecting agency.

E2. SAMPLING QUALITATIVE PROPERTIES

The presence/absence and distribution of phytoplankton in general (e.g., chlorophyll a) and at small scales can be determined using remote sensing imagery: satellites, compact airborne spectral imagery (CASI), and light and range detection (LIDAR). Refer to section 2.1 for a discussion of these sampling methods. The presence/absence of phytoplankton species should be determined by collected water samples using one of the methods recommended above. The following methods are used:

- Water samples collected for phytoplankton species composition analysis are preserved using Lugol's fixative (Throndsen 1978). Acid lugols should normally be used to ensurepreservation of siliceous material (e.g., diatom frustules). Neutral Logol's may also be used to ensure preservation of taxa with calcareous components but this is rarely required for inshore waters. Some investigators prefer to use Formalin Acetic Acid because it has a relatively low toxicity, good preservation of diatoms and armoured flagellates. Other investigators prefer

glutaraldehyde/ paraformaldehyde which is an excellent preservative of naked flagellates and for conservation of chlorophyll autofluorescence (Smith and Pauley 1990). The preservative used should be documented.

- Phytoplankton species can be identified from small subsamples (10 ml) using the settling and inverted microscope method (see Hasle 1978).
- Cupp (1943) can be used to identify marine diatoms of the West Coast of North America, and Dodge (1982) for identifying marine dinoflagellates.

E3. SAMPLING QUANTITATIVE PROPERTIES

Water samples are frequently collected to determine the biomass of phytoplankton i
(chlorophyll a) and productivity. The following methods are used:

i) **Assessment of Chlorophyll**

- Chlorophyll a is an indirect measure of phytoplankton standing stock (crop), and represents the weight of phytoplankton per unit volume or area of water and should be reported as mg per m3.
- Replicate water samples should be collected from replicate hydro-casts at each depth.
- The chlorophyll a content is estimated in the laboratory using the fluorometric technique described in Strickland and Parsons (1972). Chlorophyll a can also be estimated continuously and automatically in the field using a flow-through fluorometer.
- The sample volume for the fluorometric method ranges from 50 ml to 250 ml depending on concentration. Normally in B.C. coastal waters, 100 ml is sufficient in summer and 200 ml in winter.
- Water samples are filtered onto 25 mm diameter Whatman GF/F fiber (0.7 µm nominal pore size) or equivalent with a vacuum pump < 100 mm Hg. About 1 mg of MgCO3 should be added while filtering and the funnel should be rinsed with filtered sea water.
- After filtering, the sample can be frozen for later analysis. When freezing, it is preferable to place the folded filter in a cone made from a paper filter (e.g., Whatman No. 1, 9 cm diameter), and then wrap with foil. This absorbs some of the water and has the added advantage of easy labelling. Several paper filters can be included in a single foil wrapper.

ii) **Assessment of Productivity**

Phytoplankton productivity can be estimated one of two ways: light/dark bottle or carbon 14 method.

- Phytoplankton productivity can be estimated using the standard light/dark bottle technique (Strickland and Parsons 1972; Parsons et al. 1993). Collect at least four samples (2 dark and 2 light) of at least 250 ml and inoculate each with 1 ml of 5 lC/ml 14 (bicarbonate). Samples should be incubated for at least 2 h under fluorescent lights. Water samples should then be incubated in an incubator, or in situ at sample depth. Options for incubation include using a

deck incubator with screening to simulate the in-situ irradiance from the sample depth, usually for one-half day or 24 h (Banse 1994) or incubation in artificially-lit (fluorescent or halogen source) incubator, with screening to simulate the in-situ irradiance. In all cases, incubators may use pumped surface seawater or a cooling unit for temperature control.

- Phytoplankton productivity can also be estimated using the i4C method. Consult Strickland and Parsons (1972) and Parsons et al. (1993) for the standard traditional {4C uptake method. Note investigators should prepare their own isotope ampoules from concentrated sources, including filtering after preparation, to avoid contamination from organic carbon and to diminish metal contamination.

E4. ALTERNATIVE SAMPLING METHODS

As alluded to above, a recent trend in monitoring and "measuring" phytoplankton is to use remote sensing devices. For instance, the coastal zone colour scanner (CZCS) which operated from 1978 to 1986, measured the colour of sea water in six spectral colour bands as well as infrared. CZCS was used to determine chlorophyll, at 800 m by 800 m resolution. A new colour scanner, the SeaWifs, was launched in 1995, and will offer improved spatial and colour resolution. Manipulation of data from NOAA AVHRR weather satellite can provide information on areas of high phytoplankton biomass (e.g., Gower and Borstad 1991). Airborne sensors like LIDAR and CASI are also available to measure light spectra and estimate phytoplankton properties. The main disadvantage of these techniques compared to satellites is higher cost. Advantages include much better spatial resolution and lower probability of interference from cloud cover. See section 2.1 for a more detailed discussion of remote sensing methods.

Continuous sampling using flow-through fluorometers is not practical in nearshore shallow waters because these systems require the use of relatively large ships.

E5. CRITICAL ASSESSMENT CRITERIA

The following information (and appropriate units) should be collected and recorded when
sampling phytoplankton to determine the compatibility and accuracy of data among studies:
- water collecting device and dimensions
- depth of water samples (m) and their volume (ml)
- number of stations sampled and number of samples collected
- analyses performed and laboratory methods used
- water temperature, nutrients, light, salinity should be collected
- field guide used to identify species
- preservative used and volumes of sub-samples
- station/transect/grid location
- name of collecting agency

- date, time of day sampling conducted

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Table E1. Summary of methods used to sample the qualitative and quantitative properties of phytoplankton.

Qualitative properties (e.g., species composition)	Water samples collected using a bucket, pipe sampler, water bottle, diaphragm pump or automated sampler
	Remote sensing devices such as satellites
Quantitative properties (e.g., chlorophyll)	Water samples as described above
	Remote sensing devices

PART F. ZOOPLANKTON

The zooplankton consist of holoplankton and meroplankton. The holoplankton are permanent members of the plankton community and the shallow nearshore is typically dominated by calanoid and cyclopoid copepods, hyperiid amphipods, ctenophores, medusue and larvaceans. The meroplankton are temporary residents of the plankton that eventually recruit to the benthos. The meroplankton include larvae of many invertebrates such as polychaeta, gastropoda, echinodermata, and crustacea. Note that methods recommended for sampling icthyoplankton (fish larvae) are considered in Part G, while methods for sampling phytoplankton are considered in Part E. Zooplankton are generally unable to maintain their horizontal and vertical position against water movements. In fact, in most shallow nearshore subtidal environments zooplankton are found throughout the water column because of strong tidal or wind mixing. Nearshore zooplankton are likely to be transported less than a few km alongshore each day because of the cyclical nature of tides and water circulation in bays and inlets.

The methods used to sample the zooplankton will depend primarily on the type of water column habitat they occur in. Nearshore zooplankton that occur primarily in the mid to upper water column can be effectively sampled with plankton nets, while zooplankton occurring near the bottom or within kelp beds may be better sampled using pumps. The methods we discuss are taken from a variety of sources including the Department of Fisheries and Oceans, the Puget Sound Estuarine Habitat Assessment Protocol, and the University of British Columbia.

F1. GENERAL SAMPLING CONSIDERATIONS

An important sampling consideration is the spatial patchiness of zooplankton and the scales on which it varies. On horizontal scales, zooplankton tend to be clumped or aggregated rather than randomly distributed because of advection, turbulence, divergence or convergence of water masses, and biological factors such as nutrient availability and the presence of predators. Zooplankton are also patchy within the water column because of differences in light intensity, density gradients, and availability of nutrients at the surface, among other factors.

Life history stages or species composition of zooplankton can vary widely over time. This temporal variability is due to natural seasonal cycles, daily fluctuations in the nearshore physical environment, life history patterns, and the effects of predators. To capture temporal changes in zooplankton species composition and abundance, sampling should be conducted at least monthly, and preferably twice a month during the most productive season (March to September).

Sampling for zooplankton in and around coastal features such as tide lines, fronts or eddies requires special strategies. For instance, most of these sites are biologically quite active, but tend to vary with daily tidal cycles or seasonal water current structures. Knowledge of local oceanographic processes can be invaluable when designing a plankton sampling program.

Another consideration of sampling zooplankton is that some species exist in planktonic form for only a short period ranging from weeks to months (meroplankton). Thus investigators

must be cognizant of the species and life cycle of the zooplankton to be sampled, and coordinate the timing of sample collection with the most abundant planktonic stage.

Because plankton nets are towed, the bridles and tow lines cause water currents, pressure variations in the form of low-frequency vibrations, sound waves, and variability in light intensity. All of these factors provide cues that enable some larger zooplankton to avoid the sampling gear. Investigators should employ methods that reduce avoidance of nets by ensuring all sampling nets are constructed of dark material, sampling is conducted at night, and bridle gear does not obstruct the net mouth opening. While sampling at night is preferred because it reduces sampler bias, it may be impractical in shallow nearshore environments.

Zooplankton sampled with nets will be sampled most efficiently and effectively using different net mesh sizes. Generally, larger zooplankton (e.g., large copepods, or crab larvae) are most successfully sampled with mesh sizes > 500-pm. Medium-sized zooplankton (e.g., Calanus spp. or copepodites) are most effectively sampled with mesh of 250 to 333 pm, while small zooplankton (e.g., copepod nauplii) are best sampled with nets of 60 to 100 pm. Smaller meshed nets become clogged with phytoplankton and debris, and thus tow times should be kept short (5 - 10 min) and nets thoroughly rinsed after each tow. Clogging results in possible cross-contamination of samples and reduced sampling efficiency of the net.

