PHYTOPLANKTON ECOLOGY OF GWAII HAANAS, QUEEN CHARLOTTE ISLANDS, BRITISH COLUMBIA

by

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ABSTRACT

A National Marine Conservation Area (NMCA) has been proposed for the waters around Gwaii Haanas National Park Reserve/Haida Heritage Site and Parks Canada is interested in obtaining information on the marine resources in the surrounding waters in order to monitor and manage this marine area. Samples were taken from the waters of the fjords and island passages of the proposed NMCA in order to study the relationships between physical and chemical parameters and abundance and diversity of the phytoplankton in these nearshore areas of Gwaii Haanas.

This thesis reports nutrient concentrations, phytoplankton biomass (chlorophyll), and physical parameters during the summers (July and August) of 2001 and 2002 for these waters. Samples were collected using the PV *Gwaii Haanas II* as a ship-of-opportunity. A total of ten cruises were conducted and samples were taken for salinity, temperature, density, total suspended solids, Secchi disk depth, nitrate, phosphate, and silicic acid concentrations, chlorophyll *a* concentrations in two size fractions, and samples for phytoplankton identification.

These data were compared for spatial and interannual differences by comparing coasts (east vs. west) and by comparing years (2001 vs. 2002). Variability was very high and few comparisons were significant. Mixed layers were shallow or non-existent on both coasts and in both years. Nutrient concentrations were significantly higher in 2002 than in 2001 as there was a greater intensity of upwelling in 2002 as compared with 2001. Nitrate was observed to be a factor limiting phytoplankton growth in a large proportion of stations, and consequently N:P and N:Si ratios were lower than that required for phytoplankton growth.

Surface chlorophyll *a* concentrations showed no differences, but integrated chlorophyll *a* concentrations showed significantly higher concentrations in 2002 than in 2001. There was more sunlight and less precipitation in 2002 compared to 2001 and there was more phytoplankton at depth as the light penetrated deeper. The most abundant phytoplankton species were *Leptocylindrus danicus, Chaetoceros* spp., *Thalassiosira* spp., *Skeletonema costatum*, and a group of *Pseudonitzschia* species referred to as "A".

Canonical correspondence analysis (CCA) was performed on these data to determine the relationships between environmental variables and phytoplankton

community composition. Most of the phytoplankton species and groups were observed where nutrient concentrations were high and the depth of light penetration was greater than average. Dinoflagellates were more often found in warmer water while diatoms were more often found where the water was colder. The depth of the mixed layer had the least influence on phytoplankton distribution while the silicic acid concentration had the greatest influence. This contradicts the real data which found silicic acid to be not a limiting factor at any of the stations.

There was little spatial variability found in nutrient and chlorophyll *a* concentrations, only silicic acid had a significant difference between coasts with higher concentrations on the west coast than the east and the large size fraction (> 5 μm) of chlorophyll *a* was higher on the east coast than the west coast. Temporal variability was observed with higher nutrient and integrated chlorophyll *a* concentrations in 2002 compared to 2001. This study has provided the first extensive near-shore physical, chemical, and biological data in the waters surrounding Gwaii Haanas National Park Reserve/Haida Heritage Site, documenting nutrient and chlorophyll concentrations as well as providing a phytoplankton species list. These data will be useful as a baseline for continuing studies throughout Gwaii Haanas as it becomes an NMCA.

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Chapter 1

General Introduction

The Gwaii Haanas National Park Reserve and Haida Heritage Site (NPR/HHS) consists of 138 islands and they compose part of the Queen Charlotte Islands. It has been settled by the Haida people for more than 10,000 years. These islands are bordered on the east by the broad and shallow Hecate Strait and on the west by the Pacific Ocean with a narrow continental shelf, where the sea floor drops off to depths of over 2500 m within 30 km from shore (Thomson 1981). The land boundaries of the NPR/HHS contain 1470 km^2 (see Fig. 1.1) and the 4700 km of shoreline have abundant intertidal marine life and nesting seabirds.

The waters around Gwaii Haanas support many commercial fisheries including Pacific salmon, halibut, herring, and herring roe-on-kelp. Also, many marine mammals have been observed off the coasts of these islands, including grey whales on their annual migrations between the Bering Sea and Mexico, as well as killer whales, minke and humpback whales, dolphins, porpoises, harbour seals and sea lions. A National Marine Conservation Area (NMCA) has been proposed for these waters, which would extend approximately 10 km off shore of Gwaii Haanas and cover 3400 km^2 of surrounding waters. Figure 1.1 shows the proposed water boundaries for the Gwaii Haanas NMCA (GHNMCA) and the NPR/HHS that will serve to protect this fragile ecosystem.

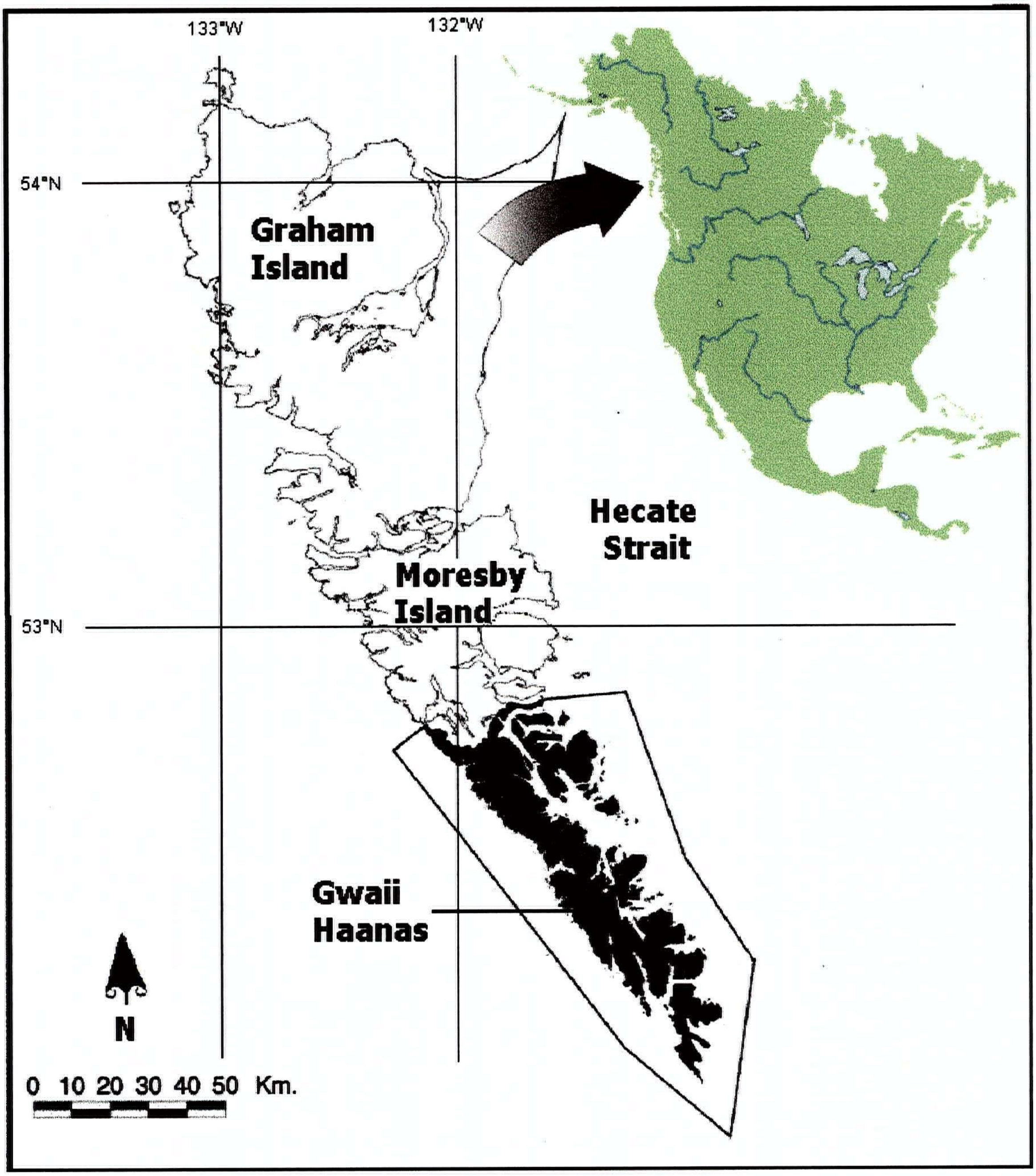

Figure 1.1: Land boundaries of Gwaii Haanas National Park Reserve/ Haida Heritage Site located at the south end of the Queen Charlotte Islands and water boundaries for the proposed Gwaii Haanas National Marine Conservation Area.

There are growing threats from overfishing, pollution, climate change, and habitat destruction, and in order to protect an area, it is important to understand and know the biological diversity of the area. This study attempts to quantify the phytoplankton and the environmental parameters within which these phytoplankton are found in the waters of Gwaii Haanas. The baseline data will be the first part of an Ocean Sciences program initiated by the Gwaii Haanas NPR/HHS in order to properly monitor and maintain the environmental quality of these waters.

1.1 British Columbia Coast

Gwaii Haanas and the Queen Charlotte Islands are located on the northern shelf of the British Columbian coast, which is an area characterized by numerous mountains and fjords, islands and inlets, straits and sounds, and a narrow continental shelf. There is a segmented mountain range stretching from Vancouver Island up through the Queen Charlotte Islands and the Alaskan Panhandle, separated only by Queen Charlotte Sound and the Dixon Entrance (Thomson 1981). There are many valuable economic resources along the British Columbian coast, the first of which is tourism. Hundreds of thousands of tourists are drawn each year to the rugged and natural beauty of the coastline, with the hope of spotting some whales. Pacific salmon are another important resource, as well as many other fisheries including herring, cod, groundfish, and shellfish.

This area is affected by two large scale pressure systems that control the dominant wind patterns along the coast, the Aleutian Low and the North Pacific High. In the fall and winter months, the Aleutian Low becomes more intense and shifts southward from the Bering Sea to the Gulf of Alaska. These southeasterly and southwesterly winds persist until early spring as air flows counter-clockwise around the Aleutian low pressure cell, and then decreases in the summer months, whereas the North Pacific high intensifies until it covers the entire Gulf of Alaska between June and August. This results in northwesterly winds flowing clockwise around the North Pacific High pressure cell (Thomson 1981). Directed by these prevailing wind forces, surface circulation in the summer consists of the eastward flowing Subarctic Current that branches into two currents (Fig. 1.2). The northern British Columbian coast is affected by the northeast flowing Alaska Current which forms the Alaskan Gyre in the Gulf of Alaska, and the southern coast is affected by the southeast flowing eastern boundary current, the California Current. In the winter, the California Current is displaced offshore by the northward flowing Davidson Current.

Longhurst (1998) divides the area into two coastal provinces according to different oceanic characteristics. The northern coast is represented by the Alaska Downwelling Coastal Province and the southern coast is represented by the California Current Province. The Alaskan Downwelling Coastal Province encompasses the coastal boundary region from 53° N where the Alaska Current originates, to the end of the Aleutian Islands. This area has a general downwelling tendency and weak upwelling is only seen off the Alaskan peninsula near Kodiak Island during the summer months (Longhurst 1998). The California Current Province extends from where the California Current originates and bends southward down to the tip of Baja California. The interaction between the southward flowing current, the coastline as a boundary, and an alternating wind regime, leads to upwelling in the summer and downwelling in the winter (Longhurst 1998).

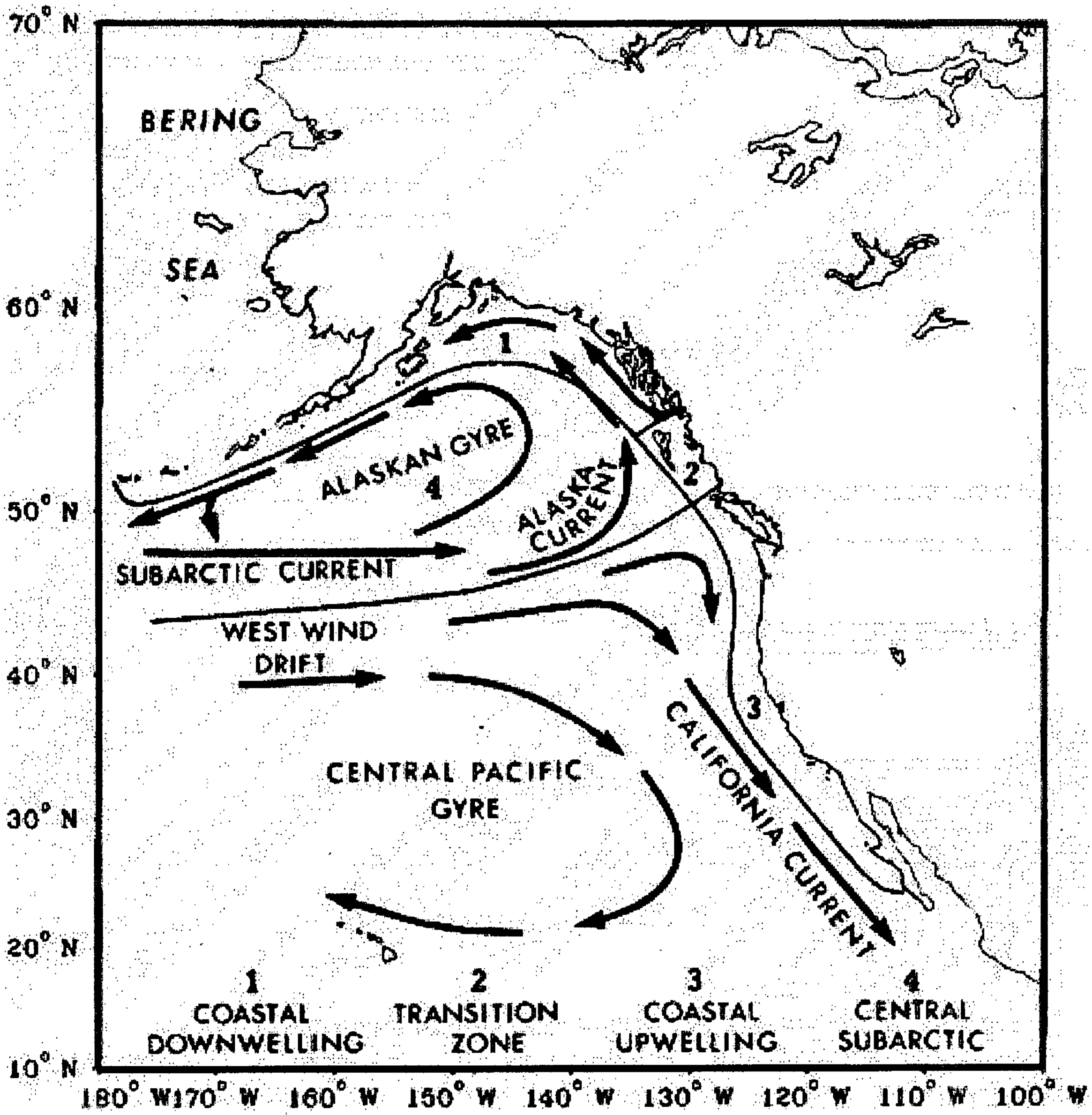

Figure 1.2: Surface circulation in the northeast Pacific Ocean (from Ware and MacFarlane 1989).

1.2 Study Area - Physical Oceanography

The Queen Charlotte Islands and the proposed GHNMCA are located at the transition between these two oceanic provinces, between approximately 52° and 53° N latitude and 131° and 132° W longitude. The west coast is bordered by the Pacific Ocean where the continental shelf is very narrow and the continental slope is steep. The coastline consists of numerous narrow inlets that are susceptible to sudden short-lived violent gusts of cold air, called williwaws. These gusts are common along mountainous coasts of high latitudes and can reach speeds of 25 m s^{-1} (Thomson 1981). Regional winds on this coast influence surface currents. In the winter, winds blow from the southeast, which creates a downwind surface drift that the Coriolis force deflects to the right (Thomson 1981). Ekman transport is directed onshore and nearshore isopycnals are depressed and the surface waters are downwelled (Thomson 1981). In the summer, the winds change direction and blow from the northwest where the opposite situation occurs and upwelling occurs on the west coast as isopycnals are raised and the Ekman transport is offshore (Thomson 1981).

Hecate Strait is a shallow submarine valley that extends for 220 km and borders part of the east coast of BC. Maximum depths along the axis of this channel range from 300 m in the south to 50 m in the north (Thomson 1989). This coast consists of numerous large and small islands and island channels, sounds, bays, and inlets of various depths. In the summer months, the wind speeds on this coast are less than in the winter, averaging about 5.5 m s^{-1} (Thomson 1981). August sea surface temperatures range from 10-13° C and sea fog is more frequent in summer than in autumn (Thomson 1989). Tides in this area are mixed, predominantly semi-diurnal and are usually about 3 to 5 m in height, but they can reach up to 7 m in Skidegate Channel (Thomson 1989). Surface currents within Hecate Strait consist of tidal streams that move north and south, on the flood and ebb tides respectively, at a maximum rate of approximately 50 cm s^{-1} in basically straight lines (Thomson 1981). There is very little freshwater drainage on either coast, and although the influence of runoff is not completely negligible, surface salinity conditions are mainly determined by the oceanic conditions (Thomson 1989).

1.3 Haida Eddies

Haida Eddies are anti-cyclonic mesoscale vortices that form off of the west coast of the Queen Charlotte Islands. These eddies generally form in the winter, mostly near Cape St. James at the southern tip of the Queen Charlotte Islands (Crawford *et. al.* submitted) and detach from the coast in the spring, moving westward into the Gulf of Alaska (Whitney and Robert 2002). At least one eddy forms off the coast of the Queen Charlotte Islands every winter (Crawford *et. al.* 2002). These eddies have been identified using satellite altimetry (Fig. 1.3) as they can have a sea surface height anomaly of up to 0.4 m (Crawford 2002). Whitney and Robert (2002) estimated that satellite altimetry can be used to locate the centre of an eddy within 25 km.

These rotating physical features can be very large, with a diameter of 200 km or larger (Crawford 2002) and can persist for several years. During their existence they may travel as far as 1000 km from where they originated (Whitney and Robert 2002). Other characteristic physical features of these eddies are that they are less saline than the surrounding waters at all depths and they are warmer than the surrounding waters at depths below the top 100 m (Crawford 2002, Crawford *et. al.* 2002, Whitney and Robert

2002). They have a baroclinic structure and can extend in depth to at least 1 km (Crawford 2002). These characteristics are also common to Sitka Eddies, which form off of the Alaskan Panhandle (Crawford 2002).

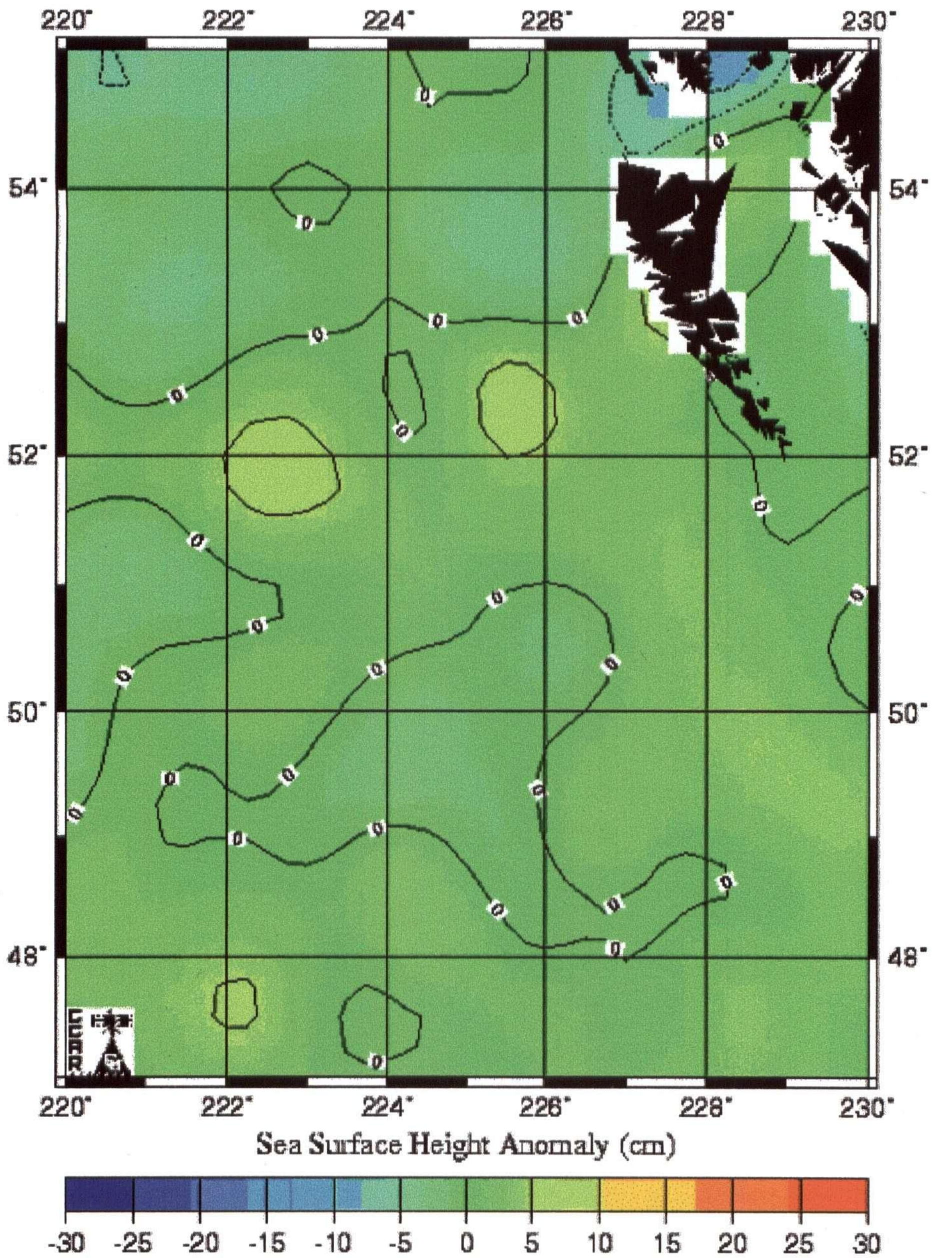

Figure 1.3: Sea surface height anomaly showing Haida Eddies (yellow) moving westward off the Queen Charlotte Islands.