F2. SAMPLING QUALITATIVE AND QUANTITATIVE PROPERTIES

The methods used to sample permanent and temporary residents of the zooplankton community will depend primarily on the type of water column habitat they occupy. Shallow nearshore zooplankton communities will generally be found (i) in the mid to upper water column or (ii) near the bottom or closely associated with algae. Ideally, to sample the total zooplankton community in any shallow nearshore subtidal habitat both sampling strategies must be employed. We now discuss the two sampling strategies.

i) **Sampling Open-water Habitats**

The bongo net is most frequently used to sample qualitative and quantitative properties of zooplankton found in the mid to upper water column. The main assumption here is that zooplankton are available to, and cannot avoid, the bongo net. The Department of Fisheries and Oceans (DFO) uses a standard bongo net and survey design (e.g., Shaw 1994) to sample pelagic zooplankton. The following highlights important standards of this method:

- The standard bongo net towing frame should be black and consist of two 60 cm diameter hoops. A dark nitex net is attached to each hoop. The mesh size of each net will depend on the zooplankton to be sampled (see above). Two different mesh sizes are commonly used during the same tow (e.g., 230 pm and 500 pm).
- For quantitative measurements of zooplankton (e.g., biomass) a flowmeter must be mounted in the mouth of at least one net (or both if different mesh sizes are used) to provide information on volume of water sampled.

- To obtain an integrated measure of zooplankton within the water column the bongo net should be towed obliquely from near-bottom to the surface. It is useful to assess the bottom depth before sampling commences because water depth changes with tidal cycles. The depth of the bongo net should be determined using a time-depth instrument or from calculations using wire angle and payout (See Shaw et al. 1994 for example calculation).
- If the water column is stratified, horizontal bongo net tows should be conducted above and below the pycuocline. The depth of a discrete tow can be regulated by controlling the amount of wire out and the wire angle, or using information from a time-depth recorder. Discrete depths can also be sample using multiple opening and closing nets (e.g., see Part I), but these sampling devices require large vessels and thus may be impractical to use in shallow nearshore areas.
- The bongo net should be deployed at night to reduce likelihood of avoidance by larger zooplankton, and should be towed at slow boat speeds (2-3 knots).
- Winch speed and payout must be carefully regulated and measured. The rate of decent of the bongo net should not exceed 1 m sec^{-1}, while the retrieval rate should be between 0.3 m sec^{-1} to 0.5 m sec^{-1}.
- At least 2 oblique bongo net hauls should be conducted in each water column habitat unit. Depending on study objectives and desired statistical sensitivity, 8-10 replicates may be more appropriate.
- The length of a bongo net tow will depend on project objectives, but will generally range 5-15 min. Longer tows result in nets becoming clogged with debris.
- At then end of each tow, both nets should be thoroughly washed down and the catch preserved immediately in a buffered formalin solution (UNESCO 1974). A typical fixative used for zooplankton, and recommended here as the standard, is 10% buffered formalin. Buffered formalin is prepared by mixing 1 part 40% formaldehyde, 9 parts seawater, and a small quantity of borax. Plankton should occupy no more than 10-20% of the sample jar volume (Tett 1987).
- All zooplankton sample containers should be labelled on the lid and with a small piece of paper placed inside with information about date, geographic location, gear type used, mesh size, tow depth, tow duration, and station number.

Note that because of shallow depths and proximity to shoals, it is possible that most zooplankton sampling will have to be done from small boats. Thus winch and davit structures may be not be capable of operating a full sized bongo net. In these circumstances, investigators should consider using a 1 m ring net, with appropriate mesh size (see above). This net is usually hauled vertically (rather than obliquely), but the majority of the remaining bongo net protocols discussed above should still be applied (tow duration, location, etc.). Miller et al. (1984) have developed a vertically-hauled closing ring net that is messenger operated. This net is very useful for discrete samples of zooplankton above and below pycuoclines.

ii) **Sampling Near Bottom/Vegetated Habitats**

In some nearshore subtidal habitats such as kelp forests, zooplankton may be found closely associated with the vegetation or benthic substrates, and thus sampling with a bongo net

or plankton net will bias collections. The most useful approach under these conditions is to use a vertically profiling pump. In good weather, the pump tubing could be deployed to suck water from discrete depths, or it could be towed behind a small boat, and the outflow screened over the side. Although there is some debate over zooplankton detection and avoidance of intakes, these problems can be minimized by using a large flow volume, low turbulence 'horn' intake, in a reasonable background tidal flow. Gasoline powered floating 'vortex' pumps have also been used to effectively sample zooplankton in shallow waters. Because of possible low filtration rates, pumps are limited to waters with plankton densities of < 10 m^3. Miller and Judkins (1981) describe several systems used to sample zooplankton in shallow coastal areas.

F3. SAMPLE MEASUREMENT PROTOCOLS

For all qualitative and quantitative zooplankton samples collected using bongo or plankton nets and pumps, the following methods should be used:

- Zooplankton biomass is reported as wet weight per m^3. Note that other units can be calculated from this (e.g., g m^{-2}). Before weighing it is important to remove as much water as possible using gently vacuum filtration or by blotting on paper until the paper absorbs no more water. Wet weights are determined on an electronic balance and reported to the nearest 0.001 g.
- Zooplankton biomass is also sometimes required in dry-weight or ash-free dry weight. Dry weight can be estimated by drying fresh or frozen zooplankton (not formalin preserved) samples at 80-100°C for 24-48 h, or until a constant weight is achieved. Dry weight is measured to nearest 0.001 g on an electronic balance. If dry weights need to be converted to ash-free weights, standard values can be used (see Parsons et al. 1984).
- If both taxonomic identification and biomass are required, it is best to use one side of the bongo net tow for taxa identification and the other side for biomass determination. Zooplankton can be identified using: Barnes (1980); Gardner and Szabo (1982); Kozloff (1987). The ICES Plankton Fiches are also useful for identifying larval and juvenile zooplankton.
- Enumeration of zooplankton life history stages usually include: 1) nauplii, 2) copepodites, 3) non-reproductive females, 4) males, and 5) ovigerous females (Simenstad et al. 1991).

F4. ALTERNATIVE SAMPLING METHODS

Larger zooplankton such as crab megalopae can avoid obliquely towed bongo nets, and thus it may be preferable to use horizontally towed nets, such as a neuston net (i.e., Jamieson and Phillips 1988). Simenstad et al. (1991) also describe a standard protocol for sampling zooplankton with a purse seine. Ultimately, it may be most beneficial to identify the type and size of zooplankton, and the likely vertical distribution of the zooplankton to be sampled before committing to a particular sampling gear or mesh size. Hydroacoustics may be useful for assessing small scale distributions of zooplankton and relative abundances. However, hydroacoustic sampling equipment is expensive, output is difficult to interpret, and echograms

still require calibration with zooplankton net sampling. See Holliday et al. (1989) and Morton and MacLellan (1992) for good discussions about acoustical sampling of zooplankton.

F5. CRITICAL ASSESSMENT CRITERIA

The following information (and appropriate units) should be collected and recorded when sampling zooplankton to deterrnine the compatibility and accuracy of data among studies:

- type of plankton net or pump used
- mesh size (mm) or pump tube diameter (mm)
- number of samples collected at each depth
- duration of plankton net haul (min) and orientation (vertical, horizontal, oblique)
- volume of water filtered by net or pump (m^3)
- rate of ascent/descent of sampling device ($m\ sec^{-1}$)

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PART G. PELAGIC FISH EGGS AND LARVAE

Available information and data about marine fish larvae and eggs is limited for the nearshore, shallow nearshore subtidal regions of British Columbia. A general but useful review of the distribution and biology of larval fishes, with emphasis on Puget Sound, was prepared by Garrison and Miller (1982). Most Larval fish sampling has occurred in areas further offshore (e.g., Mason et al, 1982, Shaw et al. 1988, Hay and McCarter 1991). However, the presence and relative importance of larval fish and eggs in the B.C. nearshore is exemplified by Dagget (1981) who found greater abundances of fish larvae at a nearshore station (10 m deep) versus an "offshore" station (30 m deep) in Juan de Fuca Strait. The nearshore distribution of herring larvae has been documented by Hay and Arai (1983), Hay and Marliave (1988), Hay and McCarter (1990, 1991).

More than 13 families of larval fish are likely to be found in surface waters of coastal B.C. In any survey, the specific species encountered will depend on the coastal habitat, season, and sampling gear. The families most frequently occurring in B.C. surface waters include Agonidae (poachers), Ammodytidae (sand lances), Bothidae (left-eyed flounders), Clupidae (herring), Cottidae (sculpins), Engraulidae (anchovies), Gadidae (codfishes), Hexagrammidae (greenlings), Liparidae (snailfishes), Pholidae (gunnels), Pleuronectidae (right-eyed flounders), Scopacnidae (rockfishes), and Stichacidae (pricklebacks). Larval fish are similar to the pelagic zooplankton (Part G) in that they are generally unable to maintain their position or distribution against water movements. Thus, most nearshore larval fish are widely distributed, reside throughout the water column or in surface layers of stratified water columns (0 m to 10 m), and may be transported by up to several kilometres alongshore each day. Species composition and densities can vary widely, even over short distances, because of variability in the density of spawning fish, in spawning behaviours' water current structure, and in biological effects (zooplankton prey or predator concentrations).