Since these eddies form on the coast and move westward, they are a mechanism of transporting coastal water out to sea. Whitney and Robert (2002) estimate that due to the large size of these eddies, 3000 to 6000 km^3 of coastal water can be moved up to 1000 km into the open ocean. This coastal water from Hecate Strait and Queen Charlotte Sound that composes the eddies, contains all of the nutrients and phytoplankton species from the coast and transports them often into a high nutrient, low chlorophyll (HNLC) area of the northeast Pacific Ocean. These areas have high macro-nutrient concentrations, but low concentrations of micro-nutrients such as iron (Martin *et al.* 1989, Boyd *et al.* 1996). For these eddies travelling out to sea, it is not the macronutrient concentrations, but the high micronutrient (Fe) concentrations of the coastal waters in Haida Eddies that likely stimulates primary productivity in the offshore HNLC region (Whitney and Robert 2002).

1.4 Coastal Upwelling

The Gwaii Haanas NPR/HHS in the Queen Charlotte Islands is bordered on the west coast by an area of upwelling in the summer months (Dodimead 1980, Thompson 1981) (Fig. 1.4). In contrast to oceanic regions, regions of coastal upwelling are very fertile with high phytoplankton productivity and biomass (Barber and Smith 1981). Coastal upwelling is found along the western boundaries of continents and are economically valuable for fisheries due to the high biological productivity in these regions. These upwelling regions cover 0.1% of the area of the ocean, but produce 50% of the fish harvest (Ryther 1969).

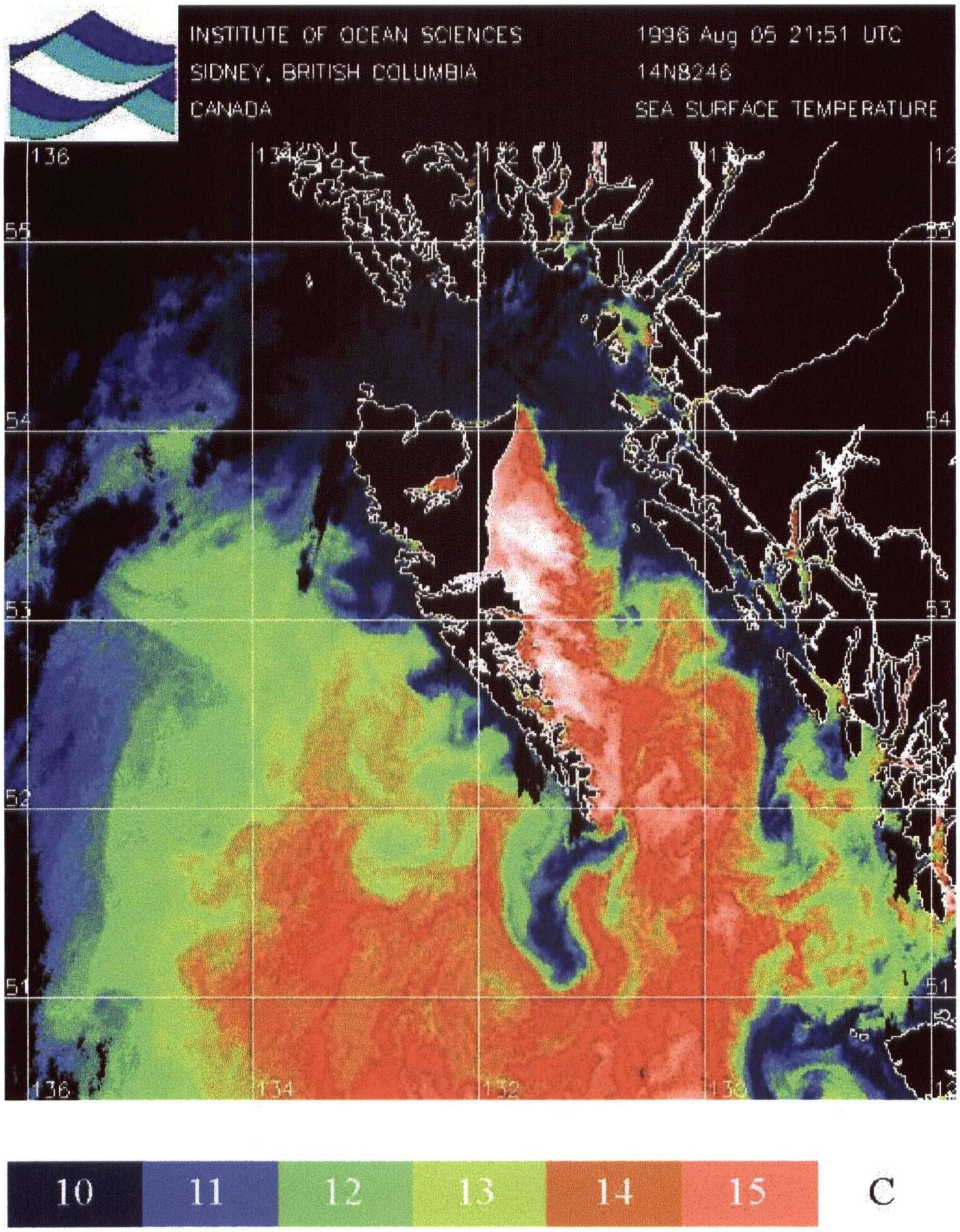

Figure 1.4: NOAA weather satellite thermal image (5 August 1996) illustrating temperature differences between the east and west coasts of the Queen Charlotte Islands. The west coast shows a band of cool (blue) upwelled water. There is a mixing region at the southern tip (blue), and the east coast consists primarily of warmer (red) water (from Robinson *et al.* 2004).

Upwelling occurs due to a combination of the alongshore equatorward winds, and the Coriolis effect, and the result is Ekman transport offshore. As the surface water is pushed offshore due to Ekman transport, it is replaced by colder, nutrient rich, deeper water that also contains a seed population of phytoplankton. When it is brought up into the euphotic zone where light is no longer limiting, high productivity in the region results from the phytoplankton response of rapid growth to the ideal light and nutrient levels.

1.5 Strait of Georgia

The northern shelf has been relatively ignored in terms of biological oceanographic research, but there have been studies conducted further south in the Strait of Georgia, located between Vancouver Island and mainland British Columbia. The Strait of Georgia is a partially enclosed basin, approximately 200 km long with an average depth of 156 m and an average width of 33 km (Stockner *et al.* 1979). Unlike Hecate Strait, freshwater runoff from the Fraser River exerts a great influence on the hydrography of the region, and salinity can vary from 0.5 near the mouth of the Fraser River in the spring, to 27-30 away from the inflow of freshwater in the winter (Harrison *et al.* 1983, Stockner *et al.* 1979). The sea surface temperatures range from 4°C in winter to 18°C in summer (Stockner *et al.* 1979). Valuable fisheries resources in the area include Pacific salmon and herring (Harrison *et al.* 1983, Stockner *et al.* 1979).

The phytoplankton community in the Strait of Georgia is dominated most of the year by diatoms. Phytoplankton abundance is limited by light in the winter, and begins to increase in the spring as more light becomes available and reaches a peak in April (Harrison *et al.* 1983, Stockner *et al.* 1979). These blooms use up available nutrients and become nitrate-limited in the spring and summer (Harrison *et al.* 1983, Stockner *et al.* 1979). Nitrate may be periodically depleted from the surface water in stratified areas and is usually higher in more turbulent regions. In the spring, the most abundant phytoplankton are chain-forming diatoms such as *Thalassiosira* spp. followed by *Skeletonema costatum* (Harrison *et al.* 1983). Species that have been observed to bloom in the summer are *Chaetoceros* spp., *Ditylum brightwellii*, *Detonula pumila*, and *Leptocylindrus danicus* (Harrison *et al.* 1983). Dinoflagellates such as *Peridinium* spp., *Gymnodinium* spp., and *Dinophysis* spp. are common in the Strait of Georgia in the summer (Stockner *et al.* 1979).

1.6 Coastal Gulf of Alaska

Coastal biological oceanography in the Gulf of Alaska has not been studied as widely, although there have been some attempts to quantify seasonal cycles of nutrients and phytoplankton (Parsons 1987, Sambrotto and Lorenzen 1987, Wheeler 1993). The Gulf of Alaska is predominantly an upwelling regime. Nutrient concentrations in the downwelled coastal waters are still relatively high, as the water that is downwelled comes from the oceanic Gulf of Alaska which is high in macronutrients (Wheeler 1993). These nutrients are often depleted in the surface layers in the summer, although some minor upwelling does occur in the summer along the coast (Sambrotto and Lorenzen 1987). In the Gulf of Alaska, productivity is higher on the shelf and slope areas than in oceanic areas (Parsons 1987, Sambrotto and Lorenzen 1987). This productivity is patchy due to local hydrographic features such as tidally mixed frontal systems that sustain nutrient concentrations. The phytoplankton community in the Gulf of Alaska is dominated by microflagellates, while the coastal areas of Prince William Sound are dominated by diatoms (Sambrotto and Lorenzen 1987). Larrance *et al.* (1977) found that the spring bloom starts in April with *Thalassiosira* spp., which then coexisted with *Chaetoceros* spp. throughout May. Subsequent productivity peaks due to wind mixing were composed of *Skeletonema costatum* (Larrance *et al.* 1977). Whitney *et al.* (submitted) also found blooms of the centric diatoms *Skeletonema costatum, Chaetoceros* spp. and *Thalassiosira* spp. in the spring in the NE Pacific.

1.7 Previous Studies

A few biological oceanographic studies have been conducted in Hecate Strait. Perry (1984) conducted a survey of phytoplankton blooms in the open waters of the northern British Columbian shelf. His samples were taken from the northern Strait of Georgia, across Queen Charlotte Sound, and around the west and north coasts of the Queen Charlotte Islands, but sampling was concentrated on an east-west transect across northern Hecate Strait. Studying the mechanisms responsible for both the generation and timing of algal blooms, Perry (1984) found that the temporal patterns were typical of coastal temperate latitude areas, but that there were regional differences due to local oceanographic and bathymetric characteristics. Winter chlorophyll concentrations were the lowest (0.05 $\mu g\ L^{-1}$), while summer chlorophyll concentrations were the highest (15 $\mu g\ L^{-1}$), and spring values were the most variable. According to his results, tidal mixing was an important mechanism regulating growth of phytoplankton across Hecate Strait in the summer and light penetration and vertical mixing were the principal physical properties leading to bloom initiation. Highly mixed areas had lower chlorophyll concentrations and diatoms were more abundant in areas of high mixing than in stratified waters. In the summer small unidentified flagellates were numerically dominant, although a variety of dinoflagellates (including *Ceratium* spp.) were seen, as well as some residual spring bloom species such as *Chaetoceros* spp., *Thalassiosira* spp. and *Skeletonema costatum*. Production was found to be nutrient-limited rather than light-limited, and the most common diatom in all of the transects was *S. costatum* (Perry *et al.* 1983).

McQueen and Ware (2002) summarized physical environmental data, water chemistry, and phytoplankton data pertaining to Hecate Strait, including Dixon Entrance and Queen Charlotte Sound. They found that there was much between-site variation in physical environmental data such as precipitation, bright sunlight hours, sea surface temperatures, and salinities in the region. Precipitation patterns showed that since the mid 1940s winters and springs have been getting progressively wetter, while summers have been drier since 1980 and falls have not shown any specific trends (McQueen and Ware 2002). Bright sunshine hours were compared at Port Hardy (southern Queen Charlotte Sound), Sandspit (northwestern Hecate Strait, Queen Charlotte Islands) and Prince Rupert (northeastern Hecate Strait) and they found that both Port Hardy and Sandspit tended to have more hours of bright sunshine than Prince Rupert (McQueen and Ware 2002). Sea surface temperatures were found to be the lowest in January and February and most variable in February, and the highest in August and least variable in the summer (McQueen and Ware 2002). When analyzing mixed layer depths in the region they found deep mixed layers (100-150 m) in the winter (January-March), while a thermocline develops in the spring (April-May) due to surface heating, precipitation and less wind mixing (McQueen and Ware 2002). In the summer (June-September) the surface mixed layer is shallow (10-20 m) or non-existent, with the thermocline extending to the surface (McQueen and Ware 2002).

In their chemical water analysis of the nutrients NO_3, PO_4, and SiO_4, McQueen and Ware (2002) found that there were few between-site differences. During the summer the nutrient concentrations varied with depth, low at the surface (0-5 m), and then doubling from 5-15 m, before gradually increasing as the water depth increased (McQueen and Ware 2002). They also found that surface nutrient concentrations were higher in the winter than they were in the summer (McQueen and Ware 2002).

McQueen and Ware (2002) also summarized chlorophyll *a* concentration data from this region. When concentrations from depths <10 m were compared from Dixon Entrance, Hecate Strait, and Queen Charlotte Sound, the results suggested that both between-year and between-site differences were small (McQueen and Ware 2002). When summarizing monthly averages, they found a distinct annual pattern with high chlorophyll *a* concentrations in the summer and low concentrations in the winter, as well as a very pronounced algal bloom in the spring, but a weak bloom in the fall (McQueen and Ware 2002). They also reported that chlorophyll *a* concentrations in this region averaged 2 $\mu g\ L^{-1}$ above 20 m in depth, but increased substantially between 20-30 m before declining in concentration below 30-40 m depth (McQueen and Ware 2002).

1.8 Remote Sensing using Satellites to Monitor Water Quality

The first example of using satellite imagery to detect phytoplankton blooms was the use of the US Coastal Zone Color Scanner (CZCS), which operated on an experimental satellite (Nimbus 7) from 1978 to 1986 (Gower 1997a, b, 1998). The CZCS radiometers measured estimates of phytoplankton biomass and chlorophyll by using the color of the surface water. These estimates were often unreliable for use in coastal areas because there was no distinction between high levels of dissolved organic matter in the water and chlorophyll (Longhurst *et al.* 1995 and references within). With the demise of the CZCS in 1986, there was no longer a sensor capable of monitoring ocean surface color until nearly 10 years later.

Satellite sensors designed for the atmosphere, such as the Advanced Very High Resolution Radiometer (AVHRR), have been used since 1986 to monitor surface water in the absence of a water color sensor. This sensor series provides low cost, daily coverage with moderate resolution that can be used to detect bright blooms in coastal waters (Gower 1997a, b, 1998). A limitation in the AVHRR sensors is that although blooms can be detected by following persistent patterns of brightness, there is no information about the spectral nature of the signal (Gower 1998). In August 1997, an improved sensor, designed for mapping ocean colour was launched, called the Sea-viewing Wide Field-of-view Sensor (SeaWiFS). This sensor had several improvements over the AVHRR and the CZCS sensors, including six bands that read in the visible spectrum, a higher signal:noise ratio, and on-board calibration capabilities (Joint and Groom 2000)

1.9 Remote Sensing to Monitor Blooms In the North East Pacific

Gower (1997a, b, 1998) reported that along the British Columbia coastline there have been a number of bright water patches that were observed with the AVHRR imagery processed at the Institute of Ocean Sciences (IOS) since 1991 (Fig. 1.5). These North Pacific blooms usually have occurred in late spring or summer, and in sheltered coastal areas and the exposed continental shelf between 48° and 55°N latitude, including the Queen Charlotte Islands (Gower 1997a, b). In one of these blooms, brightened water was observed on 28 July 1992, which spread over the next few days, reaching peak brightness. By 12 August 1992, most of Hecate Strait and parts of Queen Charlotte Sound were covered and the brightness began to fade. This event lasted a total of 22 days. A similar event in the same area started on 29 July 1995. Cloud cover interrupted the next series of images, however, images on 6, 7, 10, and 12 August showed the spreading of brightened water and by 14 August the event had faded. In this area similar events were also observed in 1993, 1996 (Gower 1997a, b, 1998), and 1997 (Gower 1998).

Gower (1997a, b) also reported bright water that was observed along 200 km of coastline on the west coast of Vancouver Island in late June 1994. This bloom was first observed on 15 June 1994, and the brightness in the water intensified until 20 June 1994 when it began to fade slowly over the next 10 days. Other less extensive bloom events have also been observed in this area in the years 1992, 1995, 1996 (Gower 1997a, b, 1998), and 1997 (Gower 1998). Gower (1997a, b) also reported a rare event, in which a bloom was observed off the edge of the continental shelf. This occurred in an area 100 km west of the tip of Vancouver Island and 150 km south of Cape St. James on the Queen Charlotte Islands in July 1996.

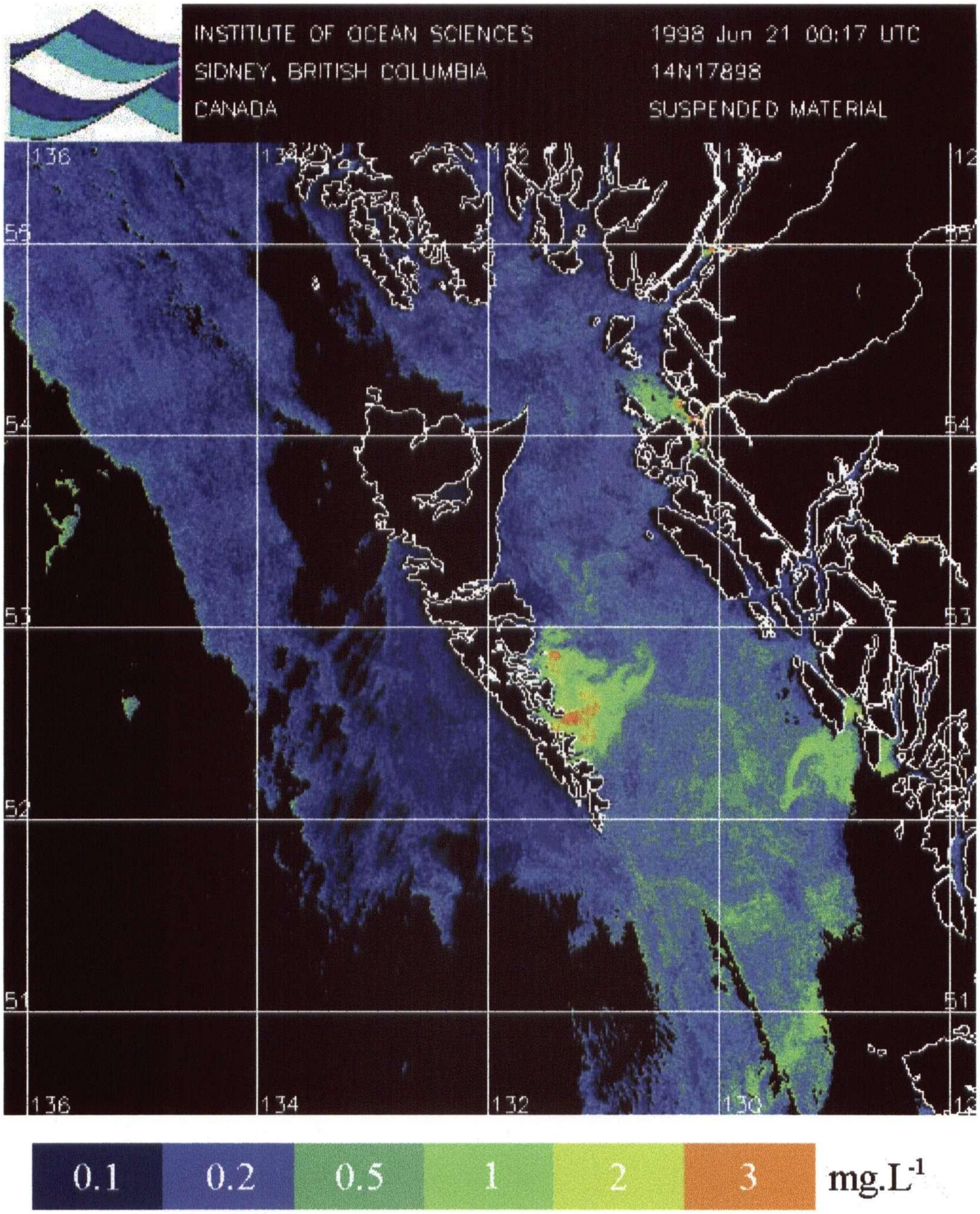

Figure 1.5: AVHRR image of suspended material (mg L^{-1}) for 21 June 1998 off the southeast coast of the Queen Charlotte Islands. Note the bright bloom event (orange/green) off the east coast (from Robinson *et al.* 2004).

Gower (1998) used SeaWiFS imagery to detect blooms in the Gulf of Alaska and in Hecate Strait, Queen Charlotte Islands. He reported that blooms that are visible from SeaWiFS imagery, can also be seen in AVHRR imagery, but they are near the lower sensitivity limit of AVHRR. An improvement with the SeaWiFS imagery over AVHRR is that it can distinguish biological substances from inorganic suspended substances (Gower 1998).

Extensive blooms have previously been observed in the area of Hecate Strait and the Queen Charlotte Islands. The original objectives of this thesis were to determine the phytoplankton composition of these highly reflectant blooms and provide ground-truthing of the remotely sensed estimates of chlorophyll concentrations, as well as to acquire physical, chemical, and biological data in order to help understand bloom dynamics in the proposed GHNMCA. Unfortunately, no bright water patches (i.e. no blooms of probably coccolithophores) were observed in the area during the field seasons of 2001 and 2002 in this study.