Most egg and larval fish surveys are conducted for scientific or stock assessment purposes. In the latter case, the estimated number of eggs and larvae can be used to backcalculate the numbers of spawning adult fish required to produce them. This is the principle of the British Columbia herring spawn surveys, but the same approach has long been used for a number of pelagic species (Saville 1963). Another relatively common purpose of sampling fish larvae is to determine the potential entrainment of larvae from submerged seawater intakes. Larval sampling is commonly done in areas that use water for industrial cooling. The Department of Fisheries and Oceans has provided a set of guidelines for minimizing entrainment (Federenko 1991). In general, estimating the potential problem of larval fish entrainment requires that sampling be done throughout the year so that the species composition and relative abundance (numbers m^{-3}) can be determined.

Irrespective of the assessment requirements (e.g., scientific or stock), both qualitative and quantitative properties of larval fishes can be sampled using towed nets equipped with a flow meter. In general, large volumes of water have to be sampled in a relatively short period because of wide distributions of larvae and their delicate structure. In most nearshore habitats, paired

bongo nets will be the most suitable sampling gear. Other towed nets may be more appropriate in confined habitat (see Part F).

G1. GENERAL SAMPLING CONSIDERATIONS

One of the most important sampling considerations is the spatial scale over which sampling occurs. Most larval fish are widely dispersed along the coast, with maximum densities of only a few larvae m^{-3}. Most investigators use gear that can sample at least 5-10 m^{-3} of water relatively quickly.

Another important sampling consideration is the efficiency of the sample net related to the size of the larvae. If larvae are small (<15 mm), they can be readily captured with a paired bongo net, with a mesh size of 350 μm. However, larger larvae will evade most nets.

Most larval fish species undergo diurnal migrations, therefore the timing of tows is an important consideration. Large differences may occur in larval fish estimates when tows are made at different times of the day, and especially between the day and the night. Oblique tows should be used to sample a range of depths with equal effort during a single towing session. If it is important to determine the abundance of larvae by depth, then an opening and closing nets, such as a Clarke-Bumpus net, should be used which are small and easily operated from small vessels. The disadvantage is that the net opening is small and it will only be effective in capturing small larvae.

Larval fish are most abundant in coastal B.C. waters from about March to mid-summer, with peak concentrations occurring in April/May. Relatively few families of larval fish occur abundantly in the fall or winter (e.g., Bothidae or Osmeridae). Depending on the purposes of the sampling, sampling for pelagic fish eggs and larvae should be conducted at least monthly during from June to October, and at least twice a month during April and May.

It is important to consider that fish larvae occur roughly at the same time as local phytoplankton blooms. Diatoms, especially the chain diatoms, will rapidly clog a net and restrict its filtering capability. Therefore, larval fish tows should be kept short in time and space; Tows should be < 5 or 10 minutes.

Some species of larval fish concentrate in near surface waters (0 m to 2 m). Under these conditions we recommend sampling with a simple 'floating" neuston net towed horizontally near the surface (e.g., Phillips and Mason 1984) in combination with the recommended standard bongo net.

There are two main logistic components to sampling larval fish: field and laboratory. The results from laboratory analyses are strongly influenced by field methods used to fix samples and by proper identification of species. Field samples of larval fish should be immediately preserved after capture using a 5% buffered formalin/seawater mixture. The preserving liquid should occupy > 75% of the sample container. Normally 1000 ml glass jars with screw top lids are used.

The date, location, time, gear type, mesh size, tow depth and duration should be labelled on the lid and jar with a felt marker. A second label should be filled out with pencil and placed in the jar before sealing (Smith and Richardson 1977). Materese et al. (1989) have written a useful guide for identifying larval fish.

When sampling for larval fish investigators should simultaneously collect information about water temperature (see Part I) and zooplankton concentrations (see Part F). Collection of this information is required because of the strong influence of both these factors on larval fish properties such as density, growth, and survival (Haldorson et al. 1993).

G2. SAMPLING QUALITATIVE AND QUANTITATIVE PROPERTIES

The most commonly measured qualitative larval fish properties are species identification, presence/absence, and distribution. Quantitative properties include density, biomass, weight length, and growth measurements. A paired bongo net is frequently used to sample qualitative or quantitative properties of larval fish. The general method for using a bongo net is the same for zooplankton and is described in Part F. Smith and Richardson (1977) also recommend that a bongo net be used to sample qualitative properties of pelagic fish larvae. The following points are specific to using a bongo net for sampling larval fish:

- Minimum mesh size of bongo nets should be > 350-pm
- The volume of water filtered should be in the range of 100 m^3 to 400 m^3.
- Boat speed should be kept as constant as possible at about 3-4 knots.
- The time of a tow should not exceed 10 minutes.
- At then end of each tow, the bongo nets should be thoroughly washed down and the larval fish catch preserved immediately in a 3.5% to 5% buffered formalin solution. The strain of the net collection will often kill many larval fish. At the time of death, the larval specimens may shrink substantially, making estimation of size impossible (Hay 1982, 1992).

G3. SAMPLE MEASUREMENT PROTOCOLS

Once samples have been collected using a bongo net, the following protocols should be used:

- Larval fish biomass should be reported as wet weight per m^3. Note that other units can be calculated from this (e.g., g m^{-2}). Before weighing it is important to remove as much water as possible using gently vacuum filtration or by blotting on paper until the paper absorbs no more water. Wet weights can be determined on an electronic balance and reported to the nearest 0.01 g.
- Because of the variability in measuring moisture content, larval fish biomass should also be reported in dry weight. Dry weight is estimated by drying fresh or frozen larval fish (not preserved) samples at 80-100°C for 24-48 h, or until a constant weight is achieved. Dry weight

should then be measured to nearest 0.001 g on an electronic balance. If dry weights need to be converted to ash-free weights, standard values can be used (see Parsons et al. 1984).

- Species identification of larval fish requires technical knowledge and experience. Expert advice should be sought before samples are analyzed. In the laboratory, larval fish should be identified using a dissecting microscope and a species specific guide such as that written by Matarese et al. (1989).
- In addition to species identification, length and weight measurements may be determined for pelagic fish larvae and eggs. Larval fish lengths should be measured to the nearest 0.1 mm using an ocular micrometer. Users can expect about 2-7% shrinkage in larval fish length when animals are stored in formalin. This can be reduced by buffering all samples with simple borax or other buffers (Hay, 1981). Refer to Smith and Richardson (1977) for standard laboratory procedures for larval fish .

G4. ALTERNATIVE SAMPLING METHODS

An hydroacoustic approach may be useful for assessing broad scale distributions and relative abundances of larval fishes but no 'off-the-shelf' system is readily available at the present time. The existing systems are expensive and output is difficult to interpret, and echograms still require calibration with net sampling. Since larval fish are sometimes found concentrated in nearsurface waters investigators should consider using floating neuston nets. Mason and Phillips (1984) describe the design of a floating neuston net for sampling larval and juvenile fishes in coastal British Columbia. The net uses a 500-pm mesh and is towed into or across waves at 4-6 knots. The net was found to be quantitatively comparable to larger volume two-boat surface trawl nets when sampling for vertically depressed distributions of near-surface larval and juvenile fish.

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Table G1. Summary of methods used to sample pelagic fish eggs and larvae.

Pelagic Fish Eggs and Larvae Property	Sampling Method
Qualitative properties (e.g., presence/absence)	Oblique tow using 500-μm mesh bongo net in combination with near-surface horizontal towed neuston net
Quantitative properties (e.g., standing stock)	As above
Alternative sampling methods	Hydroacoustics with plankton net sampling calibration

PART H. FISH

In this section we discuss methods for sampling juvenile and adult stages of marine and anadromous fish that commonly use nearshore subtidal habitats. Methods for sampling fish eggs and larvae are discussed in Part G. Ultimately, the method used to sample juvenile and adult fish in the nearshore subtidal will depend mainly on where in the water column the fish occur. Generally there are three main groupings of fish according to where they are found in the water column: pelagic, suprabenthic (associated with bottom), and benthic. The sampling method will also depend on what type of habitat the fish use. For instance, some suprabenthic species such as kelp greenlings occupy both sandy/muddy eel grass and rocky kelp habitats, and the habitat occupied will determine the most appropriate sampling method. In the discussion below we consider both the location in the water column and habitat type in recommending sampling methods for juvenile and adult fish occurring in nearshore subtidal habitats.

i) **Pelagic Fish**

Included here are very active swimmers that tend to school and inhabit the mid to upper water colurnn, (true pelagics; e.g., adult herring or salmon), or that school near macroalgae, boulders, or other natural/man-made structures (e.g., perch). Because of their avoidance capabilities, the true pelagics should be sampled using methods that encompass a large area, and that can be rapidly deployed. Pelagic fish that school near objects are more effectively sampled using less active methods such as angling.

ii) **Suprabenthic Fish**

The suprabenthic fishes are primarily found in close proximity to rocky/hard substrates, and among macroflora such as Macroc~ystis or Zostera. Suprabenthic fish are found individually in crevices, or in small schools associated with the sea floor. This group includes the lingcod, greenlings, sculpins, gobies, and most rockfishes. Sampling suprabenthic fish is difficult because of the rocky nearshore subtidal habitats they occupy. The best sampling strategy may be to combine different sampling methods such as SCUBA and active bottom sampling gear such as otter trawls.

iii) **Benthic Fish**

These fishes are usually buried in soft substrates such as mud or sand/silt or occur on top of gravel substrates. Benthic fish are either territorial or transient residents of nearshore subtidal habitats. The benthic fishes include various flatfishes such as English sole, juvenile halibut, and sand-dabs. The methods used to sample these fishes generally require disturbing the bottom sediments.