1.10 Thesis Objectives

This study is the first one to examine the physical, chemical and biological properties of the waters surrounding the proposed Gwaii Haanas National Marine Conservation Area (GHNMCA). Samples were taken from the waters of the fjords and island passages of the proposed GHNMCA in order to study the relationships between physical and chemical parameters and the abundance and diversity of the phytoplankton in these nearshore areas of Gwaii Haanas.

Specific questions addressed in this thesis are:

1) Do dissolved nutrients, chlorophyll concentrations, and regional oceanic properties differ between the east and west coasts of Gwaii Haanas (i.e. spatial variability)?
2) Did dissolved nutrients, chlorophyll concentrations, and regional ocean properties differ between the summers of 2001 and 2002 (i.e. temporal interannual variability)?
3) How do these physical and chemical differences influence the phytoplankton communities present?

1.11 Thesis Organization

Following the introduction, Chapter 2 of this thesis examines the physical and nutrient data collected along the east and west coasts of Gwaii Haanas, as well as the chlorophyll concentrations in order to relate the biological abundance with physiochemical water properties. Chapter 2 also examines differences between the east and west coasts of Gwaii Haanas and between 2001 and 2002 as well as the species composition and diversity of the phytoplankton present in Gwaii Haanas. Chapter 3 investigates and relates the phytoplankton species and abundance to the different water conditions examined in Chapter 2.

Chapter Two

Phytoplankton Biomass and Diversity and Physiochemical Water Properties in the Proposed Gwaii Haanas NMCA in Summer

2.1 Introduction

The goal of this part of the study was to obtain an inventory of physical, chemical, and biological data in the waters surrounding the proposed Gwaii Haanas NMCA and to compare them for spatial and interannual differences. These comparisons were chosen as there were a number of differences seen both between the coasts and between the two years during the two sampling seasons. Previously a distinct temperature difference between coasts was observed via satellite altimetry due to coastal upwelling along the west coast (Fig. 1.4) which brings cooler temperatures to the west coast while the east coast is warmer. The bathymetry of these two coasts is very different which could also lead to differing water properties on either coast. The east coast is a mixture of deep fjords and shallow bays with some influence from Hecate Strait which is relatively shallow, while the west coast is exposed to the open ocean with a very narrow continental shelf of less than 30 km before the sea floor drops to 2500 m depths.

The data were split into four categories to test for how these differences between coasts and between years affected the physical, chemical, and biological properties of these waters. The four categories were the east coast in 2001, the east coast in 2002, the west coast in 2001 and the west coast in 2002.

2.2 Materials and Methods

2.2.1 Sampling Sites and Procedures

Sampling was performed using the PV *Gwaii Haanas II* as a ship-of-opportunity. The *Gwaii Haanas II* services Gwaii Haanas NPR/HHS as part of Parks Canada's Haida Gwaii Watchman Program that was set up to help protect ancient Haida sites within the park boundaries. In total, 10 cruises aboard the *Gwaii Haanas II* were conducted, five in 2001 and five in 2002, including three along the west coast of Gwaii Haanas, each between 3 to 9 days in duration. Cruise details as well as weather and wind conditions at each station can be found in Appendix A. Unfortunately, the station and sampling frequency was controlled by the distance and route traveled by the *Gwaii Haanas II.* All sampling was conducted between July-August 2001 and July-August 2002 as this is when previous bright patches were observed using satellites on the east coast of Gwaii Haanas. A number of physical, chemical and biological parameters were measured at each station and sampling occurred between 8:00 and 23:00 PST. A total of 86 stations were each sampled one time only during the two year study period, with 34 stations in 2001 and 52 in 2002, and 66 stations were on the east coast and 20 on the west coast. Figure 2.1 shows the locations of these stations and the specific station locations, sampling dates and station numbers can be found in Table 2.1.

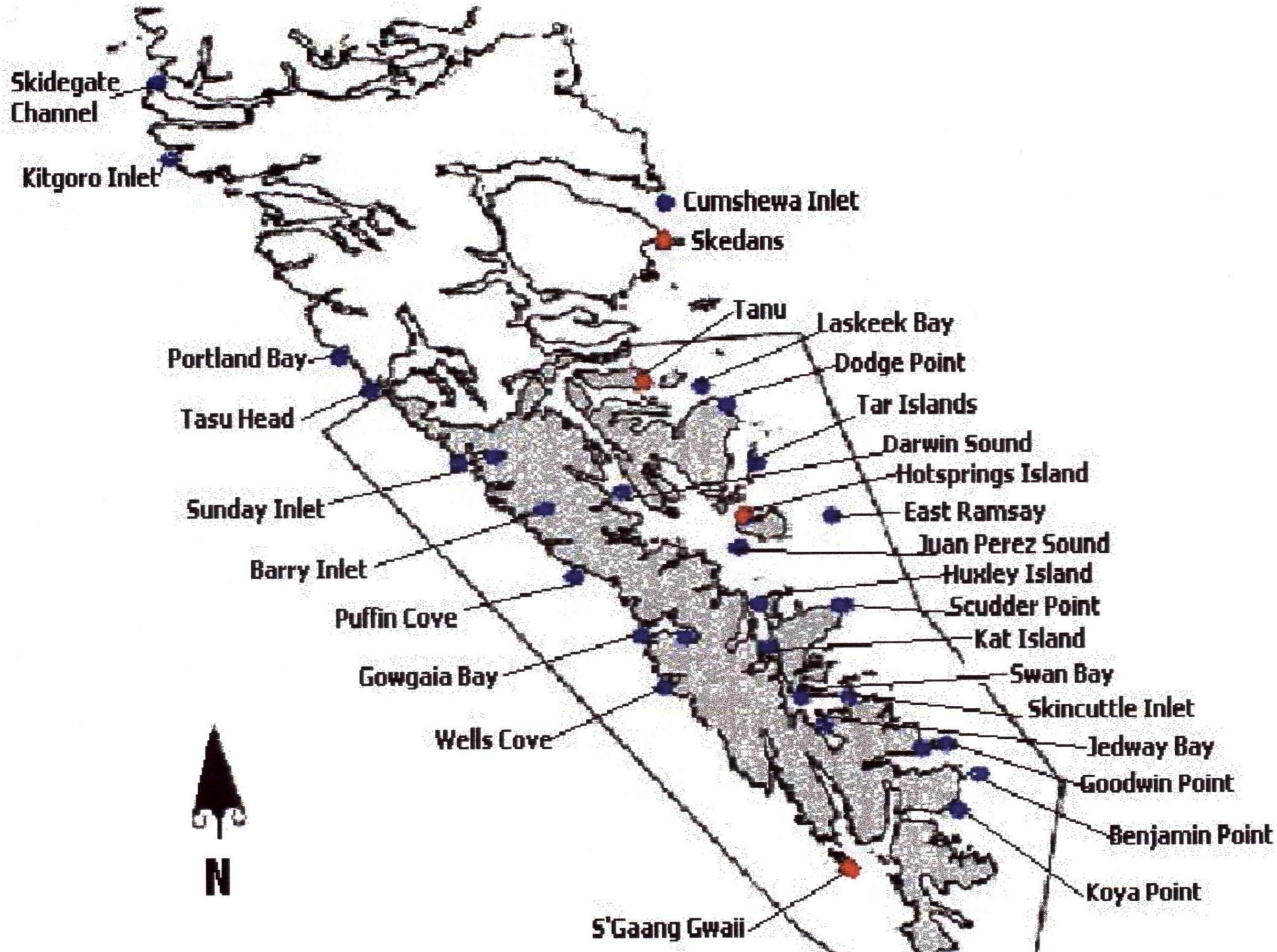

Figure 2.1: Locations of sampling stations showing stations both within and outside of the park boundary. The red dots indicate the station was at a location of an ancient Haida village.

Table 2.1: Sampling stations showing station name, number, date sampled, and exact location.

	Station	Date	Latitude	Longitude
1	Huxley	11/07/01	52°25.966'	131°27.380'
2	Tanu	17/07/01	52°45.723'	131°36.614'
3	Skedans	17/07/01	52°57.039'	131°36.500'
4	Skedans	25/07/01	52°57.982'	131°36.122'
5	Tanu	25/07/01	52°45.697'	131°36.625
6	Juan Perez	26/07/01	52°32.023'	131°26.756'
7	S'Gaang Gwaii	26/07/01	52°06.071'	131°12.930'
8	Cumshewa 5	31/07/01	53°00.643'	131°26.944'
9	Cumshewa 4	31/07/01	53°01.992'	131°40.648'
10	Cumshewa 3	31/07/01	53°01.339'	131°54.218'
11	Cumshewa 2	1/08/01	53°02.753'	131°52.814'
12	Logan 4	1/08/01	52°46.650'	131°36.393'
13	Logan 3	1/08/01	52°46.800'	131°41.856'
14	Logan 2	1/08/01	52°45.911'	131°46.781'
15	Logan 1	1/08/01	52°45.384'	131°52.805'
16	Juan Perez 1	2/08/01	52°38.232'	131°41.453'
17	Juan Perez 2	2/08/01	52°34.499'	131°36.377'
18	Juan Perez 3	2/08/01	52°31.851'	131°25.953'
19	Juan Perez 4	2/08/01	52°24.427'	131°25.458'
20	Juan Perez 5	3/08/01	52°30.280'	131°20.617'
21	Juan Perez	9/08/01	52°30.515'	131°27.251'
22	Huxley	9/08/01	52°26.011'	131°22.334'
23	Hotsprings	9/08/01	52°34.434	131°26.056'
24	Dodge Point	10/08/01	52°44.414'	131°28.810'
25	Skedans	10/08/01	52°57.886'	131°35.926'
26	Skedans	14/08/01	52°57.717'	131°35.829'
27	Tanu	14/08/01	52°45.696'	131°36.620'
28	Dodge Point	15/08/01	52°44.174'	131°28.125'
29	Huxley	15/08/01	52°25.966'	131°22.340'
30	Wells Cove	16/08/01	52°20.665'	131°32.230'
31	Gowgaia Bay	17/08/01	52°25.153'	131°36.150'
32	Gowgaia Bay Head	17/08/01	52°23.784'	131°30.682'
33	Barry Inlet	18/08/01	52°34.730'	131°47.251'
34	Sunday Inlet	19/08/01	52°38.840'	131°53.253'
35	Goodwin Rock	5/07/02	52°18.813'	131°02.229'
36	East Ramsay	5/07/02	52°35.630	131°10.620'
37	Laskeek Bay	5/07/02	52°49.601'	131°18.666'
38	Skidegate Channel	8/07/02	53°09.232'	132°34.376'
39	Tasu Head	8/07/02	52°51.358'	132°19.728'
40	Sunday Inlet	9/07/02	52°38.713'	131°56.394'
41	Gowgaia Bay	9/07/02	52°24.443'	131°25.374'
42	Wells Cove	10/07/02	52°20.443'	131°32.987'
43	S'Gaang Gwaii	10/07/02	52°05.965'	131°12.609'

Table 2.1 continued

	Station	Date	Latitude	Longitude
44	Koya Point	11/07/02	52°11.062'	131°00.248'
45	Scudder Point	11/07/02	52°27.651'	131°12.933'
46	Cumshewa Inlet	17/07/02	53°01.001'	131°35.002'
47	Skedans	17/07/02	52°57.127'	131°36.073'
48	Tanu	17/07/02	52°46.845'	131°36.714'
49	Dodge Point	18/07/02	52°44.305'	131°28.181'
50	Tar Islands	18/07/02	52°40.050'	131°26.396'
51	Hotsprings	19/07/02	52°34.092'	131°26.006
52	Juan Perez	19/07/02	52°31.993'	131°26.501'
53	Kat Island	19/07/02	52°23.342'	131°21.837'
54	Scudder Point	19/07/02	52°27.399'	131°14.429'
55	Goodwin Point	19/07/02	52°18.117'	131°04.158'
56	Koya Point	19/07/02	55°10.766'	131°00.433'
57	S'Gaang Gwaii	21/07/02	52°05.998'	131°12.391'
58	Benjamin Point	22/07/02	52°12.780'	130°59.502'
59	Juan Perez	22/07/02	52°32.345'	131°24.473'
60	Hotsprings	23/07/02	52°34.407'	131°27.010'
61	Darwin Sound	23/07/02	52°36.064'	131°38.445'
62	Tanu	24/07/02	52°45.263'	131°36.405'
63	Skedans	24/07/02	52°55.520'	131°35.569'
64	Skedans	30/07/02	52°57.110'	131°35.927'
65	Tanu	30/07/02	52°46.191'	131°36.920'
66	Dodge Point	30/07/02	52°44.149'	131°28.191'
67	Tar Islands	30/07/02	52°40.111'	131°26.464'
68	Juan Perez	31/07/02	52°33.003'	131°26.250'
69	Scudder Point	31/07/02	52°27.422'	131°14.307'
70	Benjamin Point	31/07/02	52°13.393'	130°59.696'
71	S'Gaang Gwaii	31/07/02	52°06.137'	131°12.815'
72	Darwin Sound	1/08/02	52°35.608'	131°37.856'
73	Tanu	1/08/02	52°46.900'	131°38.412'
74	Skedans	2/08/02	52°57.985'	131°35.917'
75	Cumshewa Inlet	2/08/02	53°02.440'	131°35.583'
76	Juan Perez	15/08/02	52°32.536'	131°25.217'
77	Swan Bay	15/08/02	52°20.037'	131°16.483'
78	Jedway Bay	15/08/02	52°17.721'	131°15.763'
79	Skincuttle Inlet	15/08/02	52°19.866'	131°12.014'
80	Koya Point	15/08/02	52°10.549'	131°00.826'
81	S'Gaang Gwaii	16/08/02	52°05.899'	131°12.537'
82	Gowgaia Bay	17/08/02	52°24.151'	131°35.870'
83	Puffin Cove	18/08/02	52°29.706'	131°43.923'
84	Sunday Inlet	19/08/02	52°38.889	131°53.258'
85	Portland Bay	19/08/02	52°47.642'	131°11.300'
86	Kitgoro Inlet	20/08/02	53°03.348	132°32.081'

2.2.2 Physical and Chemical Measurements

Continuous vertical profiles for temperature, salinity, density, and depth were performed using an internally recording InterOcean S4 CTD (conductivity, temperature, depth meter). The CTD was lowered at a rate of 1 m s^{-1} and measurements were recorded every 0.5 s. The depth of the mixed layer was measured using these profiles and was determined as the depth where the line on the density profile changed from vertical at the surface to having a slope. The depth of light penetration was measured using a Secchi disk. The light extinction coefficient can be estimated using the equation:

$$k_d = 1.45 / d \qquad (1)$$

where k_d is the extinction coefficient and d is the Secchi disk depth (Walker 1980). Light extinction in water is determined using the equation:

$$I_z/I_o = e^{-kz} \qquad (2)$$

where I_z/I_o is the ratio of the radiation at depth z to the incident radiation (I_o), k is the extinction coefficient, and z is the depth. To find the 1% light level, or the depth of the bottom of the euphotic zone, substitute 1% (0.01) for I_z/I_o and solve for z (Newton *et al.* 1998).

A one litre sample of surface water was also taken and filtered through a pre-weighed glass fiber filter to measure total suspended solids (TSS) in the water via gravimetric analysis.

The degree of stratification was calculated according to the following equation:

$$S = \Delta\, \rho_l - \rho_h / z \ \text{x}\ 100 \qquad (3)$$

where ρ_1 is the density at 1 m, ρ_h is the density at the depth below which the density difference was less than 0.125 units, or 25 m, which ever came first, and z is the depth over which the comparison was made (i.e., z = h).

Water samples were collected from four pre-determined depths: 0, 5, 10, and 20 m using a 5 L PVC Model 1010 Niskin bottle. Sampling was conducted to 20 m even though the photic zone was rarely that deep because at several stations there was a significant amount of chlorophyll *a* measured below the photic zone (see Appendix E), thus a more reliable estimate of integrated chlorophyll *a* was obtained. Sub-samples were taken for nutrient analysis using syringes and filtered through a 25 mm Whatman™ GF/F glass fiber filter, which was mounted in a Millipore Swinnex® filter holder. The filtrate was collected in an acid-cleaned 30 ml Nalgene® bottle and stored immediately in the freezer. These samples remained frozen until analysis in the laboratory. A Technicon® Autoanalyzer II was used for the samples collected in 2001 and a Bran and Luebbe® Autoanalyzer 3 was used for the samples collected in 2002. Dissolved nutrient concentrations for combined nitrate plus nitrite ($NO_3^- + NO_2^-$, reported as nitrate concentrations), phosphate (HPO_4^{2-}) and silicic acid ($Si(OH)_4$) were analyzed following the procedures of Wood *et al.* (1967), Hager *et al.* (1968), and Armstrong *et al.* (1967) respectively. The mean nutrient concentrations from surface to 20 m depth were integrated over the water column according to the methods of Ichimura *et al.* (1980). A sample calculation of the integration from the surface to 20 m depth is as follows:

[(concentration from surface + concentration from 5 m)/2 * (5-0)] +
[(concentration from 5 m + concentration from 10 m)/2 * (10-5)] +
[(concentration from 10 m + concentration from 20 m)/2 * (20-10)] (4)

2.2.3 Chlorophyll-*a* Measurements

A sub-sample was taken from each depth (surface, 5, 10, and 20 m) to determine chlorophyll *a* concentrations. Replicate volumes of 500 ml of water were filtered immediately through a 25 mm Whatman™ GF/F glass fiber filter (nominal porosity of 0.7 μm) as well as 25 mm polycarbonate filters (porosity 5 μm). These filters were immediately wrapped in aluminum foil and stored in a freezer until analysis in the laboratory. Chlorophyll *a* was extracted into 10 ml of 90% acetone by sonicating the filters in glass test tubes in an ice bath for 10 min and then extraction was continued in a freezer for 20-24 h. The chlorophyll *a* concentrations of each replicate sample were then determined via *in vitro* fluorometry using a Turner Designs™ (Model 10-AU) fluorometer (Parsons *et al.* 1984). Mean chlorophyll *a* concentrations from the surface to 20 m depth were integrated over the water column according to the methods of Ichimura *et al.* (1980) (see equation 4).

2.2.4 Phytoplankton Enumeration and Identification

Water samples were collected from four pre-determined depths: 0, 5, 10, and 20 m using a 5 L PVC Model 1010 Niskin bottle, and a 50 ml sub-sample was collected from each water bottle and placed into a 250 ml amber glass bottle to obtain an integrated sample from each station. The sample was fixed with non-acidified Lugol's iodine solution and stored in the dark until counting and identification in the laboratory, which was performed using a Zeiss IM inverted microscope following the procedures of Utermöhl (1958). The samples were settled for 24 h in 25 ml counting chambers and random fields of view were scanned until at least 300 cells were counted. Individual phytoplankton were identified using the descriptions in Cupp (1943), Wailes (1939), and Tomas (1996) and some assistance from Prof. F.J.R. Taylor (UBC).

Phytoplankton were identified to the species level when possible, but often identification was only at the genus level. The phytoplankton genus *Pseudonitzschia* was divided into three categories dependant on size and shape of the frustule. *Pseudonitzschia* "A" mostly resembles the species *P. pseudodelicatissima* and *P. delicatissima*. *Pseudonitzschia* "B" mostly resembles the species *P. pungens* and *P. multiseries*. *Pseudonitzschia* "C" mostly resembles *P. australis* and *P. fraudulenta*.

2.3 Results

2.3.1 Physical Characteristics

A) Total Suspended Solids and Secchi disk Measurements (2001 and 2002)

Measurements were taken for total suspended solids (TSS) and for the depth of light penetration with a Secchi disk during two years (2001 and 2002) and on the east and west coasts of Gwaii Haanas. The values are referred to as the east coast for the first (E 01) and second year (E 02), and the west coast for the first (W 01) and second year (W 02). There was no significant difference between years or between coasts for either of these parameters when a two-way analysis of variance test was performed on both the Secchi disk values ($p=0.138$ for the coasts, $p= 0.340$ for the years) and the TSS values ($p=0.649$ for the coasts, $p= 0.898$ for the years). Both the highest and the lowest TSS values were measured on the east coast of Gwaii Haanas in the 2002 sampling season and these were 0.0067 g L^{-1} at station 51 Hotsprings Island on July 19 and 0.0367 g L^{-1} at station 55 Goodwin Point, also on July 19. The deepest Secchi disk depth was measured on the east coast both in 2001 and in 2002 with a value of more than 17 m at stations 24 Dodge Point and 50 Tar Islands. These depths may have been deeper but the rope was not long enough to measure any further. The shallowest Secchi disk depth was 3.75 m at station 5 Tanu and was measured on the east coast in 2001. The actual data for these parameters are in Appendix B.

B) Sea Surface Temperature and Salinity

Due to a number of problems with the InterOcean S4 CTD, there are several stations with missing temperature and salinity data. A list of these stations and the dates when the malfunction occurred is found in Appendix B. The stations were divided into only three categories for these parameters, E 01, E 02, and W 02. For the W 01 category, there was only one station with a measurement at 7 S'Gaang Gwaii with a sea surface temperature of 11.40°C and a sea surface salinity of 31.85. No significant differences were found in either sea surface temperature ($p=0.582$ for the coasts, $p= 0.373$ for the years) or sea surface salinity ($p=0.388$ for the coasts, $p= 0.859$ for the years) amongst these three categories when a two-way analysis of variance was performed. Mean temperature values for the three categories were 12.99 ± 1.11°C for E 01, 12.47 ± 1.46°C for E 02, and 12.21 ± 0.91°C for W 02. Mean salinity values for the three categories were 31.64 ± 0.299 for E 01, 31.61 ± 0.232 for E 02, and 31.50 ± 0.562 for W 02. The sea surface temperature range was 9.89°C at station 44 Koya Point to 14.43°C at station 73 Tanu with both the highest and lowest temperatures recorded on the east coast in 2002. Sea surface salinity ranged from 30.39 at station 40 Sunday Inlet to 32.03 at station 42 Wells Cove, and lower levels were recorded on the west coast, while higher levels were recorded on the east coast. The actual data for these parameters can be found in Appendix B and vertical profiles of temperature, density and salinity can be found in Appendix C.

C) Mixed Layer Depth

Table 2.2 shows the depths of the mixed layer in the stations where salinity, temperature, and density were measured. Amongst the stations where the mixed layer depth was measured, there was very high variability, ranging from completely stratified at the surface to well-mixed. For the west coast of Gwaii Haanas in the 2001 sampling season, there was only one station measured, station 7 S'Gaang Gwaii, where the water was stratified at the surface with no mixed layer. Due to the high variability, for the other three categories the standard deviation was higher than the mean. The average mixed layer depth was 8.33 ± 12.5 for E 01, 5.92 ± 9.39 for E 02, and 2.50 ± 4.60 for W 02.

An alternate parameter, the degree of stratification was also measured (equation 3), as there were only a few stations with a mixed layer (Table 2.2). A value of zero indicates no stratification, and the higher the number, the more strongly stratified the water column. The highest stratification values were 7.1, 6.6, and 6.4 found at stations, 40 and 41 on July 9, 2001, and 84 on August 19, 2002, all on the west coast of Gwaii Haanas. The mean stratification values were 1.23 ± 1.46 for E 01, 1.04 ± 1.06 for E 02, and 2.50 ± 2.76 for W 02. There was only one stratification value measured at 7 S'Gaang Gwaii for W 01 and it was 2.7. Examples of mixed layer depth and stratification can be seen in Figure 2.2.

Table 2.2: Mixed layer depth and degree of stratification for stations where data are available. A mixed layer depth value of zero indicates no mixed layer due to stratification and a (+) indicates the mixed layer was deeper than the deepest depth measured. A stratification value of zero indicates that mixing has occurred and a value of 7 is highly stratified.

Station Number	Mixed Layer Depth (m)	Stratification Degree	Station Number	Mixed Layer Depth (m)	Stratification Degree
1	3	0	**50**	25+	0
4	17+	0	**64**	25+	0
5	0	1.5	**65**	7	0
6	0	2.7	**66**	0	1.1
7	0	2.7	**67**	10	0
11	0	3.2	**68**	0	1
12	30+	0	**69**	0	2.4
35	0	2	**70**	0	2.5
36	3	0	**71**	0	3.3
37	0	2.5	**72**	0	1.3
38	0	1.2	**73**	0	2.3
39	0	2.6	**74**	15	0
40	0	7.1	**76**	10	0
41	0	6.4	**77**	0	1.2
42	12	0	**78**	0	1
43	8	0	**79**	0	1.3
44	25+	0	**80**	0	3.7
45	0	1.3	**81**	10	0
46	25	0	**83**	0	0.7
47	0	1.3	**84**	0	6.6
48	0	1.2	**85**	0	2
49	3	0	**86**	0	0.1

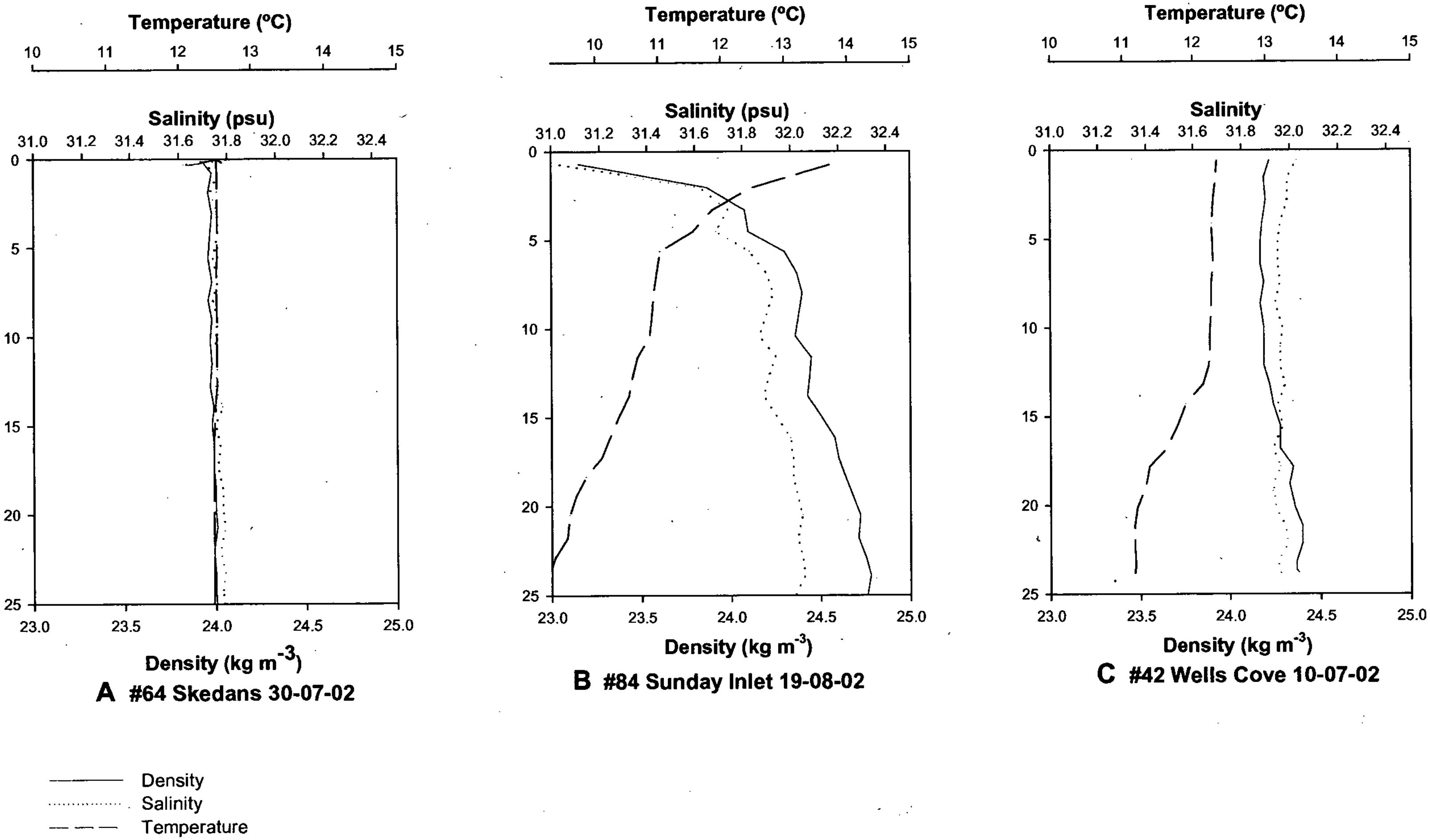

Figure 2.2: Sample profiles to illustrate mixed layer depth and stratification. A: completely mixed, B: highly stratified (degree of 6.6), C: mixed layer depth of 12 m. For station locations, see Fig. 2.1.

D) Trends and Patterns

There were no consistent trends or patterns found in the data for TSS or Secchi disk depth. Sea surface temperatures and salinities appeared to be higher on the east coast than the west coast, but these differences were not statistically significant. As for the mixed layer, a much higher proportion of the stations were stratified in 2002 as opposed to 2001, with the majority of these on the west coast of Gwaii Haanas (Table 2.4). Also, areas that were labeled as mixed had deeper mixed layers on the east coast than the west coast, while areas that were stratified had a higher degree of stratification on the west coast than the east coast. With the large error associated with the calculation of the degree of stratification and the mixed layer depth, these differences were not statistically significant.

2.3.2 Chemical Parameters

The nutrient concentrations are reported as both surface and integrated values. The integrated values are reported so that they can be compared to the integrated chlorophyll and phytoplankton concentrations. The raw nutrient data are in Appendix B and vertical profiles for these nutrients can be found in Appendix D. The values for nutrients were split into the same categories in space and time: E 01, E 02, W 01, and W 02. The average values of dissolved surface nutrient concentrations are summarized in Table 2.3 and the average values of integrated nutrient concentrations are summarized in Table 2.4. Very high variability was measured and frequently the standard deviation and the mean were similar. Therefore differences in values were not significant unless specifically stated.

Table 2.3: Mean surface nutrient concentrations (μM) for the east (E) and west (W) coast of Gwaii Haanas over two summers (2001 and 2002) and mean concentrations for the two years 2001 and 2002 and the east and west coasts. Values are shown with ±1 S.D. The number in the brackets is the number of samples in that category.

	NO_3^-	PO_4^{3-}	$Si(OH)_4$
2001	0.94 ± 1.82 (34)	0.35 ± 0.20 (34)	6.84 ± 3.57 (34)
2002	3.45 ± 3.27 (52)	0.48 ± 0.23 (52)	10.05 ± 5.37 (52)
EAST	2.16 ± 2.81 (66)	0.42 ± 0.22 (66)	7.86 ± 4.74 (66)
WEST	3.53 ± 3.57 (20)	0.47 ± 0.25 (20)	11.81 ± 4.59 (20)
E 01	0.92 ± 1.71 (28)	0.38 ± 0.19 (28)	6.30 ± 3.53 (28)
E 02	3.08 ± 3.12 (38)	0.46 ± 0.23 (38)	9.00 ± 5.22 (38)
W 01	1.07 ± 2.46 (6)	0.24 ± 0.21 (6)	9.32 ± 2.80 (6)
W 02	4.58 ± 3.53 (14)	0.56 ± 0.20 (14)	12.88 ± 4.80 (14)

Table 2.4: Mean integrated nutrient concentrations (mmol m^{-2}) for the east (E) and west (W) coast of Gwaii Haanas over two summers (2001 and 2002) and mean concentrations for the two years 2001 and 2002 and the east and west coasts. Values are shown with ±1 S.D. The number in the brackets is the number of samples in that category. Also shown are the stations with stratification (from table 2.2) and apparent nitrate limitation (where nitrate was drawn down to undetectable levels at the surface).

	NO_3^-	PO_4^{3-}	$Si(OH)_4$	Stratification	NO_3^- Limitation
2001	29.0 ± 40.3 (34)	9.14 ± 7.0 (34)	136.5 ± 71.1 (34)	4/7	23/34
2002	99.8 ± 62.0 (52)	11.6 ± 3.8 (52)	230.9 ± 96.9 (52)	24/37	10/52
EAST	62.6 ± 57.3 (66)	10.5 ± 5.88 (66)	175.1 ± 93.1 (66)	18/31	26/66
WEST	102.3 ± 77.8 (20)	11.1 ± 5.00 (20)	254.8 ± 93.9 (20)	10/13	7/20
E 01	30.4 ± 40.1 (28)	10.0 ± 7.4 (28)	133.1 ± 73.9 (28)	3/6	18/28
E 02	86.3 ± 56.9 (38)	10.9 ± 3.8 (38)	205.9 ± 94.5 (38)	15/25	8/38
W 01	22.4 ± 44.3 (6)	5.3 ± 2.8 (6)	152.4 ± 59.2 (6)	1/1	5/6
W 02	136.6 ± 62.3 (14)	13.5 ± 3.5 (14)	298.7 ± 67.9 (14)	9/12	2/14

A) Nitrate

On the east coast, the average surface nitrate concentration was 0.92 µM in 2001 (E 01) and 3.08 µM in 2002 (E 02). On the west coast, the average surface nitrate concentration was 1.07 µM in 2001 (W 01) and 4.58 µM in 2002 (W 02). Using a two-way ANOVA there was a significant difference found between the two years ($p= <0.001$) but not between the two coasts ($p=0.278$). Figure 2.3 shows the mean surface nitrate concentrations for each year and each category.

On the east coast, the average integrated nitrate concentration was 30.4 mmol m^{-2} in 2001 (E 01) and 86.3 mmol m^{-2} in 2002 (E 02). On the west coast, the average integrated nitrate concentration was 22.4 mmol m^{-2} in 2001 (W 01) and 136.6 mmol m^{-2} in 2002 (W 02). Using a two-way ANOVA there was a significant difference found between the two years ($p= <0.001$) but not between the two coasts ($p=0.142$).Figure 2.4 shows the mean integrated nitrate concentrations for each year and each category.

B) Phosphate

On the east coast, the average surface phosphate concentration was 0.37 µM in 2001 (E 01) and 0.46 µM in 2002 (E 02). On the west coast, the average surface phosphate concentration was 0.24 µM in 2001 (W 01) and 0.56 µM in 2002 (W 02). Using a two-way ANOVA there was a significant difference found between the two years ($p= 0.001$) but not between the two coasts ($p=0.861$). Figure 2.5 shows the mean surface phosphate concentrations for each year and each category.

On the east coast, the average integrated phosphate concentration was 10.0 mmol m^{-2} in 2001 (E 01) and 10.9 mmol m^{-2} in 2002 (E 02). On the west coast, the average integrated phosphate concentration was 5.3 mmol m^{-2} in 2001 (W 01) and 13.5 mmol m^{-2}

in 2002 (W 02). Using a two-way ANOVA there was a significant difference found between the two years (p= 0.002) but not between the two coasts (p=0.478). Figure 2.6 shows the mean integrated phosphate concentrations for each year and each category.

C) Silicic Acid

On the east coast the average surface silicic acid concentration was 6.30 µM in 2001 (E 01) and 9.00 µM in 2002 (E 02). On the west coast the average surface silicic acid concentration was 9.32 µM in 2001 (W 01) and 12.88 µM in 2002 (W 02). Using a two-way ANOVA there was a significant difference found between both the two years (p= 0.007) and the two coasts (p=0.014). Figure 2.7 shows the mean surface silicic acid concentrations for each year and each category.

On the east coast, the average integrated silicic acid concentration was 133.1 mmol m^{-2} in 2001 (E 01) and 205.9 mmol m^{-2} in 2002 (E 02). On the west coast the average integrated silicic acid concentration was 152.4 mmol m^{-2} in 2001 (W 01) and 298.7 mmol m^{-2} in 2002 (W 02). Using a two-way ANOVA there was a significant difference found between the two years (p= <0.001) but not between the two coasts (p=0.144). Figure 2.8 shows the mean integrated silicic acid concentrations for each year and each category.

D) Nutrient Ratios

All integrated nitrate/phosphate ratios were less than the Redfield ratio (Redfield, 1958) of 16:1. On the east coast, the average integrated nitrate/phosphate ratio was 2.37 in 2001 (E 01) and 7.09 in 2002 (E 02). On the west coast, the average integrated nitrate/phosphate ratio was 2.57 in 2001 (W 01) and 9.62 in 2002 (W 02). Using a two-

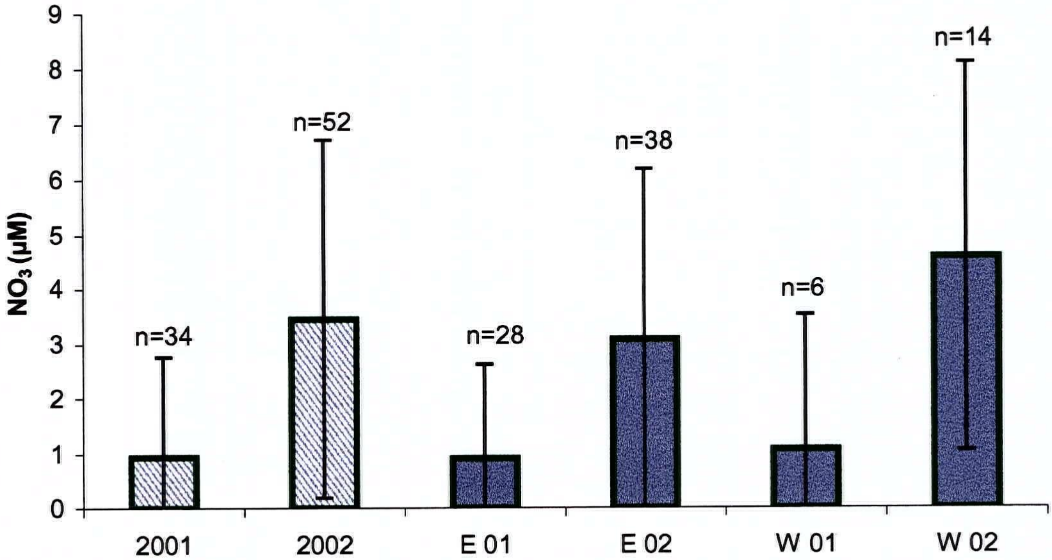

Figure 2.3: Mean surface nitrate concentrations ±1 S.D. for the east (E) and west (W) coast of Gwaii Haanas over two summers (2001 and 2002), shown as darker bars. The lighter bars show the mean concentration for the two years 2001 and 2002. Numbers above each bar are the total number of stations used to calculate each mean.

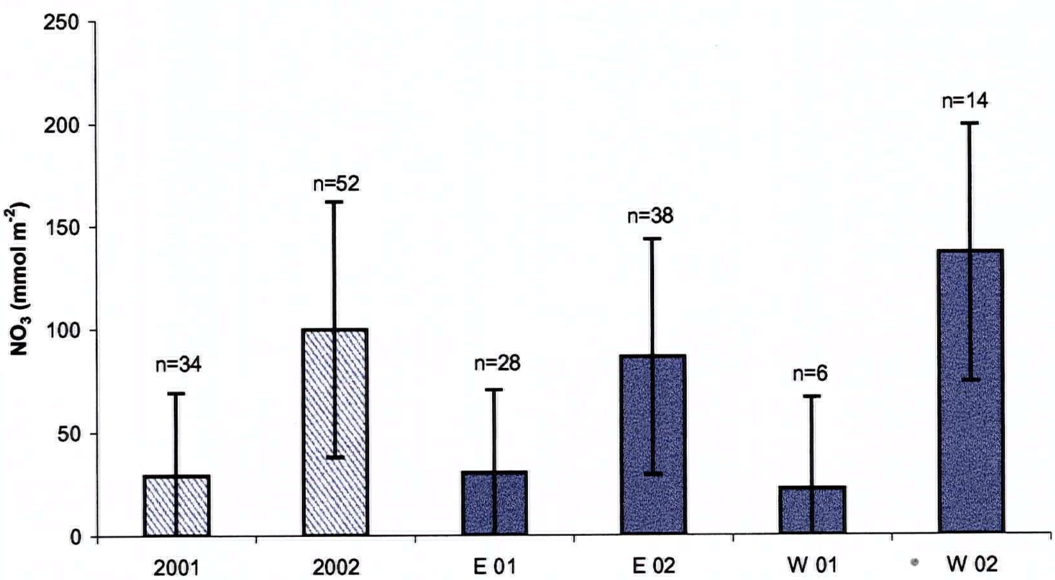

Figure 2.4: Mean integrated nitrate concentrations ±1 S.D. for the east (E) and west (W) coast of Gwaii Haanas over two summers (2001 and 2002), shown as darker bars. The lighter bars show the mean concentration for the two years 2001 and 2002. Numbers above each bar are the total number of stations used to calculate each mean.

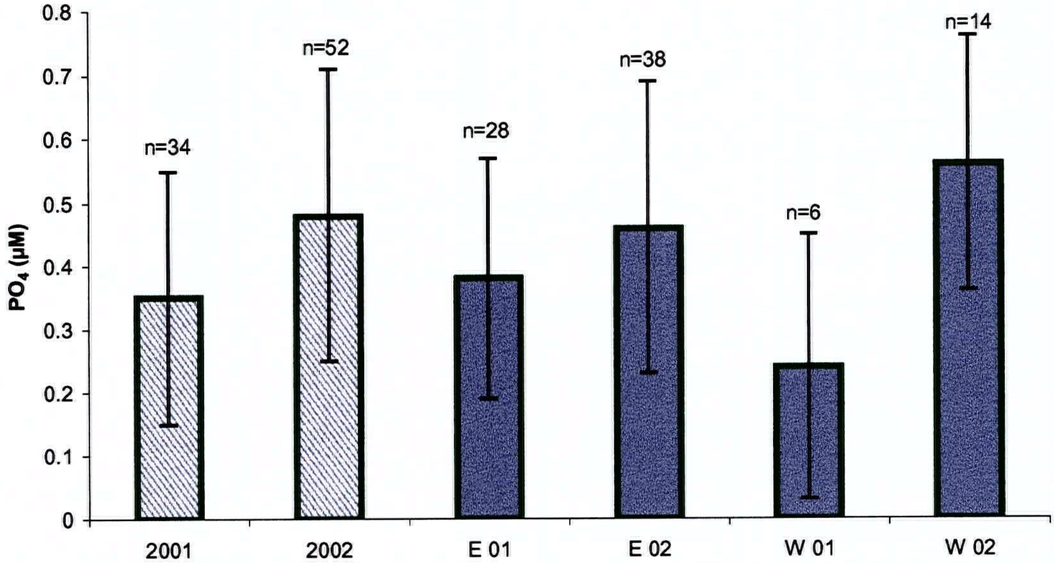

Figure 2.5: Mean surface phosphate concentrations ±1 S.D. for the east (E) and west (W) coast of Gwaii Haanas over two summers (2001 and 2002), shown as darker bars. The lighter bars show the mean concentration for the two years 2001 and 2002. Numbers above each bar are the total number of stations used to calculate each mean.