Table H1 summarizes the methods considered for sampling qualitative and quantitative properties of both juveniles and adults of the most common nearshore subtidal fish species discussed above. Several of the methods are used primarily by the Department of Fisheries and Oceans for stock assessment purposes, but they are appropriate for inventory level assessments.

H1. GENERAL SAMPLING CONSIDERATIONS

The spatial distributions of most nearshore subtidal fishes are extremely unpredictable and difficult to characterize because of seasonal migrations that are related to life history strategies. For instance, several different nearshore subtidal habitats are used primarily for rearing and staging purposes by juvenile fishes from summer to fall. The adults of most species tend to occupy the nearshore subtidal for only short periods, while occupying deeper water column or benthic habitats for most of the year.

The seasonal along-shore and across-shore migrations linked to life history stage makes recommending the frequency of sampling difficult. However in general, subtidal habitats should be sampled for fish monthly from March to September to adequately identify and enumerate species that use a habitat. In cases where certain fish species are of interest, or life history migrations known, sampling should be conducted twice monthly or even weekly.

It is important to consider the availability and vulnerability of fish to a sampling method. Availability is the proportion of fish over a strip of sea-bed that are in the path of the sampling gear. The availability of fish to sampling gear will depend on the age, size, season, time of day (or night) sampling takes place, and sampling gear used (Potts and Reay 1987). Vulnerability is the proportion of available (accessible) fish actually caught, and is a function of the sensory and locomotory skills of the fish. Vulnerability to gear usually decreases with size of fish (Gunderson 1993). Sampling for fish should take place at night because of reduced avoidance of gear and because of increased activity and availability of most fish species. The benefits of sampling at night near the coastline may however be outweighed by safety concerns.

It is also important to consider that there are biases associated with all sampling methods. It is usually assumed that fish are completely vulnerable to a sampling method and that there is no avoidance or size/species selectivity. Selectivity is the probability that a fish will be retained by the sampling method given that it is vulnerable. Selectivity bias however, results from the choice of mesh size, gear type, time of sampling, and habitat fished. For instance, larger mesh sizes select for larger fish.

The nearshore subtidal represents only a small proportion of the habitat available to, and used by, most subtidal fish. Several transects or a grid that extend beyond the nearshore subtidal can be used to assess the presence/absence and quantitative properties of fishes. For instance, a stratified random sampling design using stations and transects would allow for comparison of shallow versus deep subtidal nearshore habitats and fish.

The minimum sample sizes for quantitative estimates of fish properties (e.g., length, weight, sex, age, and reproductive status) will depend on the species (e.g., schooling or non-schooling), the associated habitat (e.g., rocky versus sandy), and the stage (age) of the fish. Between 25 to 50 individuals of each species and life history stage are usually collected for precise estimates of population parameters (Gunderson 1993).

The location (e.g., start/end) of fish sampling (trawls, transects, seine sites) should be accurately determined using navigational fixes and eleetronic positioning systems such as a differential global positioning system.

H2. SAMPLING QUALITATIVE PROPERTIES

The qualitative property of fish most frequently assessed is presence/absence. Refer to Table H1 for common methods used to sample qualitative properties of each of three main groups of fish. In this section we briefly discuss the methods that are used to sample for qualitative fish properties.

i) SCUBA Surveys

SCUBA surveys are used to sample for presence/absence of most nearshore subtidal fishes. See section 2.3 for a discussion of SCUBA surveys. The main assumption here is that the observer is not influencing the distribution or behaviour of the fish (Gunderson 1993). It is often beneficial to use a video camera to record observations during the random swim for later analysis. Factors to consider when conducting a random-timed SCUBA survey: some fish species can be difficult to detect because of cryptic coloration, hiding abilities (burying in substrate), and scare responses to divers.

ii) Passive Methods

When conditions are not suitable for SCUBA surveys (e.g. visibility or depth) passive sampling methods may be suitable. Passive fishing methods remain stationary and the fish become entangled or trapped. Passive sampling methods are considered qualitative because it is difficult to define the sampling area, which precludes direct quantitative estimates of fish such as abundance per unit of habitat. The capture field around passive methods will also vary because of nearshore subtidal habitat conditions (e.g., prevailing currents), species activity level, bait used, and investigator experience. In addition, passive gear are very species and size selective and they become saturated with prey, so that the effective sampling area diminishes with time. In nearshore subtidal habitats, two passive techniques are most appropriate for determining qualitative properties of fish: angling surveys and gill nets.

iia) Angling survey

- Habitat sites are usually divided into at least 2 depth strata (e.g., 0-10 m and 10-20 m) and angling conducted in each strata. See Hard and Richards (1989) for example.
- Each site-depth strata is fished on at least 2 non-consecutive days.
- Angling is timed, and conducted for a minimum of 15 minutes per angler per depth strata.
- Angling time is stopped when a fish is hooked, the line fouls on the bottom, or the line is reeled in. Hook size and type will depend on species sought.

- - Fishing in a site-depth strata stops if no fish are caught after some pre-determined time limit (e.g., 30 minutes).
- - Weather conditions and sea state of all sample sites should be recorded.

iib) **Gill net**

- Monofilament gillnet of at least 15 m long but < 30 m long are used. The gillnet is usually between 2 to 3 m high (e.g., Levy and Levings 1978).
- Gillnets are very selective for size of fish caught. The selectivity is related to the mesh size used. To counter this, a range of mesh sizes are used (1 cm to 10 cm, wet, stretched).
- The gillnet can either be floating (for pelagics) or sinking (for benthic and suprabenthic species). To be most effective, several gillnets (3-6) should be used and they should be set in L-shaped or T-shaped patterns. These arrays of gillnets will effectively sample the nearshore subtidal habitat (e.g. Leaman 1980).
- A floating or sinking gillnet is anchored and hung in the direction of prevailing tidal current.
- The gillnet is left to soak for no longer than 24 h, and it is checked and emptied every 12 h. To maximize the number of live fish taken from a gillnet, set 1 h before sunset and retrieve at sunrise.
- The following information should be collected for each set: secchi depth, salinity, water temperature, current strength and direction, gillnet location, soak time.

Once fish have been collected using a qualitative sampling method discussed above, investigators should use species keys such as Hart (1980) to accurately identify fish to the species level. If possible voucher specimens should be retained and verified by an expert if the experience of the collector is in doubt. Ideally a reference species collection should be maintained.

H3. SAMPLING QUANTITATIVE PROPERTIES

Sampling the quantitative properties of most marine fishes such as biomass, density, or length-weight relationships, requires the use of active fishing methods. An active method involves moving gear through the water to collect fish. Important considerations in using active methods are fish avoidance and vulnerability, and selectivity of the gear. These considerations were discussed in the introduction. There are two additional specific considerations to make when acquiring quantitative fish data using active methods: 1) the type of sampling method or gear used today must be comparable with methods used in the past, and 2) the amount of fishing effort used must be quantified. In this section we briefly discuss several sampling methods.

i) **Beach Seine**

- Beach seines are used in very shallow, subtidal habitats with easy beach access.

- Most beach seines used are > 15 m and < 36 m total length. The seine is also between 2 to 3 m high, and the hag is between 3 to 5 m wide and 2 to 3 m deep.
- The number and type of fish caught by a beach seine is primarily dependent on mesh size. The mesh size in the bag should be 4 to 6 mm, and 0.5 to 2 cm in the wings (Levy and Levings 1978; Gordon and Levings 1984). Note that both of these studies used beach seines to sample salmon.
- Tow lines of 15 to 30 m long are attached to the end of each wing to pull the net ashore.
- The seine is pulled off the beach using a small boat, or by wading. The distance the seine is taken offshore will depend on water depth, total seine length, currents, bottom topography, and slope.
- The seine is usually set on a rising tide and retrieved immediately.
- Larger beach seines are deployed at least 30 m from, and parallel to, the shore. The seine is then retrieved immediately. The seine is simultaneously and evenly pulled ashore by 2 crews spaced about 40 m apart.
- As the seine is being hauled shoreward, it is critical that the leadline be kept in direct contact with the seafloor. A recommended hauling speed for a 36 m seine is about 10 m min^{-1} (Simenstad et al. 1991).
- Smaller beach seines (< 15 m long) are set perpendicular to shore and pulled manually along (parallel) the beach over a known fixed distance of at least 30 m. The seine should then be turned to the beach and pulled to shore.
- The minimum volume sampled by small seines (15 m) is about 150 m^3, and 500 m^3 for large seines (36 m).
- Note that seine sampling efficiency will be lower over coarse rocky bottoms than fine substrates.
- Typically 3-5 seine hauls care conducted per habitat type. The variability in samples will determine the exact number of hauls. If possible seining should be coniducted at least monthly.

ii) **Trawls**

Trawls are nets towed behind a boat. An important consideration in using a trawl is that it requires a boat with enough power to pull the net at 1-2 m sec^{-1}, and that the forward motion of the boat must be maintained while setting, towing and retrieving the net. There are three main types of trawls based on where they sample the water column: surface, midwater, and bottom. Because of the difficulty in comparing data collected from different types and sizes of trawls, it is important that investigators use the same type of trawl, as determined by habitat type or objective. In general:

- Investigators should record the duration of the tow. A trawl tow should not be < 10 minutes duration.
- The distance of the tow should be accurately determined from navigational fixes and electronic positioning devices to within +/- 10 m. Distance can be determined from start/end positions of the tow and should be recorded on a chart of appropriate scale.