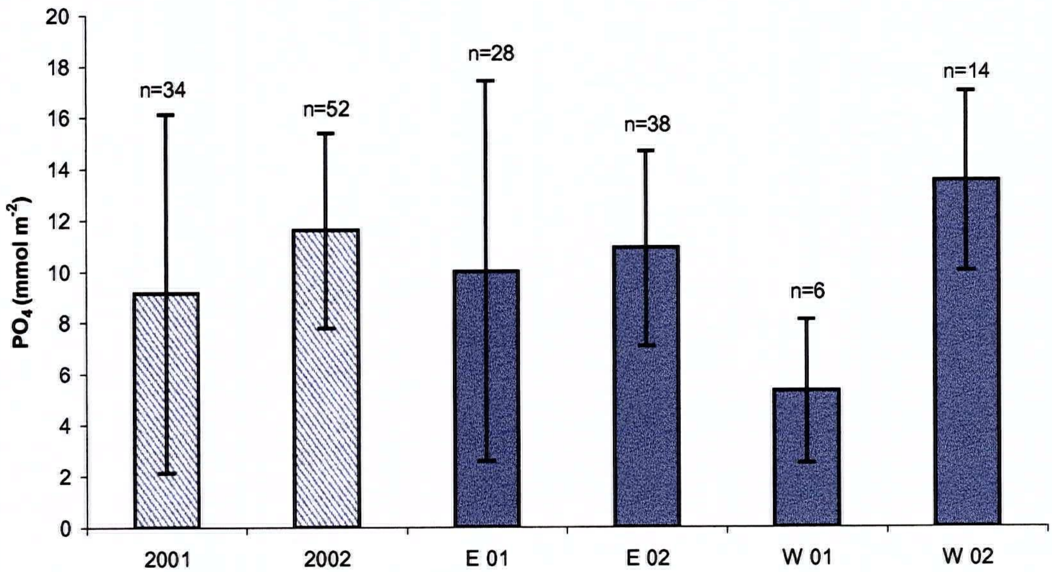

Figure 2.6: Mean integrated phosphate concentrations ±1 S.D. for the east (E) and west (W) coast of Gwaii Haanas over two summers (2001 and 2002), shown as darker bars. The lighter bars show the mean concentration for the two years 2001 and 2002. Numbers above each bar are the total number of stations used to calculate each mean.

way ANOVA there was a significant difference found between the two years (p= <0.001) but not between the two coasts (p=0.079)

All integrated nitrate/silicic acid ratios were much smaller than the ratio required for the average diatom cell composition of 1:1. On the east coast the average integrated nitrate/silicic acid ratio was 0.163 in 2001 (E 01) and 0.380 in 2002 (E 02). On the west coast the average integrated nitrate/silicic acid ratio was 0.110 in 2001 (W 01) and 0.439 in 2002 (W 02). Using a two-way ANOVA there was a significant difference found between the two years (p= <0.001) but not between the two coasts (p=0.942).

When surface nitrate/silicic acid ratios were compared, the means were also much smaller than the ratio required for the average diatom cell composition of 1:1. On the east coast the average surface nitrate/silicic acid ratio was 0.087 in 2001 (E 01) and 0.255 in 2002 (E 02). On the west coast the average surface nitrate/silicic acid ratio was 0.086 in 2001 (W 01) and 0.312 in 2002 (W 02). Using a two-way ANOVA there was a significant difference found between the two years (p= <0.001) but not between the two coasts (p=0.563).

E) Trends and Patterns

Due to the very high variability between seasons and coasts many of these trends were not be significant. On average, values for all three nutrients appeared to be higher in 2002 rather than in 2001. These differences were shown to be statistically significant when compared with a two-way ANOVA. In 2001, the east coast values appeared to be higher than the west coast on average, while the west coast values were higher than the east coast in 2002. The most obvious trend in the nutrient profiles was the occurrence of apparent nitrate limitation at the surface, where the nitrate concentration was drawn

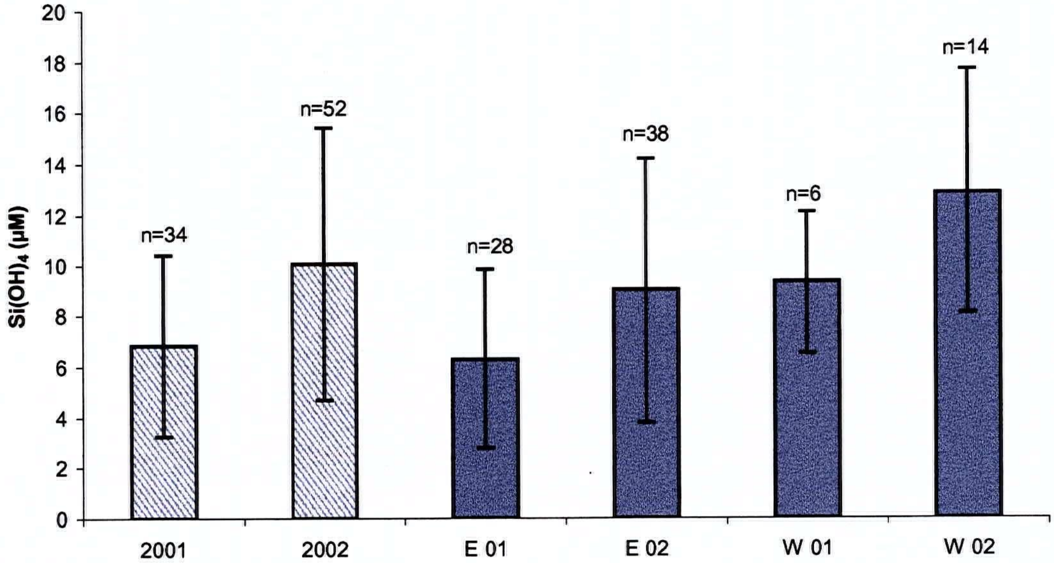

Figure 2.7: Mean surface silicic acid concentrations ±1 S.D. for the east (E) and west (W) coast of Gwaii Haanas over two summers (2001 and 2002), shown as darker bars. The lighter bars show the mean concentration for the two years 2001 and 2002. Numbers above each bar are the total number of stations used to calculate each mean.

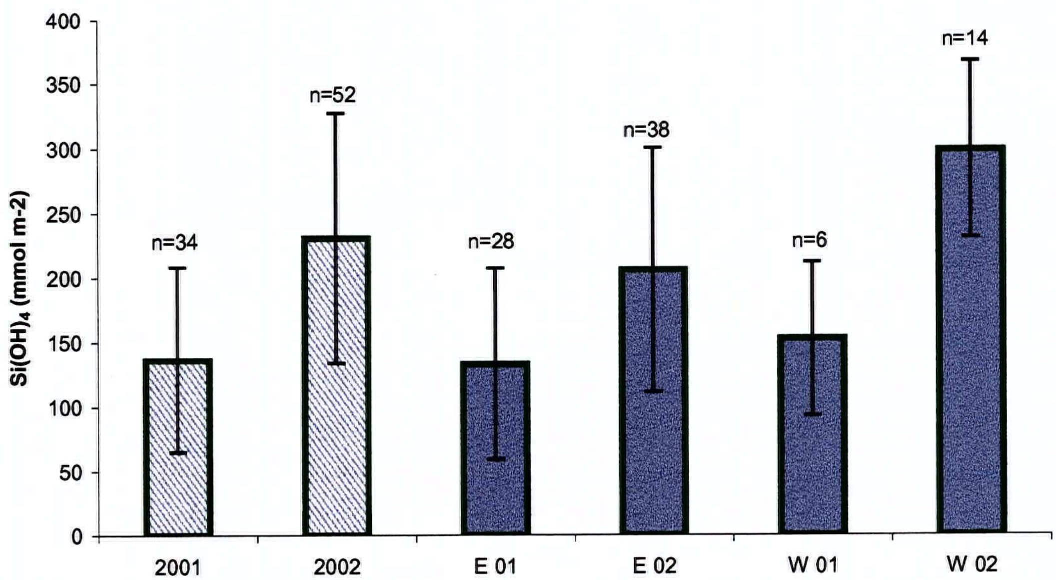

Figure 2.8: Mean integrated silicic acid concentrations ±1 S.D. for the east (E) and west (W) coast of Gwaii Haanas over two summers (2001 and 2002), shown as darker bars. The lighter bars show the mean concentration for the two years 2001 and 2002. Numbers above each bar are the total number of stations used to calculate each mean.

down to undetectable levels. This occurred in 33 of the 86 stations sampled and likely accounts for the low N:P and N:Si ratios measured as well as the high variation in the mean nitrate concentrations. Apparent nitrate limitation (where surface nitrate values were drawn down to undetectable) occurred more often in 2001 than 2002 as seen in Table 2.4. One occurrence of apparent phosphate limitation was noted at station 34 Sunday Inlet where the phosphate concentration was drawn down to undetectable concentrations at the surface, on the west coast of Gwaii Haanas. Silicic acid concentrations were very high at all the stations and it was not found to be a limiting nutrient at any of the stations.

2.3.3 Biological Parameters

The original data for chlorophyll *a* concentrations are in Appendix B and vertical profiles are in Appendix E. The chlorophyll *a* concentrations were split into the same categories in space and time: E 01, E 02, W 01, and W 02. The average surface chlorophyll *a* concentrations are summarized in Table 2.5 and the average integrated chlorophyll *a* concentrations are summarized in Table 2.6. Very high variability was measured and frequently the standard deviation and the mean were similar. Therefore values were not significant unless specifically stated.

A) Total Chlorophyll a

On the east coast, the average surface total chlorophyll *a* concentration was 4.12 mg m^{-3} in 2001 (E 01) and 4.20 mg m^{-3} in 2002 (E 02). On the west coast, the average surface total chlorophyll *a* concentration was 5.38 mg m^{-3} in 2001 (W 01) and 3.35

mg m^{-3} in 2002 (W 02). These values were not found to be significantly different using a two-way analysis of variance test (p=0.778 for coasts and p= 0.187 for years). The average surface total chlorophyll *a* concentration for 2001 was 4.34 mg m^{-3} and for 2002 it was 3.97 mg m^{-3}. Figure 2.9 shows the mean surface chlorophyll *a* concentrations for each year and each category.

On the east coast, the average integrated total chlorophyll *a* concentration was 64.2 mg m^{-2} in 2001 (E 01) and 94.2 mg m^{-2} in 2002 (E 02). On the west coast, the average integrated total chlorophyll *a* concentration was 57.5 mg m^{-2} in 2001 (W 01) and 72.5 mg m^{-2} in 2002 (W 02). Using a two-way ANOVA significant differences were found between years (p=0.023) but not between coasts (p=0.147). Figure 2.10 shows the mean integrated chlorophyll *a* concentrations for each year and each category.

B) Large Size Fraction of Chlorophyll a (> 5 μm)

On the east coast, the average surface large size fraction of chlorophyll *a* was 1.15 mg m^{-3} in 2001 (E 01) and 1.21 mg m^{-3} in 2002 (E 02), and on the west coast, the values were 0.845 mg m^{-3} in 2001 (W 01) and 0.649 mg m^{-3} in 2002 (W 02). The average surface large size fraction chlorophyll *a* concentration was 1.09 mg m^{-3} for 2001 and 1.06 mg m^{-3} for 2002. Using a two –way ANOVA these means were not found to be significantly different (p= 0.090 for coasts, p= 0.793 for years).

On the east coast, the average integrated large size fraction of chlorophyll *a* was 22.6 mg m^{-2} in 2001 (E 01) and 33.7 mg m^{-2} in 2002 (E 02), and on the west coast, the values were 9.76 mg m^{-2} in 2001 (W 01) and 14.3 mg m^{-2} in 2002 (W 02). Using a two-

Table 2.5: Mean surface chlorophyll concentrations ($mg\ m^{-3}$) for the east (E) and west (W) coast of Gwaii Haanas over two summers (2001 and 2002) and mean concentrations for the two years 2001 and 2002 and the east and west coasts. Values are shown with ±1 S.D. The number in the brackets is the number of samples in that category.

	Total	>5 µm
2001	4.34 ± 3.60 (34)	1.09 ± 1.14 (34)
2002	3.97 ± 1.87 (52)	1.06 ± 0.76 (52)
EAST	4.16 ± 2.74 (66)	1.18 ± 0.98 (66)
WEST	3.96 ± 2.50 (20)	0.71 ± 0.60 (20)
E 01	4.12 ± 3.57 (28)	1.15 ± 1.21 (28)
E 02	4.20 ± 1.97 (38)	1.21 ± 0.78 (38)
W 01	5.38 ± 3.89 (6)	0.85 ± 0.73 (6)
W 02	3.35 ± 1.41 (14)	0.65 ± 0.56 (14)

Table 2.6: Mean total integrated chlorophyll concentrations (mg m^{-2}) for the east (E) and west (W) coast of Gwaii Haanas over two summers (2001 and 2002) and mean concentrations for the two years 2001 and 2002 and the east and west coasts. Values are shown with ±1 S.D. The number in the brackets is the number of samples in that category. Also shown are the percentage values of the total concentration for the two size fractions (< 5 µm and > 5 µm).

	Total	<5 µm (% of total)	>5 µm (% of total)
2001	63.0 ± 35.2 (34)	67.7	32.3
2002	88.3 ± 36.0 (52)	68.1	31.9
EAST	81.7 ± 40.5 (66)	64.7	35.3
WEST	68.0 ± 24.2 (20)	80.8	19.2
E 01	64.2 ± 37.1 (28)	64.8	35.2
E 02	94.2 ± 38.5 (38)	64.2	35.8
W 01	57.5 ± 27.5 (6)	83.0	17.0
W 02	72.5 ± 22.2 (14)	80.3	19.7

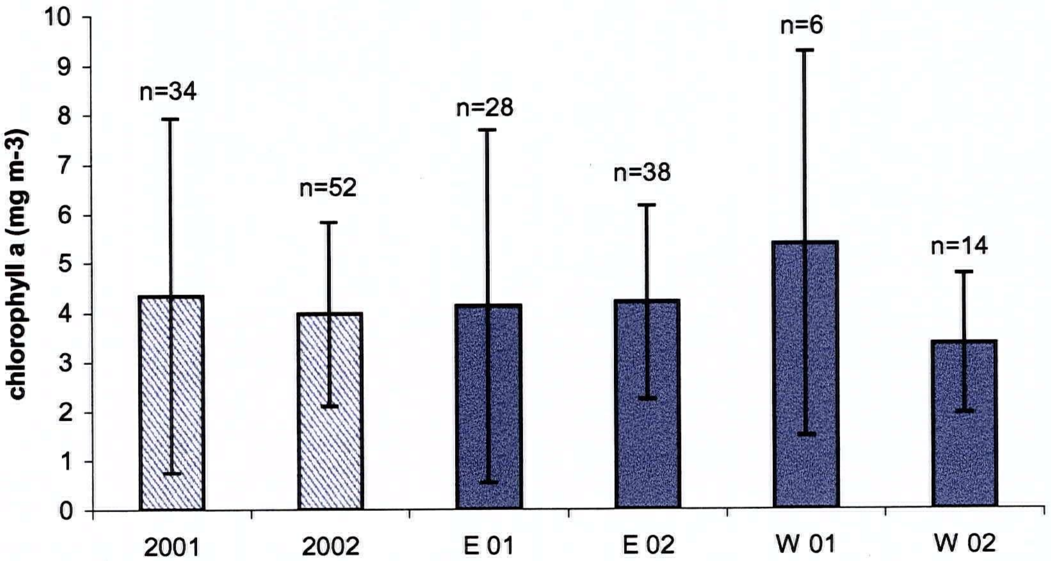

Figure 2.9: Mean surface chlorophyll *a* concentrations ±1 S.D. for the east (E) and west (W) coast of Gwaii Haanas over two summers (2001 and 2002), shown as darker bars. The lighter bars show the mean concentration for the two years 2001 and 2002. Numbers above each bar are the total number of stations used to calculate each mean.

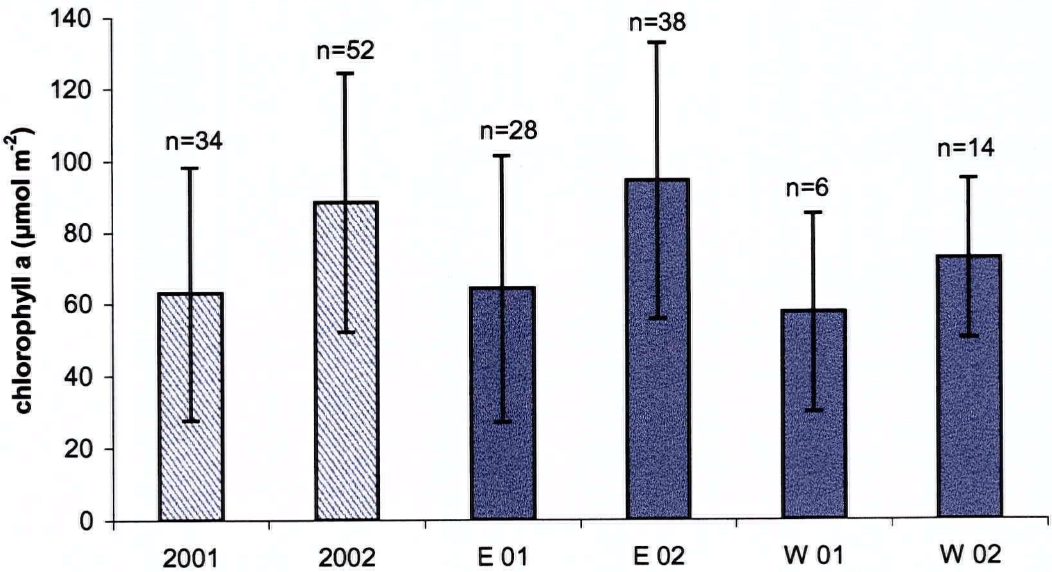

Figure 2.10: Mean integrated chlorophyll *a* concentrations ±1 S.D. for the east (E) and west (W) coast of Gwaii Haanas over two summers (2001 and 2002), shown as darker bars. The lighter bars show the mean concentration for the two years 2001 and 2002. Numbers above each bar are the total number of stations used to calculate each mean.

way ANOVA there was a significant difference found between coasts ($p=0.002$) but not between years ($p=0.127$).

C) Species Composition and Diversity

Species identification was performed to the species level whenever possible, however some were identified only to the genus level (e.g. *Chaetoceros* spp., *Thalassiosira* spp.), while others were identified to higher taxonomic groups. Some examples of these are the *Pseudonitzschia* categories A, B, and C, and the unidentified centric and pennate diatom groups. Another limitation in this phytoplankton diversity analysis is that only the large phytoplankton groups were considered and that groups of smaller phytoplankton such as picoplankton and other flagellates were not identified and counted, and it appears that there may have been high concentrations of these groups, especially on the west coast. Also, station 83, Puffin Cove, is missing as this sample was destroyed in the shipping of the samples. In total, 60 groups or species were identified from these samples along the coasts of Gwaii Haanas. Tables 2.7 and 2.8 list these groups and species and show where they occurred in the four categories of space and time. The original data with cell concentrations for these groups can be found in Appendix F.

Phytoplankton abundance data were analyzed for species diversity using the following indices:

The Shannon-Wiener Index (H') = $-\Sigma p_i (\log_{10} p_i)$ (MacArthur 1965)

The Simpson Dominance Index (SI) = Σp_i^2 (Simpson 1949)

Pielou's Evenness Index (J) = H'/Ln S (Pielou 1966)

where: p_i = proportional abundance of the *i*-th species

S = number of species

When a two-way analysis of variance was performed on these data, there were no statistically significant differences found amongst the four categories for any of the three indices both between coasts and between years. Table 2.9 shows the mean values from this analysis.

D) Trends and Patterns

Both the surface total and surface large size fraction chlorophyll *a* concentrations were not shown to be statistically significant either between the two sampling seasons (2001, 2002), coasts (east, west), or amongst any of the four categories (E01, W01, E02, W02). Mean total integrated chlorophyll *a* was significantly higher in 2002 than in 2001. Also, east coast values appeared to be higher than west coast values in all of the categories, but this was only found to be significant for the large size fraction. In both years the east coast had a higher percentage of the larger size fraction category (35.2 and 35.8%) than the west coast (17.0 and 19.7%) (Figure 2.11). The most common diatom species or groups found in these communities were *Leptocylindrus danicus, Chaetoceros* spp., *Thalassiosira* spp., *Skeletonema costatum* and *Pseudonitzschia* "A". No clear patterns were seen amongst the diversity, dominance and evenness indexes between any of the four categories of the years 2001 and 2002.

Several stations had an obvious dominant (>50%) species or group. Stations 2 (E 01), 5 (E 01), 6 (E 01) and 7 (W 01) were dominated by *Pseudonitzschia* "A". Stations 9 (E 01), 10 (E 01), 64 (E 02), 74 (E 02), and 75 (E 02) were dominated by *Rhizosolenia setigera.* Stations 53 (E 02), 47 (E 02), 69 (E 02), 70 (E 02), 72 (E 02), and 76 (E 02) were dominated by *Skeletonema costatum*. Stations 43 (W 02), 44 (E 02), 45 (E 02), 57

Table 2.7: Diatom species and mean concentration (cells L^{-1}) for the east (E) and west (W) coast of Gwaii Haanas over two summers (2001 and 2002). An integrated sample was obtained by mixing an equal amount of sample from 0, 5, 10, and 20 m. Values are shown with ±1 S.D. and n = 28 for E 01, 38 for E 02, 6 for W 01, and 14 for W 02. A value of zero indicates the species was not observed.

Species or Group Name	E 01	E 02	W 01	W 02
Asterionella glacialis	0	149 ± 665	244 ± 597	52 ± 189
Asteromphalus heptactis	246 ± 430	41 ± 219	115 ± 181	14 ± 50
Bacteriastrum delicatulum	0	115 ± 669	0	0
Ceratulina pelagica	631 ± 2490	775 ± 3100	0	105 ± 377
Chaetoceros spp.	1210 ± 2370	35800 ± 57800	1220 ± 2980	103000 ± 188000
Coscinodiscus centralis	204 ± 709	2750 ± 4860	0	291 ± 607
Coscinodiscus lineatus	138 ± 648	0	35 ± 86	0
Coscinodiscus perforatus	53 ± 179	23 ± 100	0	0
Coscinodiscus radiatus	69 ± 324	39 ± 218	0	0
Cylindrotheca closterium	611 ± 988	2720 ± 6780	446 ± 695	2250 ± 1690
Dactyliosolen fragilissimus	383 ± 1440	815 ± 4380	93 ± 144	132 ± 334
Ditylum brightwellii	359 ± 881	37 ± 191	0	0
Eucampia zodiacus	1280 ± 3930	68 ± 378	975 ± 2390	2830 ± 8200
Fragilaria spp.	33 ± 157	120 ± 597	0	646 ± 851
Gyrosigma/Pleurosigma spp.	444 ± 1850	32.5 ± 189	0	0
Leptocylindrus danicus	5210 ± 6700	10200 ± 13400	2010 ± 2860	3160 ± 4550
Leptocylindrus mediterraneus	203 ± 731	0	0	0
Leptocylindrus minimus	247 ± 964	1540 ± 7940	154 ± 261	10 ± 35
Licomorpha abbreviata	134 ± 360	139 ± 307	185 ± 207	255 ± 388
Melosira spp.	83 ± 285	205 ± 869	252 ± 618	391 ± 1410
Navicula spp.	263 ± 490	1420 ± 2990	114 ± 184	883 ±2140
Nitzschia longissima	0	654 ± 3760	35 ± 86	43 ± 131
Odontella longicruris	84 ± 394	0	0	178 ± 436
Pseudonitzschia "A"	265000 ± 702000	21100 ± 41700	37800 ± 92500	22600 ± 20610
Pseudonitzschia "B"	43000 ± 95400	27600 ± 72000	8730 ± 19400	12000 ± 17700
Pseudonitzschia "C"	15300 ± 54700	13800 ± 27400	7070 ± 17300	20900 ± 66800
Rhizosolenia robusta	0	91 ± 528	140 ± 344	449 ± 699
Rhizosolenia styliformis	0	0	0	14 ± 50
Rhizosolenia setigera	32800 ± 45700	56800 ± 175000	987 ± 1730	1110 ± 2290
Rhizosolenia imbricata	345 ± 743	656 ± 1710	1040 ± 1940	327 ± 729
Skeletonema costatum	8830 ± 27300	130000 ± 291000	12700 ± 31000	13300 ± 20500
Thalassionema nitzschioides	1410 ± 2180	1950 ± 4590	1050 ± 989	2610 ± 3130
Thalassiosira spp.	4410 ± 6350	19500 ± 31600	2400 ± 2860	10000 ±10500
Centrics <10 µm	585 ± 383	3940 ± 7390	1770 ± 2310	6060 ± 8000
Pennates <25 µm	1680 ± 3580	1800 ± 2600	2500 ± 2600	1810 ± 2280

Table 2.8: Coccolithophore, silicoflagellate, and dinoflagellate species and mean concentration (cells L^{-1}) for the east (E) and west (W) coast of Gwaii Haanas over two summers (2001 and 2002). An integrated sample was obtained by mixing an equal amount of sample from 0, 5, 10, and 20 m. Values are shown with ±1 S.D. and n= 28 for E 01, 38 for E 02, 6 for W 01, and 14 for W 02. A value of zero indicates the species was not observed.

Species or Group Name	E 01	E 02	W 01	W 02
Coccolithophores	371 ± 753	28800 ± 64700	1170 ± 1390	7150 ± 9530
Dictyocha speculum	277 ± 808	1390 ± 1770	384 ± 626	1420 ± 1770
Ebria tripartita	37 ± 120	309 ± 778	278 ± 431	136 ± 376
Alexandrium spp.	3280 ± 6050	1650 ± 5570	333 ± 451	1840 ± 5370
Amphidinium sphenoides	257 ± 532	72.2 ± 336	105 ± 258	0
Ceratium fusus	2530 ± 10200	459 ± 2670	0	0
Ceratium lineatum	1390 ± 2590	748 ± 2220	483 ± 483	0
Ceratium longipipes	86 ± 218	6 ± 37	0	0
Dinophysis acuminata	4870 ± 5080	511 ± 723	272 ± 490	45 ± 111
Dinophysis acuta	4600 ± 7080	325 ± 1020	0	0
Dinophysis fortii	120 ± 562	0	0	0
Dinophysis norwegica	886 ± 1140	537 ± 1320	1010 ± 2480	323 ± 1140
Dinophysis parva	426 ± 716	19 ± 80	0	0
Glenodinium danicum	2730 ± 3310	994 ± 1940	2240 ± 1550	1640 ± 1860
Gonyaulax spp.	3880 ± 3190	2140 ± 6720	6060 ± 11700	539 ± 693
Gymnodinium spp.	7660 ± 6420	7510 ± 15100	18400 ± 21600	6160 ± 5390
Gyrodinium spp.	2690 ±3310	1980 ± 3170	3250 ± 2890	1660 ± 2180
Heterocapsa triquetra	4580 ± 5030	3480 ± 17400	3040 ± 2700	564 ± 1180
Oxyphysis oxytoxoides	73 ± 190	24 ± 141	0	0
Peridinium spp.	1660 ± 2050	382 ± 641	559 ± 622	354 ± 650
Phalachroma rotundatum	11 ± 52	0	0	3 ± 22
Prorocentrum compressum	0	0	11800 ± 22900	0
Prorocentrum micans	1840 ± 3410	444 ± 1670	790 ± 1410	127 ± 457
Protoperidinium spp.	2820 ± 2900	2240 ± 3410	1770 ± 2800	386 ± 682
Scrippsiella trochoidea	2630 ± 3570	3480 ± 9370	1370 ± 1270	583 ± 1050

Table 2.9: Mean values of the phytoplankton diversity indices for integrated samples for the east (E) and west (W) coast of Gwaii Haanas over two summers (2001 and 2002). Values are shown with ±1 S.D.. The number in the brackets is the number of samples in that category.

	Diversity (H')	**Dominance (SI)**	**Evenness (J')**
2001	0.702 ± 0.197 (34)	0.929 ± 0.310 (34)	0.243 ± 0.208 (34)
2002	0.641 ± 0.189 (52)	0.824 ± 0.301 (52)	0.296 ± 0.212 (52)
EAST	0.862 ± 0.223 (66)	0.282 ± 0.222 (66)	0.662 ± 0.205 (66)
WEST	0.861 ± 0.255 (20)	0.264 ± 0.173 (20)	0.669 ± 0.153 (20)
E 01	0.955 ± 0.076 (28)	0.232 ± 0.218 (28)	0.718 ± 0.209 (28)
E 02	0.808 ± 0.314 (38)	0.311 ± 0.222 (38)	0.629 ± 0.198 (38)
W 01	0.834 ± 0.258 (6)	0.285 ± 0.173 (6)	0.644 ± 0.151 (6)
W 02	0.874 ± 0.263 (14)	0.254 ± 0.179 (14)	0.680 ± 0.159 (14)

W 02), and 71 (W 02) were dominated by *Chaetoceros* spp. Stations 51 (E 02) and 52 (E 02) were dominated by coccolithophores. Station 32 (W 01) was dominated by *Gymnodinium* spp. Station 33 (W 01) was dominated by *Prorocentrum compressum.* Station 36 (E 02) was dominated by *Thalassiosira* spp. and station 41 (W 02) was dominated by *Pseudonitzschia* spp. Figure 2.12 shows the proportion of each group of phytoplankton (diatoms, dinoflagellates, silicoflagellates, coccolithophores) in each of the four categories.

2.3.4 Water Properties at One Station

Station 38 Skidegate Channel was chosen as a sample station in order to explain the observations at an individual station. This station was sampled on 08-July-02 at 2:45 PM and it fits into the W 02 category. The weather was overcast and the winds were fairly light, blowing 7 kn in the direction of 60°NW. The Secchi disk was 4 m, yielding a light extinction coefficient of 0.363 (equation 1) and the depth of the 1% light level was 12.7 m (equation 2). The concentration of TSS was 0.0332 g L^{-1}. The sea surface temperature was 12.54°C, and the sea surface salinity was 30.60.

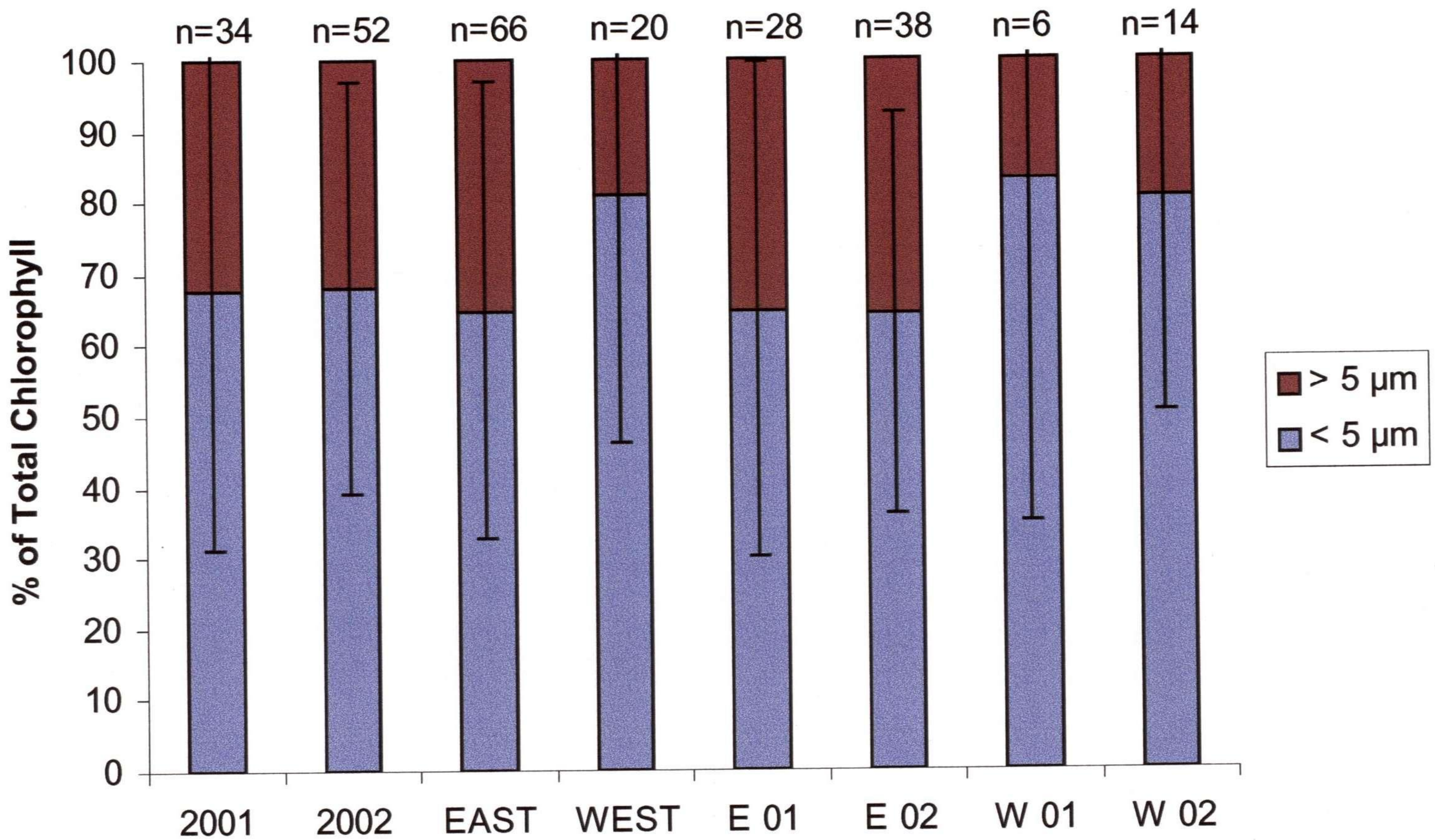

Figure 2.11: Relative contributions of the < 5 µm size fraction and the > 5 µm size fraction to total chlorophyll for the east (E) and west (W) coast of Gwaii Haanas over two summers (2001 and 2002). Also shown are the relative contributions for the two years (2001 and 2002) and for the east and west coasts. Numbers above each bar are the total number of stations used to calculate each mean.

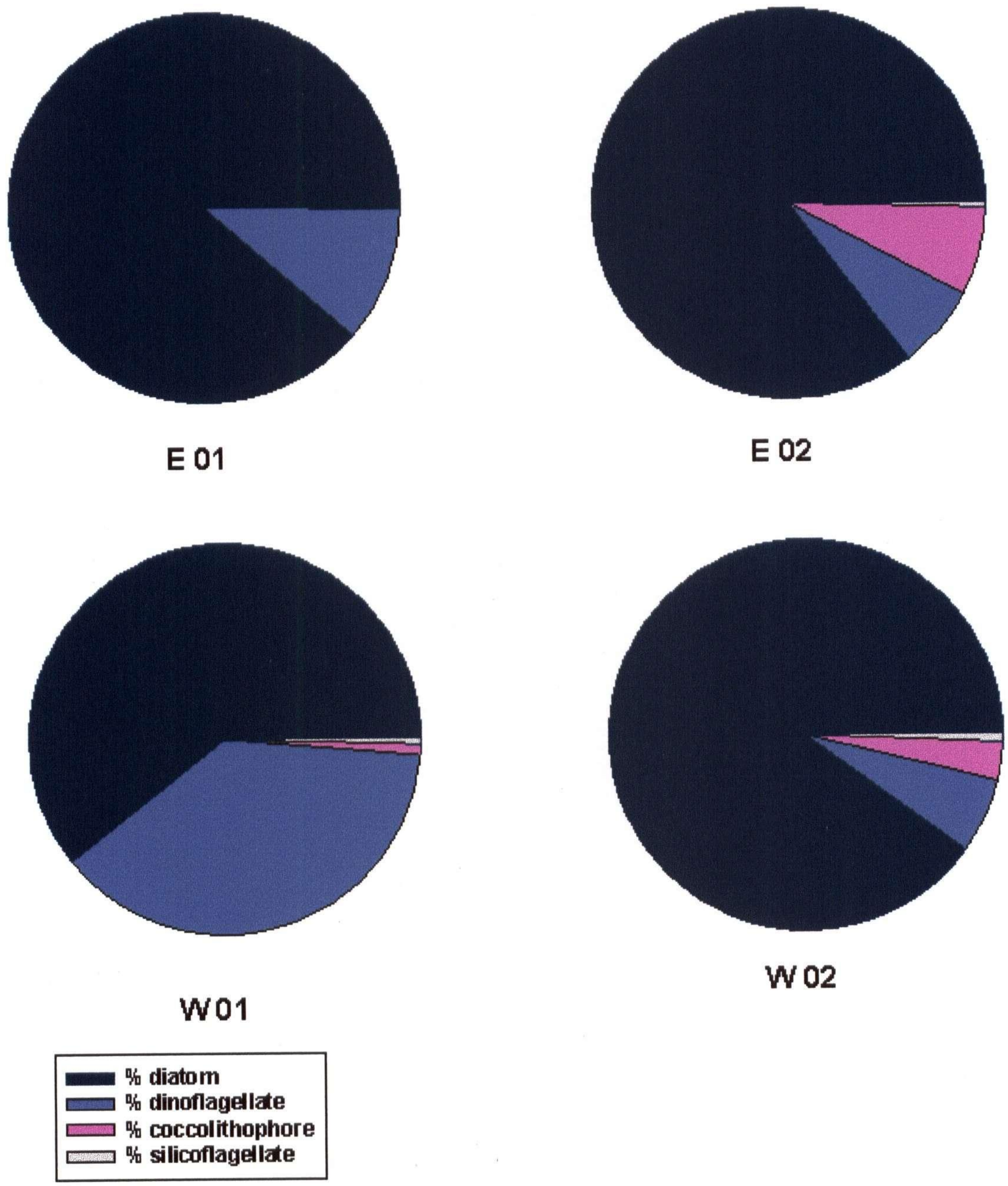

Figure 2.12: Percent contribution of each phytoplankton group to total cell abundance for the east (E) and west (W) coast of Gwaii Haanas over two summers (2001 and 2002)., n = 28 for E 01, 38 for E 02, 6 for W 01, and 14 for W 02.

This station was weakly stratified with a stratification degree of 1.2 (Table 2.1). The original data for the nutrient and chlorophyll *a* concentrations at each depth are shown in Table 2.10, while the vertical profiles are shown in Figure 2.13. At the surface the nutrient concentrations were low, but they were not drawn down to undetectable levels, while the chlorophyll *a* concentrations are high (6.03 mg m^{-3}). These cells were probably not photo-inhibited at the surface as the sky was overcast. At a depth of 5 m the nutrient concentration increased slightly. The maximum chlorophyll *a* concentration (6.22 mg m^{-3}) occurred at 5 m, but it was only slightly higher than the surface concentration.

At a depth of 10 m, the nutrient concentrations began to increase and this continued to 20 m where there was a substantial increase and high nutrient concentrations at depth. The deep mixing began at about 22 m (Fig. 2.13 C). The chlorophyll *a* concentration decreased at 10 m (4.99 mg m^{-3}) and these phytoplankton were probably becoming light-limited , as the 1% light depth and the bottom of the euphotic zone occurred at 12.7 m. By 20 m the chlorophyll *a* concentration has dropped to 1.64 mg m^{-3}. The most abundant phytoplankton species or groups found at this station were *Chaetoceros* spp. (21,600 cells L^{-1}), coccolithophores (15,300 cells L^{-1}), and *Skeletonema costatum* (12,300 cells L^{-1}).

Table 2.10: Nutrient (μM) and chlorophyll concentrations (mg m^{-3}) at each depth for station 38, Skedans on the east coast of Gwaii Haanas (see Fig. 2.1).

Depth (m)	HPO_4	NO_3	$Si(OH)_4$	Chl a (>0.7μm)	Chl a (>5 μm)
0	0.24	0.21	10.9	6.03	0.33
5	0.41	2.06	11.6	6.22	0.67
10	0.42	2.95	11.8	4.99	0.58
20	0.78	6.53	17.3	1.64	0.09

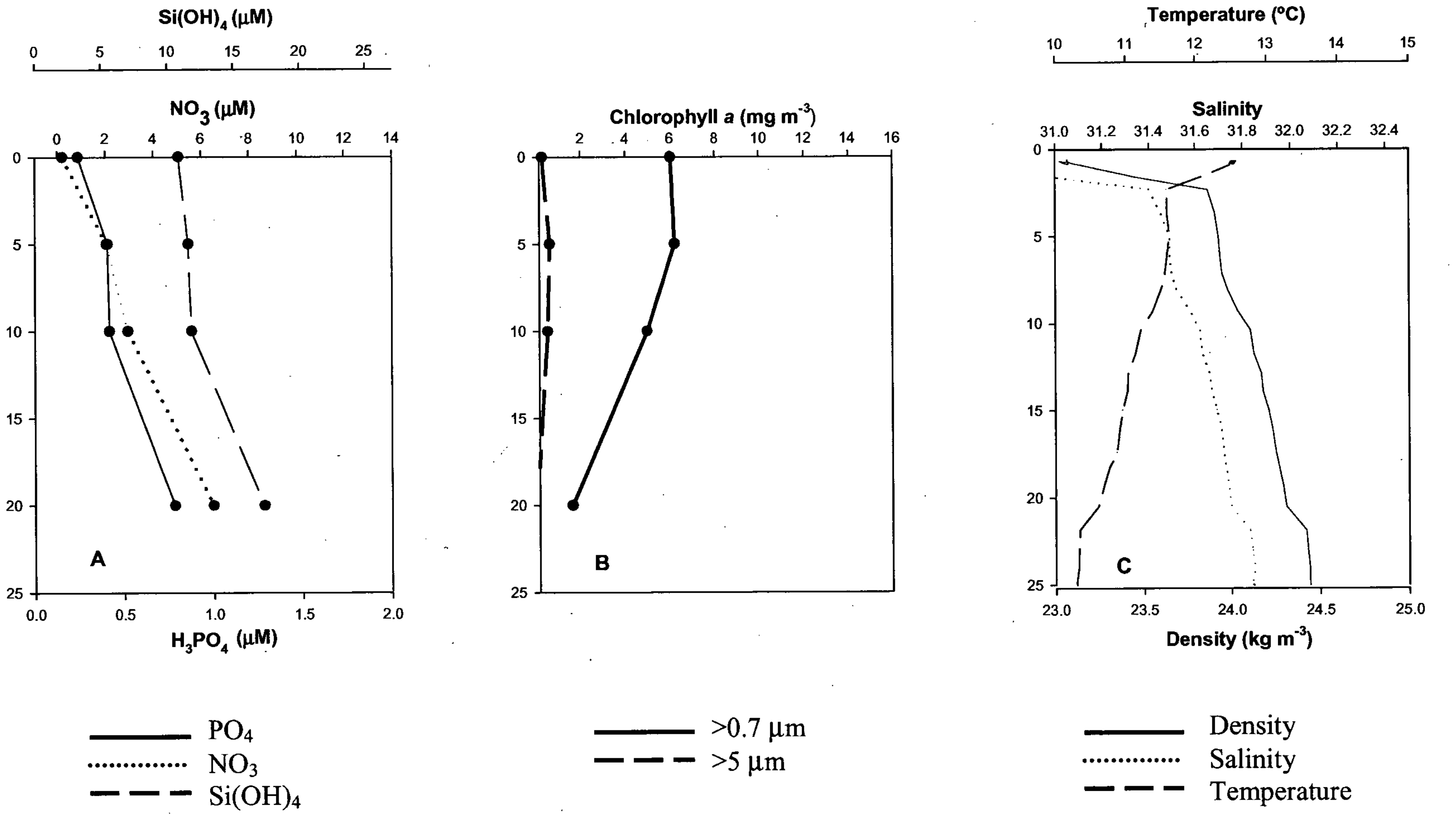

Figure 2.13: Vertical profiles of A) nutrient concentrations, B) chlorophyll concentrations, and C) physical properties for station #38 at Skedans on the east coast of Gwaii Haanas (see Fig. 2.1) to show a complete data set for one station

2.3.5 Station Variability

To show how one region can vary over time, stations 47, 64, and 74 Skedans were chosen. These were sampled on July 17, 30, and August 02, 2002 respectively. Table 2.11 shows the different weather and physical parameters at these stations and Figure 2.14 shows the vertical profiles of temperature, salinity, and density for these three stations. Table 2.12 and Figure 2.15 compare the integrated biological and chemical parameters at these stations. Skedans is located on the east coast of Gwaii Haanas (see Fig. 2.1).