- The volume of water filtered by a trawl is determined using a flowmeter, or by using mouth area, boat speed, and distance towed calculations (See Shaw 1994 for example).
- Mesh sizes vary with trawl type and study objectives, but commonly the cod end has a minimum mesh size of < 5 mm.
- The direction of a trawl tow will depend on tidal currents. Sampling should be done at or near slack water to reduce the effect of tidal currents.
- Night tows are preferred because of reduced avoidance by fish, but may be impractical because of safety concerns. At least 2 to 3 tows should be conducted per habitat unit. The required number of tows should be determined using power analyses.
- Trawls are most suited for sampling motile pelagic fishes, or for sampling non motile benthic fishes. Cryptic reef dwelling species are difficult to sample using trawls and are best sampled using alternative methods (see below). For sampling benthic fishes most investigators use a relatively small (2.3 m) plumb staff beam trawl. Staff-beam trawls are recommended over otter trawls because the rigid beam prevents the net opening from changing during a tow. The net is also designed and rigged to follow the contours of the sea bed closely, while tickler chains scrub the bottom in advance of the net (See Gunderson and Ellis 1986). Plumb trawls can also be easily manipulated by small vessels and they can be operated close to shore.
- Since pelagic fishes are less susceptible to small trawls, most investigators use a larger 6-8 m trawl, such as a Kodiak surface trawl (3 m deep) to sample pelagic fishes such as juvenile salmon (Levings and Kotyk 1983). This trawl requires two small boats (< 14 m) operating about 30 m apart. Simenstad et al. (1991) recommend using a 7.6 m otter trawl to capture more motile fish species in shallow nearshore habitats. This trawl has a mesh of 6 mm in the bag, and is towed at < 5 km h^{-1}. The ratio of wire out to water depth (scope) should range
- between 3: 1 to 5: 1.

iii) **Purse Seines**

Samples of highly motile pelagic fish for quantitative estimates should also be collected using a large purse seine. Simenstad et al. (1991) describe a commercially modified 58 m purse seine with 13 mm mesh. This seine was used in the shallow nearshore, and sampled about 270 m^3 at one time. This seine system was effective in shallow nearshore waters because only one or two operators were required and it was operated from a small boat. See also Hamer (1989) and Groot and Cooke (1987). In general, to be effective:

- Setting, pursing, and retrieving can be done from a small boat (< 15 m). The total seining process should take no more than 30 minutes.
- The round haul procedure is often used instead of holding the purse seine open in the current because only one boat is required, and because the sample area/volume remains constant and can be readily calculated.
- Mesh size ranges from 1 to 2 cm, and the seine is usually not deeper than 10 m for effective operation in shallow waters.
- Seining conducted during the day should be compared to seining conducted at night
- Seining is more effective if done at flood (high) or slack tide.

iv) **SCUBA Transect Surveys With Removals**

In some nearshore subtidal habitats such as rocky kelp forests it may be impossible to use remote sampling methods such as trawls and purse seines. In addition, some suprabenthic fish species are simply not available to these active remote sampling methods. Quantitative data for suprabenthic fishes can be collected by using a SCUBA transect survey. In some instances divers may have to use spear-guns or snagging devices to collect fish (See Houck 1980). The important point is that SCUBA sampling effort must be quantified. The simplest way to quantify effort is to deterrnine the area swept by the divers over a fixed transect length, width, and height. SCUBA transect survey methods are discussed in section 2.3. Methods specific to sampling fish are discussed below:

- SCUBA observations of fish should be made along transects of known area. Transect lengths are usually at least 100 m long and 2 m wide, giving an effective area swept of 200 m2.
- Transect width is usually set to the width of underwater visibility. A 2 m metal pole is useful for defining the minimum transect width. In the case of sampling benthic fish in soft sediments, the diver can push the 2 m pole along the bottom to disrupt buried flatfishes (see Walton and Bartoo 1976).
- It is preferable that two divers independently cover the entire transect, one after the other about 15 minutes apart.

H.4 SAMPLE MEASUREMENT PROTOCOLS

After fish have been collected, the following methods are used:

i) **Number**

- · The number of individuals of each fish species and life history stage caught by any one gear are counted. However, some larger gear (e.g., purse seines) may result-in extremely large samples. In such a case, count all individuals in a subsample of known weight or volume and then extrapolate the number of fish to the total sample weight or volume. An estimate of the precision of the extrapolation should be provided.
- · Fish density is reported as the number per m^2 (area) or per m^3 (volume).

ii) **Length**

- An important consideration is that an appropriate measurement unit should be used to accurately represent the length of a fish. Shaw (1994) recommends that fish be measured to the nearest millimetre and reported to the nearest rounded cm. For example, a 40 cm fish is 395 mm to 404 mm long.
- Three main lengths can be measured depending, in part, on fish species. See Shaw (1994) for a detailed explanation and figure of fish lengths measured. Generally, total length is from the tip of the snout to the tip of the tail. Total length is appropriate for species lacking a well defined fork in the caudal fin such as rockfish or sculpins. Fork length is from the tip of the

snout to the fork of the tail. Fork length is usually measured on species with a distinct fork in the caudal fin such as herring, salmon, or smelts. Standard length is the distance from the tip of the snout to the base of the caudal fin rays (hypural).

- All fish lengths are determined using a fish board graduated in mm and cm. The snout of the fish should be placed against a vertical end piece on the board at O mm, with the fish laying in a straight line, natural position. Lengths are then be read directly from the graduated scale.
- Storage mediums can affect fish length. For instance, formaldehyde results in shrinkage over time. Either determine the amount of shrinkage by comparing to fresh fish, or measure length using fresh specimens wherever possible. Storage conditions should be clearly specified.
- At least 25 to 50 individuals of each fish species and stage be selected randomly and measured for length.

iii) **Weight**

- An important consideration is that an appropriate measurement unit should be used to accurately represent the weight of a fish. Fish greater than 1 kg are measured to the nearest whole g, while smaller fish are measured to the nearest 0.1 g.
- Fish weight is usually reported in wet weight. Estimate wet weight of fish by blotting off excess water, and weighing on an electronic halance, or dual-beam balance. The weighing device should be calibrated before each weighing session, and checked once during weighing to tare for excess build-up of slime or water.
- Biomass or standing stock is reported as g wet weight per m^2 or m^3.
- The storage medium affects the weight of fish. For instance, freezing results in lowered estimates of weight by shrinking the size of the fish. Estimate wet weight using fresh specimens wherever possible.
- If necessary dry weights can be determined for fish by drying at 100°C for > 48h, or until a constant weight is obtained. Report dry weights to nearest mg.

iv) **Age**

- Ageing of fish should be conducted by counting distinguishable yearly growth rings (annuli) on hard body parts such as scales, fin rays, or otoliths.
- Different species of fish will require that different body parts and methods be used for accurate age determination. Generally, scales are unreliable for ageing old, slow growing species such as rockfish, but are adequate for ageing salmon (see Shaw 1994) and herring. Scales generally underestimate the true age of fish by a proportionally larger amount as the true age increases.
- Refer to Chilton and Beamish (1982), Anderson and Gutreuter (1983), and Cailliet et al. (1986) for standard methods for ageing various marine fish species.

v) **Reproductive Status**

- The main method for determining sexual maturation is internal examination for the presence or absence of testes or ovaries. However, the development stages differ markedly depending

on the species and age of the fish. Shaw (1994) discusses methods for determining reproductive status of salmonids.

H5. ALTERNATIVE SAMPLING METHODS

An alternative method for sampling the distribution or biomass of schooling pelagic or suprabenthic fishes is hydroacoustics. A survey vessel should move over a pre-defined grid of precisely determined stations. The main limitations of using hydroacoustics are poor species discrimination, poor sampling capabilities near surface and bottom, and in shallow waters, requirement of ground truthing, and potential bias associated with target strength and calibration. Alternative methods for assessing qualitative properties such as presence/absence or distribution include aerial surveys that incorporate visual observations, infrared photography, or laser beams (LIDAR). Also see Borstad et al. (1992) for a discussion about using CASI to assess herring fish schools.

H6. CRITICAL ASSESSMENT CRITERIA

The following information (and appropriate units) should be collected and recorded when sampling fish to determine the compatibility and accuracy of data among studies:

- sampling date, time (PST), accurate location of gear (longitude and latitude, degrees, minutes, and seconds)
- gear type, dimensions (length, width, height, depth in m), mesh size (mm)
- tow characteristics: duration (min), distance (m), depth of set or tow (m), speed (km), volume of water sampled (m3)
- hauls per site, number of samples and stations per habitat, start/end, length of beach seined, area of habitat represented by sample
- soak characteristics: duration (min), orientation to shore (degrees), depth (m)
- habitat description: substrate, temperature (°C), dissolved oxygen (mg/l), salinity (ppt), current speed and direction, depth (m), dominant vegetation, habitat type
- method of sample storage, sampling agency/individual

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Table H1. Summary of methods used to sample qualitative and quantitative properties of juvenile and adult fishes using shallow nearshore subtidal habitats.

Fish Group	Example Fish Species	Typical Nearshore Subtidal Habitats	Sampling Methods For:		Minimum Sampling Frequency
			Qualitative Properties	Quantitative Properties	
Pelagic – water column	Migratory adult salmon (pink, chum, sockeye, chinook, coho, steelhead, dolley varden)	various	Gillnet; Angling	Purse seine; Surface trawl	Monthly during summer
Pelagic – water column	Resident adult salmon (cutthroat)	various	Gillnet; Angling	Purse seine; Angling	Monthly during summer
Pelagic – understory	Juvenile salmon	estuaries, eel grass beds, cobble beach, kelp	SCUBA random-timed survey; Beach seine	Beach seine; Purse seine; Surface trawl	Weekly during summer
Pelagic – water column	Adult herring	offshore mainly, shallow vegetated areas for spawning	Gillnet	Purse seine; Gillnet	Monthly Jan to March
Pelagic – understory	Juvenile herring	various	Beach seine	Beach, purse seine	Monthly May to Oct.
Pelagic – understory	Pile, Shiner, kelp, striped perch	*Macrocystis* and *Nereocystic* habitats	SCUBA random-timed survey	SCUBA transect survey; Angling	Monthly
Pelagic – water column	Eulachon, surf smelt	estuary, mudflats, eelgrass	SCUBA survey timed	Beach seine; Otter trawl	Weekly in spring
Pelagic – understory and water column	Small pelagics (e.g., tubesnouts, sand lance)	kelp, eelgrass, open	SCUBA random-timed survey	SCUBA transect survey	Monthly in summer
Suprabenthic	Solitary rockfishes (e.g., china, copper)	Rocky reefs, kelp	SCUBA random-timed survey	Angling; SCUBA transect survey	Monthly in summer

Table H1 (cont'd)

Fish Group	Example Fish Species	Typical Nearshore Subtidal Habitats	Sampling Methods For:		
			Qualitative Properties	Quantitative Properties	Minimum Sampling Frequency
Suprabenthic/pelagic - understory	Schooling rockfishes (e.g., black, juvenile cooper)	Rocky reefs, kelp, eelgrass	SCUBA random-timed survey	Angling; Otter trawl; SCUBA transect survey	Monthly in summer
Suprabenthic	Lingcod, rock and kelp greenling	Rocky areas, nearshore subtidal reefs, kelp, eelgrass	SCUBA random-timed survey	Angling; SCUBA transect survey; Staffbeam trawl	Monthly in summer
Suprabenthic - cryptic reef dwelling	Spinynose and longfin sculpins, blackeye goby	Rocky areas, nearshore subtidal reefs	SCUBA random-timed survey	SCUBA transect survey	Monthly in summer
Suprabenthic	Kelp klingfish	Rocky areas	SCUBA random-timed survey	SCUBA transect survey	Monthly in summer
Benthic	Sand dabs, Rock and Dover sole, starry flounder	eelgrass, estuaries, mudflats	SCUBA random-timed survey; Beach seine	Beach seine; Staffbeam trawl	Monthly in summer
Benthic	Juvenile English sole, Juvenile halibut, big skate	muddy, sandy/gravel	SCUBA random-timed survey; Beach seine	Beach seine; Staffbeam trawl	Monthly in summer

PART I. CHEMICAL AND PHYSICAL PROPERTIES OF SEA WATER

This section discusses methods used to collect data on the following water column properties: water temperature, salinity, dissolved oxygen, inorganic nutrients (e.g., nitrates, phosphorous), and light (Table I1). Most of the methods discussed are routinely used by the Institute of Ocean Sciences, Sidney (DFO) and Environment Canada to sample and monitor nearshore water properties. Additional physical/chemical data may be required to delineate water column habitat units. This includes information about hathymetry, currents, tides, run-off, and wind. We briefly describe who collects these data, how these variables are measured, and where the information is located.

11. GENERAL SAMPLING CONSIDERATIONS

There are several considerations to make when sampling physical and chemical properties of sea water in a water column habitat unit:

- Investigators should be cognisant of both horizontal and vertical spatial heterogeneity in chemical and physical properties of nearshore subtidal waters. Spatial complexity in the nearshore subtidal is a result of wind mixing, tidal mixing, coastal currents, and run-off. As a result of these processes, stratif~ed coastal areas may require different sampling strategies than mixed areas. For instance, replicate water samples should be collected from vertically mixed regions, while replicate samples should be collected both above and below the pycuocline of a stratified area.
- Physical and chemical water properties vary daily, seasonally, and yearly because of natural seasonal cycles, daily fluctuations in the nearshore physical environment (e.g., tides), and biological processes (e.g., excretion). Simmenstad et al. (1991) recommend that nearshore chemical properties should be sampled over the entire representative tidal cycle (26-30 h) at least once during each stage of the tidal moon, and at least seasonally during the maximum and minimum freshwater flow periods. Sampling of some chemical properties such as nutrients should also be conducted over several consecutive days, twice a month (preferably weekly), during the most productive season (March to September) to fully characterize the range in values.
- Sampling for chemical or physical water properties takes place at point stations, at stations along transects, or at a grid of stations. The survey method used will depend on the property sampled, on tidal and current features of the nearshore subtidal habitat, and on study objectives. Water samples used for chemical analysis should be collected at point stations and specific depths. A transect of stations is appropriate if an alongshore or across shore gradient in the property is suspected. A grid of stations should be used if there is large spatial homogeneity in habitat unit. Stratified random sampling should be considered for studies over local and regional scales.
- When sampling physical and chemical properties it is critical that the location of point stations, transects, and grids be accurately determined and recorded. Station position in the

nearshore subtidal can be determined using navigational fixes with land-bearings, but investigators should use differential global positioning systems.

- It is also critical to accurately determine and record the sample depth. Report depths in metres to the nearest 0.1. Sample depth should be determined from calibrated pressure sensor on automated samplers (e.g., CTD), or from metre markings on the hydrocast line, or from an echo sounder. During hydrocasts, the wire angle should be measured and depths corrected accordingly.
- There are two steps in assessing chemical properties of sea water: field sampling and laboratory analyses. In this document we discuss methods for field sampling sea water. Readers are referred to Strickland and Parsons (1972) and Forbes and Waters (1993) for accepted standard laboratory methods for analyzing sea water properties. For chemical analyses Strickland and Parsons (1972) give an outline of the method including its capability (e.g., precision), special apparatus and equipment required, sampling procedures, sample storage protocols, specific reagents required, and necessary calculations for parameters.

I2. METHODS FOR SAMPLING SEA WATER

Most of the physical and chemical sea water properties considered here can be sampled manually or automatically. The method used will depend on the availability and cost of instrumentation, the property measured, and the study objectives. The utility of automated collection devices (e.g., conductivity-salinity-depth sound; CTD) is that data are continuously recorded, and aecurately measured and stored. Automated samplers will however, require calibration using manual techniques. Where possible both an automated and manual collection method are discussed. Before discussing specif~c standards for each water property, we identify two major requirements.

- Sample replication will depend on project objects and property measured, but at least two replicate water samples should be collected (i.e., two hydro-casts) at each station depth. In addition, it is important to collect replicate water sub-samples from each hydro-cast for laboratory analyses.
- All sample containers must be labelled with at least the following information: date, time of day collection was made, station name and location, depth, method used to collect sample, replicate number, water property to be analyzed for, name of collecting agency.

To facilitate the presentation of methods for collecting physical and chemical water property data, we consider four sampling locations in the water column:

i) **Surface Water Samples**

Surface water samples are usually collected by dipping a well-rinsed bucket over the side of the boat. Sub-samples are taken from within the bucket.

ii) **Integrated Water Samples**

The segmented integrating pipe sampler (Sutherland et al. 1992) is particularly useful for inshore sampling of water properties, combining advantages of both integrated and discrete depth samples.

iii) **Diserete Depth (Grab) Samples**

Sea water samples from specific depths can be collected using pumps or water bottles such as 1.7 L Niskin bottles. Pumps will quickly sample water from depth but may bias samples by introducing water from surrounding depths, or by introducing oxygen into samples. Water bottle casts (hydro-cast) should be conducted in shallow nearshore subtidal habitats. It is important to release the weighted 'messenger' only after the bottle has been lowered to the desired depth. Water should be drawn immediately after each cast by ensuring that bottle tubing is placed directly in to the sample container before water is released.

iv) Water Column Profile

It is possible to obtain a profile from many hydro-casts, but automated samplers such as a conductivity-temperature-depth sound (CTD) or a YSI oxygen meter are most frequently used. The automated sensor should generally be lowered at a rate of 0.5-1.0 m sec^{-1} until 1-2 m from the sea floor. The exact speed of lowering the CTD is dependent on the type used; manufacturer's specifications should be consulted. Determine maximum depth before the hydro-cast. Data should be collected from the automated sampler at every metre on ascent and descent. The sensors should be accurate to within +/- 0.03°C, +/- 0.05 ‰, and +/- 1% pressure (depth). All automated samplers must be calibrated with manually collected samples (see above). Larger CTDs usually have a rosette sampler attached from which water samples at discrete depths can be taken.

I3. SAMPLING PROPERTIES OF SEA WATER

In this section, we discuss common methods used to collect eight physical and chemical properties of sea water.