Station 47 had the highest nutrient concentration of all three stations as well as the lowest concentrations of chlorophyll in both the total and large size fraction. It also had the lightest wind (2 knots), the highest surface salinity (31.85), the lowest surface temperature (11.04°C), and the deepest Secchi disk depth (13.5 m). The weather was consistently sunny and the water was very lightly stratified at the surface (degree of 1.3), but this stratification broke down after about 2 m (see Fig. 2.14). The most common phytoplankton species at station 47 was *Skeletonema costatum*.

Station 64 had moderate nutrient concentrations compared to the other two stations as well as moderate concentrations of total chlorophyll *a* and the highest concentration of the large size fraction of chlorophyll *a*. The winds were stronger at this station (7 knots). The surface salinity was 31.62; the surface temperature was 12.65°C, and the Secchi disk depth was 7.25 m. The weather was a mix of sunny and cloudy patches and the water was mixed to at least 25 m. The most common phytoplankton species at this station was *Rhizosolenia setigera.*

Table 2.11: Station variability in the region of Skedans on the east coast of Gwaii Haanas (see Fig. 2.1). Included are physical parameters TSS = total suspended solids at the surface, Secchi = depth of Secchi disk, SST = sea surface temperature, SSS = sea surface salinity, MLD = depth of mixed layer, Strat = degree of stratification.

Station	**TSS (g/L)**	**Secchi (m)**	**SST (°C)**	**SSS**	**MLD (m)**	**Strat**	**Weather**	**Wind (kn)**
47	0.0308	13.5	11.04	31.85	0	1.3	sunny	2
64	0.0109	7.25	12.65	31.62	25+	0	sunny patches	7
74	0.0327	7.25	13.87	31.47	15	0	sunny patches	9

Table 2.12: Station variability in the region of Skedans on the east coast of Gwaii Haanas (see Fig. 2.1). Included are total (> 0.7μm) integrated chlorophyll *a* (mg m^{-2}), large size fraction of integrated chlorophyll *a* (mg m^{-2}), and integrated nutrients (mmol m^{-2}).

Station	**Total Chl *a***	**> 5 μm Chl *a***	**PO_4**	**NO_3**	**SiO_4**
47	46.3	16.3	16.2	146	300
64	102	72.1	10.6	44.5	140
74	158	46.2	6.0	4.01	35.3

Station 74 had the lowest nutrient concentrations of all three stations compared. This station had the highest concentrations of total chlorophyll and a moderate concentration of the large size fraction of chlorophyll *a*. The winds were the strongest at this station (9 knots). The salinity was 31.47; the surface temperature was 13.85°C, and the Secchi disk depth was 7.25 m. The weather was a mix of sunny and cloudy patches and the water was mixed to a depth of 15 m. The most common phytoplankton species at this station was also *R. setigera*.

2.4 Discussion

The data were split into four groups based on which coast the station was located and which year the station was sampled. Most of the differences in the results occurred between the two sampling seasons rather than between the two coasts. One reason for these broad differences could be due to the vastly different weather experienced between the two sampling seasons. Table 2.13 shows the difference in the amount of precipitation between the two years. The first year (summer 2001) was very cloudy and wet with little sunshine and much rain, 170.4 mm of total precipitation for July and August. In contrast, the second year (summer 2002) was sunnier and warmer with less rain, only 88.2 mm of total precipitation for July and August.

A less obvious difference between the two seasons was the difference in upwelling intensity. Figure 2.16 shows a comparison of the 2001 and 2002 and the ten-year average upwelling intensity from the Bakun Upwelling Index, measured off the British Columbia coast at 48°N, 125°W. The upwelling intensity of the summer of 2001 was below the ten-year average, while in the summer of 2002 it was higher than 2001 in

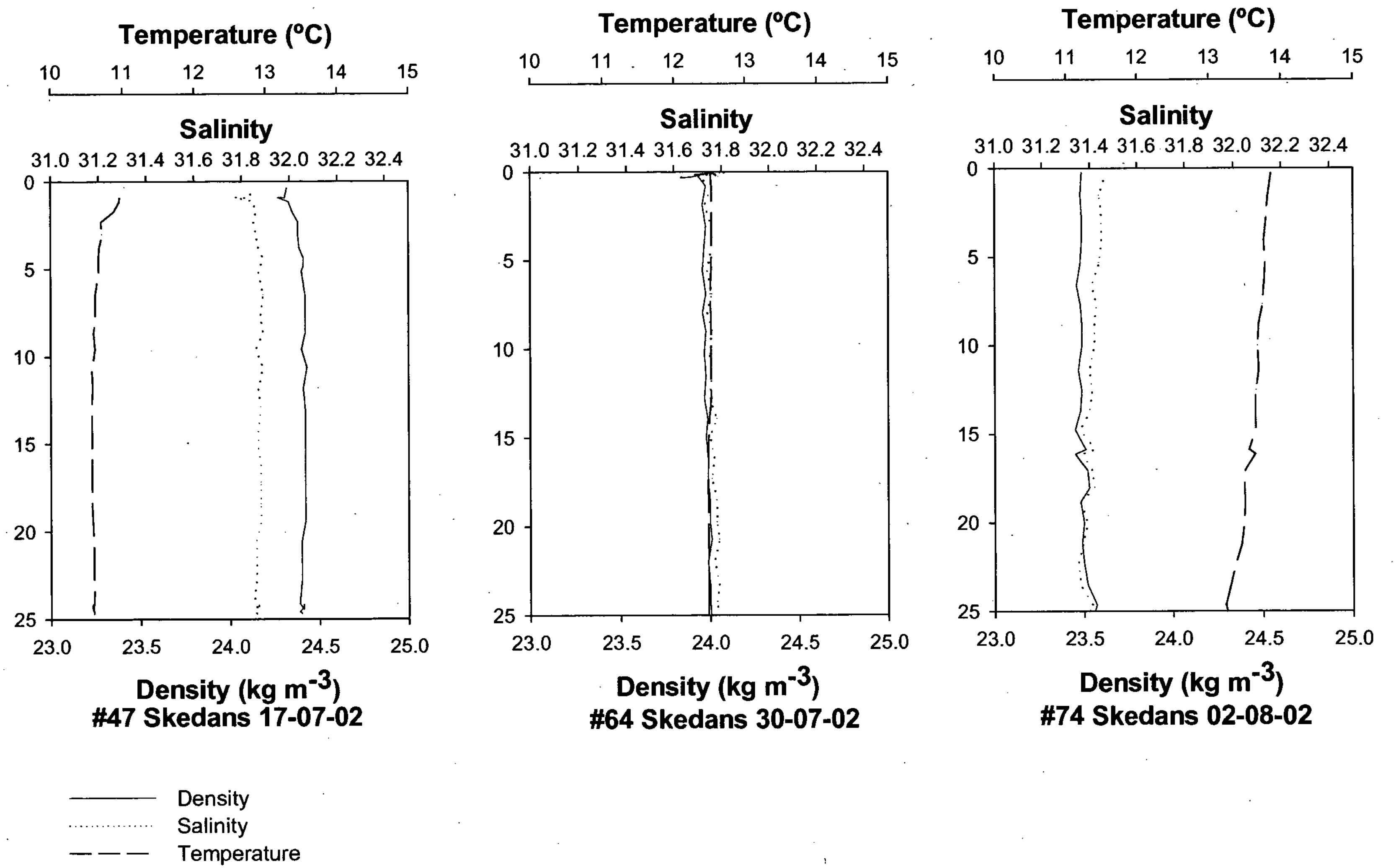

Figure 2.14: Vertical profiles showing temperature, salinity, and density to show station variability during a three week period at Skedans on the east coast of Gwaii Haanas (see Fig. 2.1) at stations 47, 64, and 74.

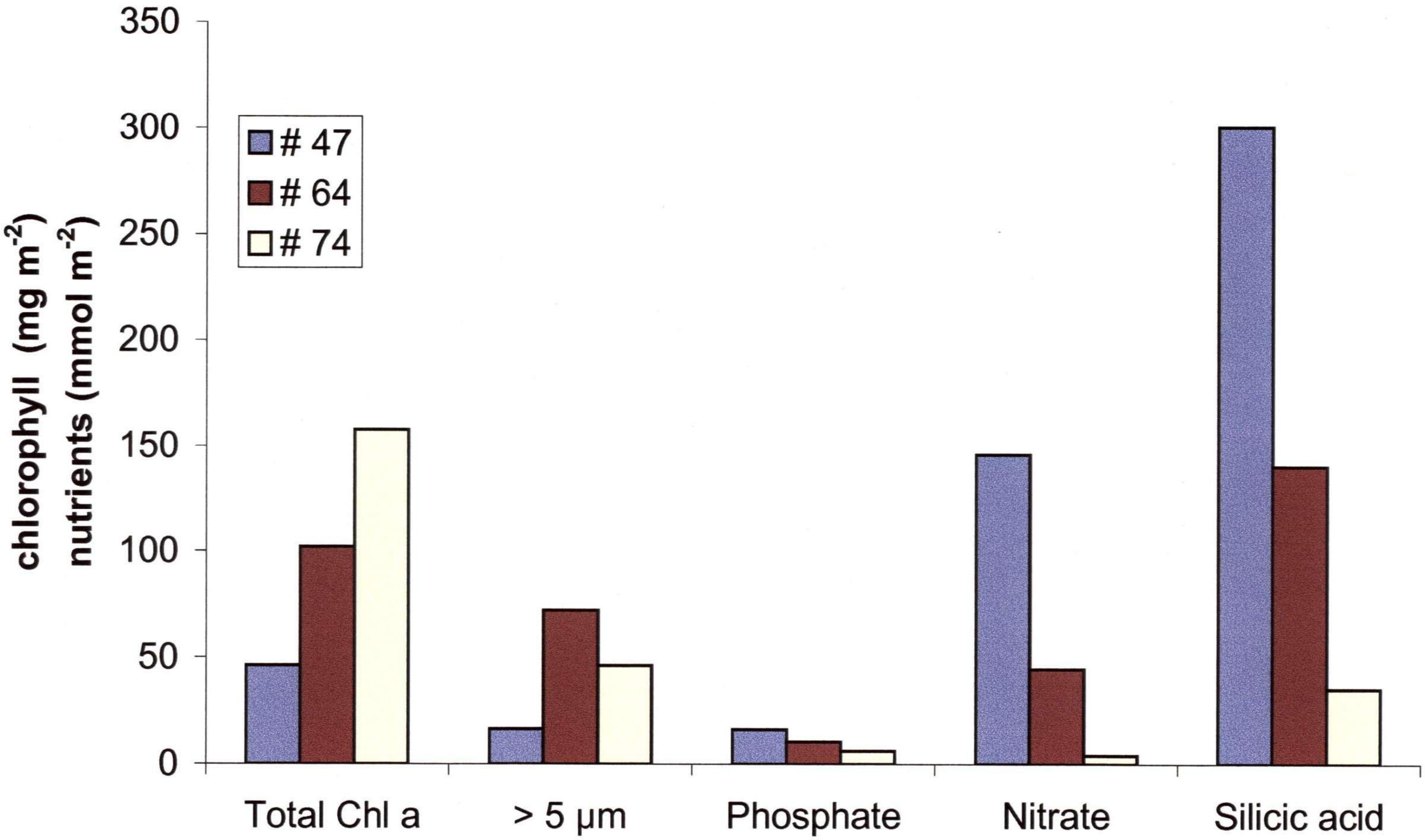

Figure 2.15: A comparison of stations 47, 64, and 74 at Skedans on the east coast of Gwaii Haanas (see Fig 2.1) to show temporal variability in integrated nutrients and chlorophyll.

early July before dropping below the 2001 level in mid-July, and then increasing again to exceed the ten-year average from mid –August onwards (Fig. 2.16).

Another reason for the differences could be a difference in the sampling strategy between the two years. During the first season the sampling occurred very close to shore due to weather conditions and during the second season sampling was conducted further offshore and a greater number of stations were sampled. A fourth reason for the interannual differences that were observed could be related to the observed difference in sea surface height seen along the east coast between the summer of 2001 and the summer of 2002 (Fig. 2.17). Changes in sea surface height are caused by changes to the density of the water column due to surface heating, water fluxes to the system, or advection of water of different densities. Elevated sea surface height is caused by water of a low density at the surface, usually resulting in warmer temperatures and stratification of the water column. A depressed sea surface height is usually caused by denser water at the surface that results from mixing of cold water brought up from below the surface.

The data show very high variability (from undetected nitrate to very high values) in the measured parameters between the four categories chosen, leading to some correlations not being statistically significant. Lack of statistical significance could also be due to the categories were too broad and that much detail was lost within them, or that there are large uncertainties in measuring some types of data such as cell counts. When comparing large categories such as these, therefore it is important to look at some of the individual occurrences as well as trends and patterns rather than just the statistical significance.

Table 2.13: Total precipitation (in mm) at Sandspit, Queen Charlotte Islands (source: Environment Canada).

Month	2001	2002
May	95.4	73.4
June	45.4	74.8
July	48.4	63
August	122	25.2
Total	**311.2**	**236.4**

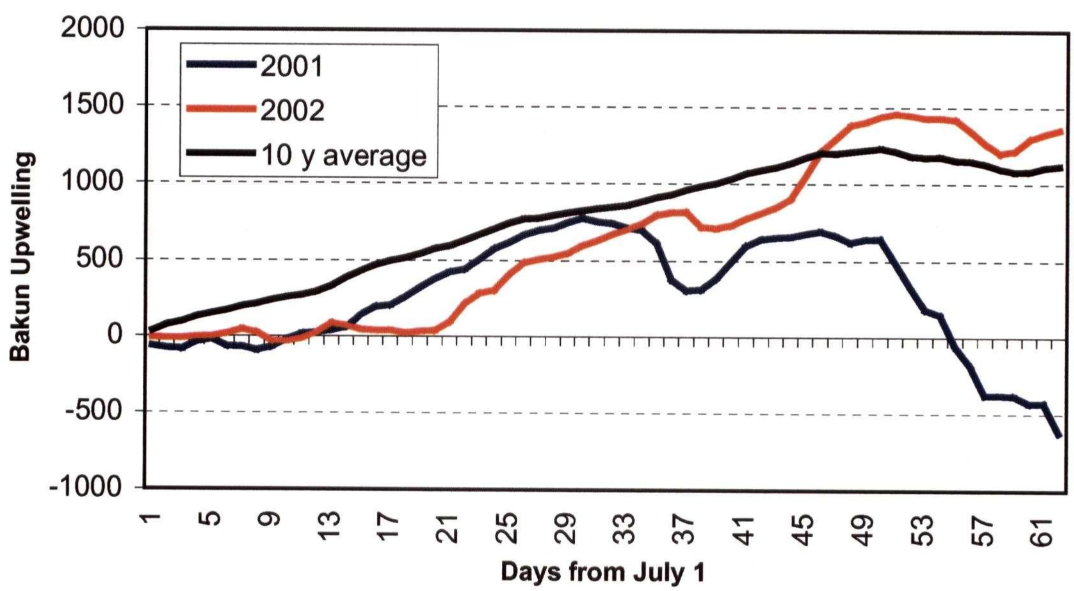

Figure 2.16: Bakun Upwelling Index off the BC coast at 48°N, 125°W showing intensity of upwelling for 61 days from July 1 for 2001, 2002, and a 10 year average.

2.4.1 Physical Characteristics

When both coasts and both sampling seasons were compared in a four-way comparison for both total suspended sediments and the Secchi disk depth, there were no significant differences found between the means for any of the four categories E 01, E 02, W 01, W 02. Therefore none of the categories had either less turbidity due to suspended sediments or more water clarity than any of the other categories. Also, there was no significant relationship between TSS and the Secchi disk depth, or TSS and total surface chlorophyll *a* concentration (Spearman Rank Order correlation, $p > 0.050$). Both extreme high and low values for TSS occurred on the east coast in the second year. The lowest occurred at Station 55 Hotsprings Island, possibly due to a fresh water inflow from the hotsprings diluting the seawater. The highest value of TSS was measured on the same day as the lowest value, at station 55 Goodwin Point which was chosen as it was believed to be an area of high tidal mixing, but unfortunately the S4 was not operating when this station was sampled.

The deepest Secchi disk value was recorded on the east coast in both the first and second year. Both of these occurred on bright sunny days and at stations with relatively low surface chlorophyll concentrations. The shallowest Secchi disk value of 3.75 m corresponded with the shallowest euphotic zone (11.9 m, equations 1 and 2). This station (station 5) was not the station with the highest TSS concentration, but it did have maximum chlorophyll at the surface. Unfortunately this station was only sampled to a depth of 10 m, so there is no record of chlorophyll concentration below 10 m.

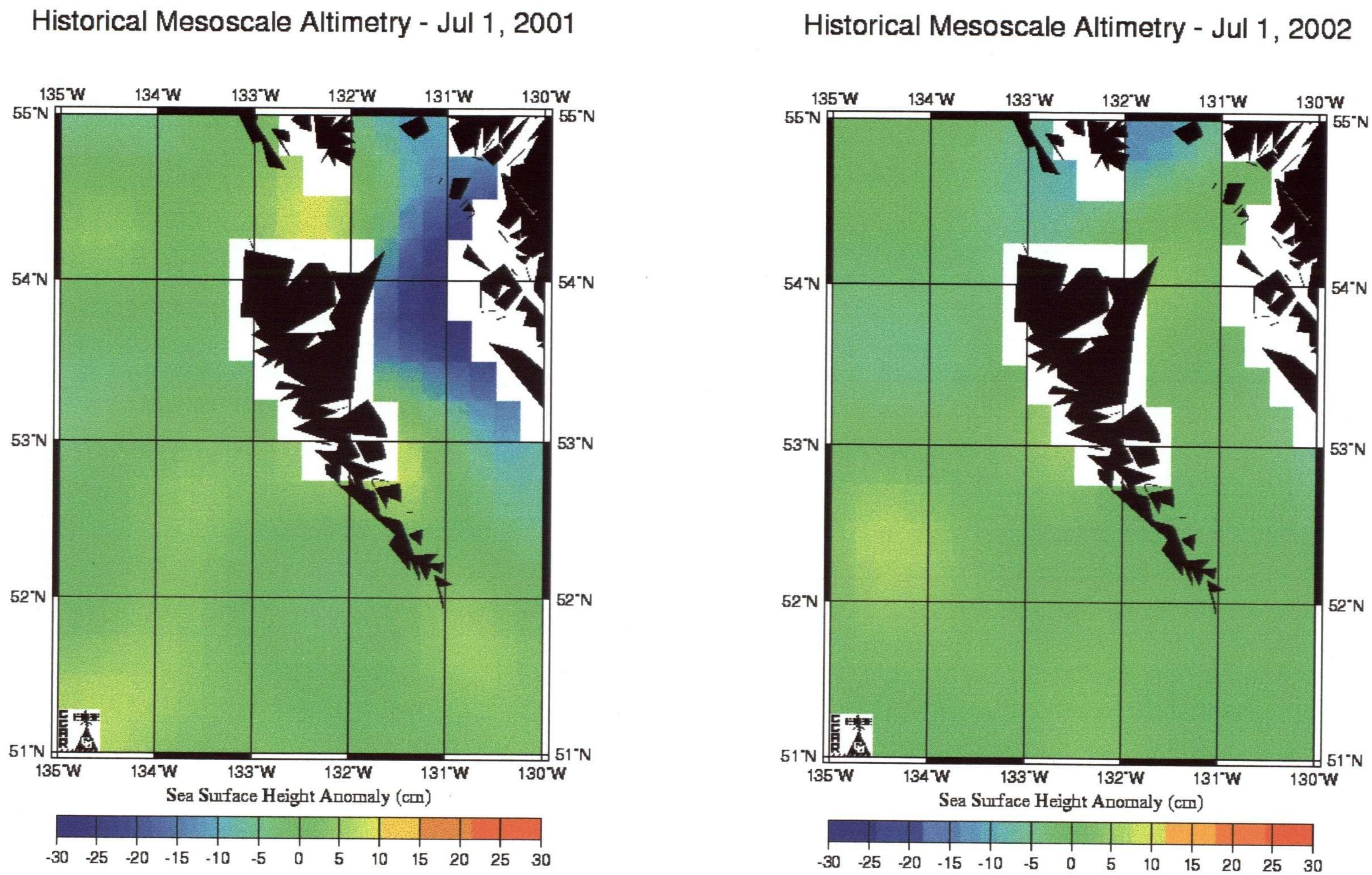

Figure 2.17: Satellite altimetry showing differences in sea surface height anomaly along the east coast of Gwaii Haanas between the summers of 2001 and 2002.

Both extreme values for sea surface temperature were also on the east coast in 2002, and no significant differences were found amongst the four categories. The lowest surface temperature was recorded at station 44 Koya Point which was a very well mixed station with cold deep water mixed up to the surface. The warmest surface temperature was found at station 73 Tanu which is in a relatively shallow and protected area which was highly stratified and was sampled on a warm sunny day.