I3.1. Inorganie Nutrient Sampling

- Inorganic nutrients include nitrites, nitrates, phosphates, silica, ammonia and urea.
- Water samples for inorganic nutrient analysis are usually collected at the same time that phytoplankton samples are taken (see Part E).
- For each station or depth sampled, collect replicate 25 to 50 ml samples and place into screw-top glass or plastic vials (the latter is preferred for silicates). The sample vials should be properly labelled, and sealed tightly. Samples should be frozen immediately for later analysis in the laboratory. It is strongly recommended that samples be quick frozen in an alcohol bath

(minus 40°C) (Macdonald et al. 1986). Rinse acid-cleaned vials three times with sample water before filling, allowing ample room in the vial for expansion after freezing.
- In the laboratory, colorimetric methods with a segmented-flow (Auto-analyzer) or flow injection analyzer are used (e.g., Lachat Instruments; see Strickland and Parsons 1972).

I3.2. Salinity

- Salinity is reported in Practical Salinity Units (PSU; approximately equivalent to parts per thousand, ‰), and measured to the nearest 0.01, preferably 0.001.
- Collect replicate samples from replicate hydrocasts at each station depth. Water samples should be collected in 100 to 250 ml screw-topped containers. The containers should be rinsed three times with sample water before filling to below the neck and capped.
- Salinity should be determined in the laboratory from measurements of electrical conductivity and temperature using an induction salinometer. The salinometer should be standardized using IAPSO Normal Standard sea water.
- A salinity profile can be collected using a conductivity-temperature-depth (CTD) probe. The CTD should be calibrated each time it is turned off.

I3.3. Dissolved Oxygen

- Dissolved oxygen should be reported in mg/l, to the nearest 0.01.
- Collect replicate water samples from replicate hydrocasts at each station depth. Water samples are collected in 125-250 ml glass, stoppered BOD bottles. The bottles should be allowed to overflow 2-3 times. Fill bottles, using a flexible (e.g., amber or silicone) tube from the Niskin bottle spigot to the bottom of the sample bottle, to rim and add fixative (see below) before stoppering. Contact between air and water sample should be avoided.
- Water samples should be "fixed" with manganous sulphate and alkaline iodide solutions within 15 minutes of being drawn.
- The water samples are analyzed in the laboratory for oxygen concentration using the azide modified Winkler titration technique within 24 h of sampling (Strickland and Parsons 1972).
- An oxygen meter system is used when profile information is required. Membrane electrode oxygen meters (e.g., YSI) should be calibrated with samples analyzed using the Winkler titration method. Calibrate a meter after each time it is turned off.
- It is important to simultaneously record associated water temperatures with dissolved oxygen measurements to determine percent saturation relationships.

I3.4. Water Temperature

- Water temperatures are recorded in Celsius to the nearest 0.1°.
- Surface temperatures is determined by collecting water in a bucket and measured using a mercury-in-glass thermometer, or good quality, calibrated electronic thermometer. This

method reduces the risk of loosing the thermometer overboard, and reduces errors associated with evaporative cooling of the wet glass. Leave the thermometer in the bucket for at least 2 minutes for an accurate reading.

- Temperatures are measured at depth by lowering a reversing thermometer. These thermometers have a column of mercury that is physically separated upon mechanical inversion of the thermometer at depth. Leave the thermometer at depth for at least 5 minutes for accurate in situ readings (Thomson et al. 1986). Electronic reversing thermometers are also available. These have the advantage of increased reliahility, faster response time, and improved accuracy but their cost is high (> 3k).
- Water temperature profiles are collected automatically using an automated sensor such as a CTD. The CTD is lowered through the water column at a rate specif~ed by the manufacturer, and measurements taken on both the ascent and descent.

I3.5. Irradiance

- The photometer (for energy) or the quantum meter (for quanta) are automated samplers that is used to measure underwater irradiance. Photosynthetically active radiation (PAR) should normally be recorded in quanta, and measured to the nearest TE in m-2 s-1 using a spherical (4X) quantum sensor in the water, and a flat plate sensor for surface measurements. Measurements are taken at 1 m intervals, with concurrent surface measurements.
- To manually estimate integrated irradiance a Secchi disk is used. This sampling device has an historical precedent and is easy to use. A 30 cm diameter white disk is lowered from the shady side of the boat. A line marked at 1 m intervals allows the user to visually determine the maximum depth of the disk and thus the vertical transmission of light. An empirical relationship can be used to indirectly estimate the relative irradiance changes with depth: extinction coefficient, k = 1.71Secchi depth (m) (Parsons et al. 1984).
- The position of the sun (i.e., time of day and season), sea state, and weather conditions should be accurately documented. It is important to frequently calibrate these solar radiation measuring devices. See Parsons et al. (1984) and Duncan (1990) for detailed discussions of methodologies used to measure solar radiation in the water column.

I3.6. Additional Physical Properties

Additional physical properties such as currents, tides, run-off, and wind may need to be collected, and the following section discusses useful information about these physical properties.

- Surface water temperature and salinity data are available from daily lighthouse observations. The period of measurements is in excess of 50 years for a number of locations such as Departure Bay and Race Rocks (Freeland 1991).
- Bathymetric data (charts and additional survey information) are available from the Department of Fisheries and Oceans Hydrography Branch in Sidney.

- Currents and tidal data are available for many locations from DFO Hydrography Branch. Software providing surface current estimates for any southern Strait of Georgia location is available from Channel Consulting (Tideview; Channel Consulting Ltd. #3 - 2020 Douglas St. Victoria, B.C. V8T 4L1).
- Meteorological data is collected by Atmospheric Environment Service (Environment Canada) for many locations. Particularly useful data (not necessarily available for all locations3 include: air temperature, atmospheric pressure, wind speed, and hours of bright sunshine. For some studies, monthly mean values may be most appropriate. Up to mid-1989, wind speed data was also summarized into bins (% calm, %1-5 km h-1, etc.) which is useful for some applications.
- Coastal run-off of major coastal river systems, as well as rivers local to the study area are collected and maintained by Environment Canada.
- Sea surface data from AES/DFO weather buoys (sea-surface temperature, air temperature, wind speed/direction, wave height) is available in near real-time (i.e., within an hour via the Institute of Ocean Sciences 'Oceans' bulletin board system.

I4. ALTERNATIVE SAMPLING METHODS

A recent trend in monitoring and "measuring" sea water properties such as surface water temperatures, water current, and amount of surface solar radiation is to use remote sensing methods. For instance, LANDSAT satellites produce high resolution (57 m by 57 m) information that can be used to map coastline, sedimentation, and to estimate suspended sediments concentrations in surface waters. Bathymetry can also be mapped using airborne laser systems (e.g., LIDAR). Airborne sensors are also available for surface temperature and water colour spectra. Disadvantages are higher costs compared to satellites and reduced spatial coverage. Advantages include much better spatial resolution and lower probability of interference from cloud cover. See Appendix 1 for a detailed discussion of remote sensing methods. Moored or bottom-mounted instruments offer the capability for continuous measurement or various water properties. The types of instrument that may be useful in this context include sediment traps to measure vertical flux of organic matter, dissolved oxygen, nitrate, temperature and conductivity sensors, optical sensors (transmissometers, fluorometers) and current meters. Disadvantages include capital and maintenance costs, diff~culty of securing in shallow water environments, with potential for loss from fishing activity and weather, and, in some cases, interference from re-suspended bottom material. The advantage is continuous data coverage over long time periods.

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Table 11. Summary of methods used to sample chemical and physical properties of sea water, on the basis of location in the water column.

Property	Surface	Integrated	Discrete Depth	Profile	Alternatives
Temperature	Bucket and thermometer	NA	Reversing thermometer	CTD	Satellite
Dissolved oxygen	Bucket and Winkler titration	Tubing and Winkler titration	Water bottle	Oxygen meter	
Nutrients	Bucket and autoanalyzer	Tubing and autoanalyzer	Water bottle	In-flow analysis	
Light	Photometer	Secchi disk	Photometer	Photometer	Satellite
Salinity	Bucket and salinometer	Tubing and salinometer	Water bottle	CTD	

PART J. SEDIMENTS/SUBSTRATES

Sediments are important determinants of the biological communities inhabiting the nearshore subtidal. Studies most frequently measure the type and extent of sediments, while only occasionally measuring properties such as particle size, structural elements, porosity, pH, temperature, organic matter, capillary rise, permeability, and toxic bioassays. Bottom sediments are influenced by interactions among several major factors: source, transport, deposition, hiodeposition and hioturbulence (Holme and McIntyre 1984). Simenstad et al. (1991) recommend that sediment properties only need to be sampled yearly (or at most semi-yearly) to assess sporadic accretion activity and the effects of benthos. In general, short-term temporal variability in sediment properties is not as important compared to sampling biota.

An important source of information about the type and extent of nearshore subtidal sediments is found on coastal hydrographic charts or f~eld sheets. These charts are produced by the Canadian Hydrographic Service and the General Surveys Branch, Ministry of Lands and Parks. Investigators may require more detailed or up-to-date or larger scale information about sediments. This section discusses methods used for collecting qualitative and quantitative samples of sediments. Investigators should consult Buchanan (1984) and Tetra Tech (1986) for a discussion of methods of analyzing sediments in the laboratory.

J1. GENERAL SAMPLING CONSIDERATIONS

There are two main considerations when sampling for sediments: First, accurate positioning of the location of the sampling station is needed. The limitations on navigational accuracy and the knowledge of sediment sampler position (such as towed hydroacoustical fish), can sometimes result in a plus or minus 5-10 m accuracy in characterizing sea bed features in shallow waters. Second, it is important to realize that most sediment samplers remove or describe a relatively small section of the sea bed, and thus there is a need for structured repetitive sampling. This sampling design consideration also reflects the need for navigational accuracy for representative coverage.

J2. SAMPLING QUALITATIVE PROPERTIES OF SEDIMENTS

Qualitative properties of sediments include spatial coverage, depth, type of sediment, etc.. The main methods used to sample qualitative information about nearshore subtidal sediments are hydroacoustical in nature, and include: depth-sounding, sweep mapping, sub-hottom profiling, side-scan sonar imaging and swath mapping. We summarize the main advantages and disadvantages of each system from Hodgins and Harper (1995), but the reader is referred to this paper for detailed discussions of methods used for detecting acoustical reflectance off the seabed.

The main advantage of using depth sounders is that they are relatively simple and inexpensive systems to operate and maintain. These hydroacoustic systems can be interfaced with

navigational systems, and they can be linked with post system processors to provide an indication of seabed character (see section 3.1.3). These bottom classification systems provide real-time electronic processing for characterizing seabed sediments (e.g., Kalvi et al. 1994). The main disadvantage of using a depth sounder is that it provides a limited spatial picture of sea bed (e.g., provides profile of surface only), and repetitive surveys are highly dependent on navigational accuracy.

Sweep mapping systems are essentially a series of echo sounders that produce high resolution bathymetric maps, in waters in less than 30 m. The main disadvantage is that they require specially designed vessels, and highly trained personnel. In addition, sweep mapping systems cannot be used in rough conditions.

Sub-bottom prof~ling systems are hasically depth sounders that use more power and lower frequencies to penetrate the sound pulse into the sediments. The main advantage is that they are relatively simple, towed devices that can be interfaced with navigation devices. These systems provide an indication of the immediate subsurface layer to 1 m, depending on survey conditions and sediment contrast (e.g., Simpkin and Davis 1993). The main disadvantage is that sub-bottom prof~ling provides limited spatial coverage, and these systems cannot detect thin, near surface layering.

Side-scan sonar imaging produces a 'map-like' image of the seabed, that are analogous to aerial photographs over land. Acoustic pulses are transmitted laterally from a 'towed fish', and the reflectance off bottom roughness are recorded. The main advantages include a real-time map image of seabed roughness, which can help to optimize a sampling programme. The main disadvantage is that the instrumentation is relatively complex and costly to operate, and it requires considerable post-survey processing. The resolution of side-scan sonar surveys depends on the instrument, towf~sh stability, navigational accuracy, and operator skill.

Swath mapping uses a hydroacoustic device with a multibeam, single beam transducer. The system is very similar to side-scan sonar but is more complex and expensive. These systems are mainly used in deep water, but high frequency systems have been used in shallow waters (Alleman et al. 1993). The greatest advantage is in-situ interpretation of the data.

A second general set of methods used to sample qualitative information about nearshore subtidal sediments is to use visual survey techniques of still or video cameras, or diver observations. The main purpose of this sampling is to verify if sediments recorded hydroacoustically are representative of the surrounding sea bed. The reader is referred to Hodgins and Harper (1995) for a detailed discUssion of these methods. Simple, shallow-water bottomtriggered still camera systems provide a high resolution image of seabed that can easily be catalogued for comparison with repetitive surveys. The main disadvantage of these systems is the limited area of seabed image (e.g., 1-2 m2), and that real-time processing is not usually possible, and post processing takes several days. Video and still camera systems can be mounted on various underwater platforms, such as ROV's, and they provide real-time imagery of the seabed. More appropriate for the shallow nearshore are SCUBA observations using cameras, slates, and they provide for a high degree of confidence in determining seabed conditions (see section 2.1).

The main disadvantages of SCUBA verifications are the limited time underwater, high level of effort for smaller spatial scales, and increased safety risks.

J3. METHODS USED TO COLLECT QUANTITATIVE SEDIMENT SAMPLES

Sediment samples are collected and tested for a variety of quantitative properties such as texture, porosity, grain-size, mineralogical analyses, trace metal or organic content (e.g., Ecological Services for Planning Ltd. 1993). Three main approaches are used to collect sediment samples: cores, diver sampling, and grabs.

Cores are frequently used to collect quantitative information about sediments, especially if vertical extent is required. As a corer penetrates through the sediment, there may be some disturbance of the surface, but the basic layering is usually maintained. Sediments are usually collected from a box or tube corer that is operated from a ship. Coring devices include gravity corers, vibra-corers, and box corers. The main advantages of coring include: corers are relatively simple devices to operate; useful in confirming sub-bottom profiles generated from hydroacoustic devices (see above); and the sample can be split into layers and the vertical extent of sediments determined. The main disadvantage of coring is that gear is large and requires large vessels with winches and space for onboard storage and extraction. In addition, samples taken from most corers cover a small surface area, depth penetration can be limited to < 20 cm, and the sediment prof~le can become compressed.

A second general set of methods used to collect sediment samples for quantitative analyses is a SCUBA survey. The main advantage of SCUBA is that sampling can be conducted in shallow nearshore waters, whereas coring from a ship may be restricted. In general, divers collect sediment samples using hand-held cores or grabs (see below).The diameter of a hand-held corer is usually between 2 and 5 cm, and the core can collect sediments down to 20 cm depth. The main advantage of diver sampling using a corer or grab is that very precise sampling is possible, and sampling stations can be relocated if properly staked. In addition, the diver can determine if the sample site is representative of the surrounding sea bed. The main disadvantages of SCUBA surveys in general have been discussed above and in section 2.1.

The last method discussed for collecting sediment samples for quantitative analysis is appropriate if nearshore subtidal conditions are inappropriate for SCUBA. There are many types of grabs (e.g., see Eleftheriou and Holmes 1984), but most models can penetrate the top 10-20 cm of sediment and they cover between 0.1-10 m2. Grabs are operated from over the side of a boat/ship, and they are rapidly lowered to the sediment surface. The grab then bites a sediment sample and is hauled back to the surface. Users should be aware of several important inherent limitations of grab sampling. Grabs can sometimes sample ineff~ciently because the jaws become jammed opened with material, and thus sediments fall out as the grab is raised. In rough weather, the rise and fall of the vessel will not allow the grab to "bite" properly. Sample volume collected using a grab can vary widely depending on the sediment type. This problem can generally be overcome by adding weight to the grab. However, pressure waves from the decent of heavy grabs tend to "sweep away" loose surface sediments.

In general, the investigator should ensure that the grab sampler can be easily handled on board and it must create a minimum bow wake while descending, give a leak-proof seal when sample is ascending, prevent disturbance of sample when ascending, and allow for easy access to the sample surface. The samples should be continuously monitored for leakage by verifying that overlying water is present; that the surface is flat and thus the sample has had minimal disturbance or winnowing; and that the sampler is not over filled. If these criteria are not met then the sediment sample should be rejected. After receiving the sediment sample, surface water should be slowly siphoned off and then the sample should be sub-sampled using a flat scoop device rather than a corer. Once a sediment sample has been collected, standard laboratory protocols for analysis of sediment properties are discussed in Buchanan (1984). The main advantage of using a grab is that it collects a relatively large volume of sediment, and it is easy to use. In addition, the samples are typically representative of the surficial seabed, and a wide variety of analyses can be conducted on a single grab sample. The main disadvantages are that a large number of grab samples may need to be collected if bottom sediments are patchy. The grab seldom collects an undisturbed sample; sample replication is dependent on accurate navigation (station positioning), and post survey processing takes several weeks.

J4. CRITICAL ASSESSMENT CRITERIA

The following information should be collected and recorded when sampling sediments to determine the comparability and accuracy of data among studies:

- Number of stations or transects sampled
- Sampler type, model and dimensions
- Area (m2) of sea bed sampled - Depth of sampling stations (m)
- Depth and extent of sediment type, sea bed slope
- Type and extent of macroalgae
- SCUBA survey duration (min), sampler used
- Location of voucher sediment samples

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Table J1. Summary of methods used to sample sediment properties.

Sediment Property	Recommended Standard Sampling Method
Type and extent	1) Hydroacoustical methods 2) SCUBA survey with camera imaging
Organic content, toxicity, etc.	1) Coring from a vessel 2) Diver excavations using hand-held corers or grabs 3) Grab from vessel

APPENDIX II. KEY TO IMPORTANT TERMS

Habitat: Habitat can be described as the combination of biological and physical characteristics of the environment that influence a species survival, growth, or reproductive success. Biotic characteristics include vegetation, invertebrates, fish, etc.. Abiotic properties include non-living components such as sediment type, oxygen concentration, water temperature, etc.. Habitat properties vary temporally and spatially.

Mapping: Mapping is the process of geographically representing the location, distribution, and extent of resource or habitat properties (e.g., presence/absence, abundance, etc.) on paper or in digital form. Nearshore subtidal: Nearshore subtidal areas occur below the lowest low water (i.e., nearshore subtidal areas are always submerged), to the depth of light penetration in coastal waters (about 30 m).

Resource: A resource is considered to be any biotic or abiotic property of habitat that has economic, ecological, social, or cultural value. This report focuses primarily on the economically valuable resources such as vegetation, invertebrates, and fishes, and physiochemical habitat properties that may influence these resources.

Sampling/surveying: The process of collecting information and data about the properties of habitats and their resources. Properties include presence/absence, standing stock, aerial extent, slope, etc. The method used to collect the information is typically resource or habitat specific.

Standard: Standard is defined in the Oxford dictionary as "a measure serving as a basis or example or principle to which others conform or should conform or by which the accuracy or quality of others is judged". The formal definition of standard implies that the quality (reliability) and usability of the data will be determined by how it was collected, and that data which do not meet certain criteria should be rejected by users.