The lowest surface salinity value was measured on the west coast at station 40 Sunday Inlet, which was relatively protected from the open ocean and had several small creeks emptying into the inlet that may have decreased the salinity at the surface. The highest surface salinity was recorded on the west coast at station 42 Wells Cove which was a small, open cove that was exposed to the open ocean and this may have influenced its surface salinity. No significant differences were found amongst the categories for sea surface salinity, but generally higher salinities were recorded on the east coast, while lower salinities were recorded on the west coast.

These results are not what was expected as coastal upwelling occurs along the west coast in the summer (Fig. 1.4) and high salinities and colder temperatures were expected on the west coast while warmer, less saline water was expected on the east coast. These data could be influenced by the locations of the samples taken on the west coast. In many cases, the weather and seas were too rough on the west coast of Gwaii Haanas to sample, so that the samples were taken in inlets and bays, very close to shore where the water was calmer. As seen in the results for the mixed layer depth and the degree of stratification, the shallowest mixed layers and highest degrees of stratification were all on the west coast. These more sheltered waters would be expected to be warmer with lower salinities due to creek inflow that should enhance stratification. Further offshore, the waters were probably colder and more saline on the west coast.

The mixed layer depths on the east coast were either 0 m, indicating that the thermocline extended to very near the surface and the station was stratified, or between 3-30 m. A higher proportion of the stations were stratified in 2002 (65%) as opposed to 2001 (57%) due to the increased sunlight and decreased rainfall (Table 2.1) in 2002 that warmed the surface waters and inhibited mixing. The stations that had the highest levels of stratification were stations 40 Sunday Inlet, 41 Gowgaia Bay, and 84 Sunday Inlet. These stations were all located in an area on the west coast that was partially closed off from the open ocean and had small creeks draining into the area which decreased the surface salinity. In addition, the weather on either the sampling day or the previous day had been very warm and sunny, which would increase surface temperatures. With a lack of mixing from below and lower salinities and increasing temperatures, the water became stratified.

2.4.2 Chemical Parameters

For all three nutrients, both surface and integrated nutrient concentrations were much higher on both coasts during 2002 compared to 2001 and these differences were significant in each case. Almost all of the means were higher for the west coast than the east, but these differences were not significant except for silicic acid concentrations which were significantly higher on the west coast. According to the Bakun Upwelling Index measured off the British Columbia coast at 48°N, 125°W, the upwelling intensity during the summer of 2001 was below the ten-year average (Fig. 2.16). The upwelling intensity for the summer of 2002 was higher than 2001 in early July before dropping below the 2001 level in mid-July, and then increasing again to exceed the ten-year average from mid –August onwards (Fig. 2.16). If more deep, high nutrient water was upwelled to the surface in 2002 than 2001, this could explain the higher nutrients found in 2002 compared to 2001.

Both integrated and surface nitrate concentrations had the largest increase, 3-6 times higher in the second sampling season. This is supported by the fact that in 2001, 68% of the stations were apparently nitrate limited (drawn to undetectable levels at the surface) while in 2002 only 19% of the stations sampled showed apparent nitrate limitation. The nitrate concentrations in 2002 also had the highest variability of all of the nutrients due to the many undetectable concentrations, and in many cases the variability was higher than the mean. The surface and integrated nitrate mean concentrations were significantly different between years but not between coasts, but differences between coasts in apparent nitrate limitation were observed. On the east coast, apparent nitrate limitation occurred in 64% and 83% of the stations in E 01 and E 02 compared to 21% and 14% in W 01 and W 02.

Both surface and integrated phosphate concentrations had a much smaller but still a statistically significant increase between the two years but not between the two coasts. The variability around the means was also lower than for the nitrate concentrations. One interesting point to note is that both the mean surface and integrated concentrations for the west coast in 2001 (W 01) were lower than the E 01 value. This is also the category in which an occurrence of phosphate limitation was found in late August 2001 and could be an effect of the reduced upwelling late in the 2001 sampling season.

Surface and integrated silicic acid concentrations followed the same pattern as nitrate concentrations but the variability was much lower and silicic acid was not found to be a limiting nutrient at any time during either season. Concentrations were significantly higher in 2002 than 2001. When the east and west coasts were compared, significantly higher concentrations were found on the west coast. There was no significant relationship between salinity and silicic acid concentrations (Spearman Rank Order correlation, $p > 0.050$).

$NO_3/Si(OH)_4$ surface ratios were much smaller than the ratio of 1:1 required for phytoplankton growth. This is because NO_3 concentrations were drawn down by phytoplankton to low or undetectable concentrations at several stations and NO_3 was likely a limiting nutrient at some stations, while $Si(OH)_4$ concentrations were very high at every station and silicate was not considered to be a limiting nutrient at any station. The same is true for the NO_3/PO_4 integrated ratios which were lower than the 16:1 ratio required for phytoplankton growth. Phosphate concentrations were generally high except for one case of apparent phosphate limitation where the phosphate concentration was drawn by phytoplankton to an undetectable level.

2.4.3 Biological Parameters

Surface chlorophyll *a* concentrations from both size fractions showed no significant differences when the two coasts and the two years were compared. A significant difference was found between coasts for the large size fraction (> 5 μm). When the integrated chlorophyll *a* concentrations were compared, significant differences were found between the two years for total chlorophyll, and a significant difference was found between coasts for the large size fraction (> 5 μm). There were more phytoplankton at depth in 2002 than in 2001, for the total chlorophyll *a*.

In almost all of the stations, the total chlorophyll *a* concentrations were much larger than the concentrations of the large size fraction (> 5 μm). This indicates that there were high concentrations of small phytoplankton such as nanoflagellates. Although these small cells were seen when counting the samples, especially on the west coast, they were not included in the counts which consisted of larger phytoplankton such as diatoms, dinoflagellates, silicoflagellates and coccolithophores. This is a major limitation in the phytoplankton diversity analysis.

There were no significant differences between the four categories or between the sampling seasons for any of the three diversity indices applied to the phytoplankton data. The majority of phytoplankton communities consisted of *Leptocylindrus danicus*, *Chaetoceros* spp., *Thalassiosira* spp., *Skeletonema costatum* and *Pseudonitzschia* "A", although some stations showed one dominating (>50 %) species. These are all typical coastal species found along the west coast of British Columbia. What is surprising is how important the < 5 μm size fraction is to the community, as coastal communities are usually diatom dominated but these communities seemed to be dominated by picoplankton.

2.4.4 Station Variability

The region of Skedans can be quite variable over time as seen from the comparison of stations 47, 64, and 74. Station 47 on July 17, 2002 had comparatively high nutrient levels compared to the other two stations and low chlorophyll *a* concentrations. The nutrients were high because there was not a large amount of phytoplankton to consume them. Weak surface stratification developed at this station due to the light winds and sunny weather which prevented mixing, but the stratified layer was shallow and below 2 m, and this station was mixed to depth. The photic zone was the deepest at this station due to the bright and constant sunshine and the spring bloom species, *Skeletonema costatum* was the most abundant in the colder temperatures of this station.

Station 64 on July 30, 2002 had stronger winds and there was no stratification at the surface of this station. The total integrated chlorophyll *a* was higher and the phytoplankton depleted the nutrients, which were lower than at the previous station. The photic zone was not as deep at this station, but there was deep mixing and warmer temperatures to a considerable depth. The large size fraction of integrated chlorophyll *a* concentration was the highest due to high concentrations of the large diatom, *Rhizosolenia setigera* found at this station.

Station 74 on August 02, 2002 had slightly stronger winds than station 64 and it also had no stratification at the surface. Total integrated chlorophyll *a* concentrations were high and concentrations of all three of the nutrients were thus drawn down to very low levels. Nitrate was almost undetectable. Although this station had the highest concentration of total chlorophyll *a,* it did not have as high a concentration of the large size fraction of chlorophyll *a* as station 64. *R. setigera* was the most abundant phytoplankton species here as well, but there was also a larger number of small phytoplankton. The water temperatures were the warmest at this station and this extended down to depth.

2.4.5 Comparison to Previous Studies in the Region

The results from this study show that there is very little surface mixing around the southern end of the Queen Charlotte Islands in the summer months. When mixing occurs it is shallow and often the waters are stratified at the surface. This is consistent with the data from McQueen and Ware (2002) who reported that the mixed layer is very shallow, 10-20 m or even non-existent between June-September.

In this study nitrate concentrations were generally low to undetectable at the surface and increased at depth. Perry (1984) reported that summer nitrate concentrations (measured at 3 m depth) were negligible in the summer, either low because they were low all year in the region, or most likely they are drawn down by the spring bloom in April and not replenished until the fall. The data from McQueen and Ware (2002) also correspond with the findings in my study in that the summer nutrient concentrations were low at the surface (0-5 m), approximately doubling at 5-15 m and then increasing in concentration with depth.

Mean nutrient concentrations on the east coast were 0.92 and 3.08 μM for nitrate for 2001 and 2002, 6.30 and 9.08 μM for silicic acid in 2001 and 2002, 0.38 μM and 0.46 μM for phosphate in 2001 and 2002. Comparing these values with data from Robinson (unpublished data), the concentrations in my study were similar to mean surface nutrient concentrations found in Hecate Strait. Mean surface concentrations of samples taken from Hecate Strait between July 2-6, 2000 were 0.30 μM for nitrate, 5.30 μM for silicic acid, and 0.34 μM for phosphate, while mean concentrations of samples taken from Hecate Strait between August 25 – September 06, 2000 were 1.99 μM for nitrate, 11.03 μM for silicic acid, and 0.55 μM for phosphate (Robinson, unpubl. data). The original data for these studies can be found in Appendix G.

Nutrient concentrations in Juan Perez Sound (see Fig. 2.1) measured by Whitney (pers. comm.) showed relatively depleted Si concentrations at the surface when compared to oceanic waters, but Si concentrations increased with depth due to remineralization in the basins. Whitney also found higher Si concentrations on the east coast than the west coast, most likely due to riverine inputs as a very high concentration of 1700 μM was measured in waters from Hotsprings Island (see Fig. 2.1) (Whitney, pers. comm.). This contrasts with the results of this study for surface $Si(OH)_4$ concentrations which show significantly higher concentrations on the west than the east coast.

Mean surface chlorophyll *a* concentrations ranged from 3.35 to 5.38 mg m^{-3} in the four categories compared in this study and there were no significant differences either between coasts or between years. The concentrations on the east coast were 4.12 mg m^{-3} in 2001 and 4.20 mg m^{-3} in 2002 and were measured within a close distance to the shore. These concentrations are higher than the mean concentrations found by Perry (1984) of 2.77 mg m^{-3} in August 1978 and 2.11 mg m^{-3} in July 1979 for a depth of 3 m, but these concentrations were measured further offshore in Hecate Strait. A few studies conducted by Robinson (unpublished data) in Hecate Strait also found lower mean chlorophyll *a* concentrations in the summer with means of 1.06 mg m^{-3} for July 2-6, 2000 and 0.90 mg m^{-3} for the period between August 25 and September 06, 2000. Another study by Peterson (unpublished data) in Hecate Strait also found a lower mean chlorophyll *a* concentration of 1.93 mg m^{-3} for August 9-11, 2000. The original data for these studies can be found in Appendix G. McQueen and Ware (2002) also reported lower chlorophyll *a* concentrations, averaging 2 mg m^{-3}, although their findings also suggest that both the between-year and between-site differences in chlorophyll *a* concentrations were small.

The mean surface chlorophyll *a* concentrations were slightly but not significantly higher than the east coast concentrations with 5.38 mg m^{-3} in 2001 and 3.35 mg m^{-3}in 2002, and these were measured close to shore and in inlets and bays on the west coast. Robinson (unpublished data) also measured chlorophyll off the west coast of Gwaii Haanas but not as close to shore and found a mean surface chlorophyll *a* concentration of 1.04 mg m^{-3} for July 4-11, 2000, which is substantially lower than the values measured in this study. Whitney (unpublished data) measured surface chlorophyll *a* concentrations at several stations far off the west coast and found much lower chlorophyll *a* concentrations of 0.31 mg m^{-3} for June 2000 and 0.70 μg L^{-1} for September 1999. The original data for these studies can be found in Appendix G.

The taxonomic composition of phytoplankton around the waters of Gwaii Haanas consisted of a number of small unidentified (and uncounted) nanoflagellates as well as many dinoflagellate and diatom species, dominated by *Leptocylindrus danicus*, *Chaetoceros* spp., *Thalassiosira* spp., *Skeletonema costatum* and *Pseudonitzschia* "A". This is in agreement with Perry's (1984) findings where in Hecate Strait in the summer many small unidentified flagellates were common, as well as a variety of dinoflagellates (including *Ceratium* spp.) and residual spring bloom species such as *Chaetoceros* spp., *Thalassiosira* spp., *Skeletonema costatum*, with *S. costatum* being the most common.

2.5 Summary

Physical, chemical, and biological properties of the waters surrounding Gwaii Haanas NMCA were measured and analyzed in July and August of 2001 and 2002. These data were then divided into four temporal and spatial groups according to which coast and which year they were sampled in order to evaluate spatial and interannual variability. There was very high variability found in the physical data and therefore none of the physical parameters were statistically significant, although as there was more sunlight and less rain in 2002 than in 2001, and more stratification was observed in 2002 and on the west coast.

There was a greater intensity of upwelling in 2002 compared to 2001 leading to interannual variability with higher 2002 concentrations seen for both surface and depth-integrated nutrient concentrations for all three nutrients as greater concentrations of nutrients were upwelled from below. Silicic acid also showed a significant increase in concentration on the west coast compared to the east coast in the year 2002.

Surface chlorophyll *a* concentrations were not significantly different either between coasts or between years for either total chlorophyll *a* or the larger size fraction, but the total integrated chlorophyll *a* concentrations showed interannual variability with significantly higher concentrations in 2002 than in 2001. There was more sunlight and less precipitation in 2002 compared to 2001 and there was more phytoplankton at depth as the light penetrated deeper. Chlorophyll *a* concentrations in the large size fraction (> 5 μm) also showed higher values on the east coast than on the west coast. The dominant phytoplankton species were *Leptocylindrus danicus*, *Chaetoceros* spp., *Thalassiosira* spp., *Skeletonema costatum* and *Pseudonitzschia* "A".

Chapter Three

Effects of Environmental Parameters on Species Composition and Diversity in the Proposed Gwaii Haanas NMCA in Summer

3.1 Introduction

Chapter 2 describes the physical and chemical environmental parameters found in the waters of the proposed Gwaii Haanas NMCA, as well as the diversity of species and groups that are present. This chapter uses this information to determine if there is a relationship between phytoplankton community composition and variation in the environment. To test whether the environmental parameters affect the distribution of phytoplankton species, Canonical Correspondence Analysis (CCA) was used. This technique of multivariate gradient analysis tests if phytoplankton distributions or sites are correlated with environmental parameters through ordination and reciprocal averaging. This results in a two-dimensional plot that approximates the weighted averages of species or sites with respect to environmental variables, where points represent species or sites and arrows (vectors) represent environmental variables (ter Braak 1986, 1995, ter Braak and Verdonschot (1995), and Legendre and Legendre (1998)).

Correspondence Analysis (CA) and Detrended Correspondence Analysis (DCA) are other gradient analyses and they have been previously criticized for a number of reasons such as the "arch" or "horseshoe" effect where the second axis is a curvilinear function of the first axis which can be encountered with CA (Palmer 1993). DCA has its own problems such as a poor performance with skewed species distributions and inability to handle complex sampling designs very well (Palmer 1993). Palmer (1993) conducted an experiment to test whether CCA encountered these same problems and he concluded that CCA has all of the advantages and none of the disadvantages that one would encounter using DCA. Therefore CCA was used in this study.

3.2 Materials and Methods

The data used in this chapter are from Chapter 2 and the materials and methods from Chapter 2 explain how these samples were collected and processed. Only the sites with a full suite of data were used in this analysis, and therefore the stations where the physical data are missing (Appendix B) were not included, as well as station #83 where the phytoplankton species sample was lost. The software that was used is CANOCO version 4 by ter Braak and Smilauer (1998). The environmental variables used in this analysis were sea surface salinity, sea surface temperature, Secchi disk depth, phosphate, silicic acid, and nitrate concentrations, total suspended solids, and mixed layer depth.

3.3 Results

In CCA the centroid point represents the average value of the variable and the arrow points in the direction of higher than average values of that variable. The arrow can be extrapolated backward, and any value opposite that arrow has a lower than average value for that variable. The length of the arrow is equal to the rate of change in that direction. Arrows pointing in the same direction have a positive correlation, while arrows pointing in opposite directions have a negative correlation. Those arrows at right angles to each other have no correlation (ter Braak 1995). This chapter shows the results for all of the data collected in this study. For a breakdown of the data into plots for coasts and years see Appendix H.

Figure 3.1 is a biplot that shows the relationships between the environmental parameters and the species or groups identified within the stations and Table 3.1 is a list of abbreviations for species or group names shown in Figure 3.1. As expected, most of the species and groups were clustered in the lower right quadrant where both depth of light penetration and nutrient concentrations were greater than average (Fig. 3.1). Representatives from all of the categories (diatoms, dinoflagellates, coccolithophores, and silicoflagellates) were found in this quadrant. There were very few groups or species in the quadrant diagonal this one (top, left) as this is where lower than average nutrients and shallow depth of light penetration occur. The groups found here were *Pseudonitzschia* "A" and *Dinophysis acuta* and were probably more highly correlated with the higher salinity in this quadrant, rather than the lower nutrients.

Along the temperature axis, mostly dinoflagellates including *Oxyphysis oxytoxoides, Amphidinium sphenoides, Dinophysis norvegica, D. acuminata, D. acuta, D. parva,* and *Gonyaulax* spp. and a few diatoms were found in the higher than average region (above the horizontal axis), while only diatoms including *Odontella longicruris, Rhizosolenia styliformis, Eucampia zodiacus, Thalassionema nitzschiodes,* and *Chaetoceros* spp. were seen in the extreme of the lower than average temperature quadrant (lower, left). The diatoms and silicoflagellates including *Dictyocha speculum* and *Ebria tripartita* were mostly clustered around the nutrient axes, especially silicic acid in the lower right quadrant, while the dinoflagellates and coccolithophores, although higher than average for nutrient concentrations, were found clustered between the Secchi disk axis and the temperature axis.

According to Figure 3.1, the depth of the mixed layer had a very short vector arrow, indicating that it was not a very important variable in determining the distribution of species or groups in this region, whereas all three of the nutrient vectors had long arrows, indicating that they were more important. Regarding relationships between environmental variables, sea surface temperature had no relationship with sea surface salinity, but it was negatively correlated with all of the other environmental variables. Sea surface salinity had a positive correlation with total suspended solids and depth of the mixed layer, but a negative correlation with all three nutrients and Secchi disk depth. The Secchi disk depth was positively correlated with all three nutrients, but showed no relationship with total suspended solids or the mixed layer depth. The nutrients were all positively correlated with each other as well as the total suspended solids concentration and the mixed layer depth. Also, the mixed layer depth and the concentration of total suspended solids were positively correlated.

Figure 3.2 shows the distribution of sites with respect to the environmental variables. All of the stations on the west coast were associated with cooler than average surface temperatures, except for station 41 which was warmer than the average surface temperature. The east coast stations were found on both sides of the temperature axis. All of the 2001 stations were on the higher than average side of the temperature axis, except station 7, which was like a west coast station. This is more likely due to lower than average nutrient concentrations than due to higher temperatures.

The majority of the stations were on the higher than average side of the nutrient concentration axes, with most of them clustered between the total suspended sediment concentration axis and the Secchi disk depth axis. The only stations on the lower than

Table 3.1: List of abbreviations for species or group names used in Figures 3.1 and 3.3.

Species or Group	Abbreviation	Species or Group	Abbreviation
Asterionella glacialis	AG	*Thalassionema nitzschioides*	TN
Asteromphalus heptactis	AH	*Thalassiosira* spp.	TN
Bacteriastrum delicatulum	BD	Centric <10	CEN
Ceratulina pelagica	CP	Pennate <25	PEN
Chaetoceros spp.	C	Coccolithophore	COC
Coscinodiscus centralis	CC	*Dictyocha speculum*	DS
Coscinodiscus lineatus	CL	*Ebria tripartita*	ET
Coscinodiscus radiatus	CR	*Alexandrium* spp.	A
Cylindrotheca closterium	CY	*Amphidinium sphenoides*	AS
Dactyliosolen fragilissimus	DF	*Ceratium fusus*	CF
Ditylum brightwellii	DB	*Ceratium lineatum*	CLI
Eucampia zodiacus	EZ	*Ceratium longipipes*	CLO
Fragilaria spp.	F	*Dinophysis acuminata*	DC
Gyrosigma/Pleurosigma spp.	GP	*Dinophysis acuta*	DAC
Leptocylindrus danicus	LD	*Dinophysis norwegica*	DN
Leptocylindrus minimus	LM	*Dinophysis parva*	DP
Licomorpha abbreviata	LA	*Glenodinium danicum*	GD
Melosira spp.	M	*Gonyaulax* spp.	GD
Navicula spp.	N	*Gymnodinium* spp.	GM
Nitzschia longissima	NL	*Gyrodinium* spp.	GR
Odontella longicruris	OL	*Heterocapsa triquetra*	HT
Pseudonitzschia "A"	PN A	*Oxyphysis oxytoxoides*	OO
Pseudonitzschia "B"	PN B	*Peridinium* spp.	P
Pseudonitzschia "C"	PN C	*Phalachroma rotundatum*	PR
Rhizosolenia robusta	RR	*Prorocentrum compressum*	PC
Rhizosolenia styliformis	RST	*Prorocentrum micans*	PM
Rhizosolenia setigera	RST	*Protoperidinium* spp.	PT
Rhizosolenia imbricata	RI	*Scrippsiella trochoidea*	ST
Skeletonema costatum	SC		

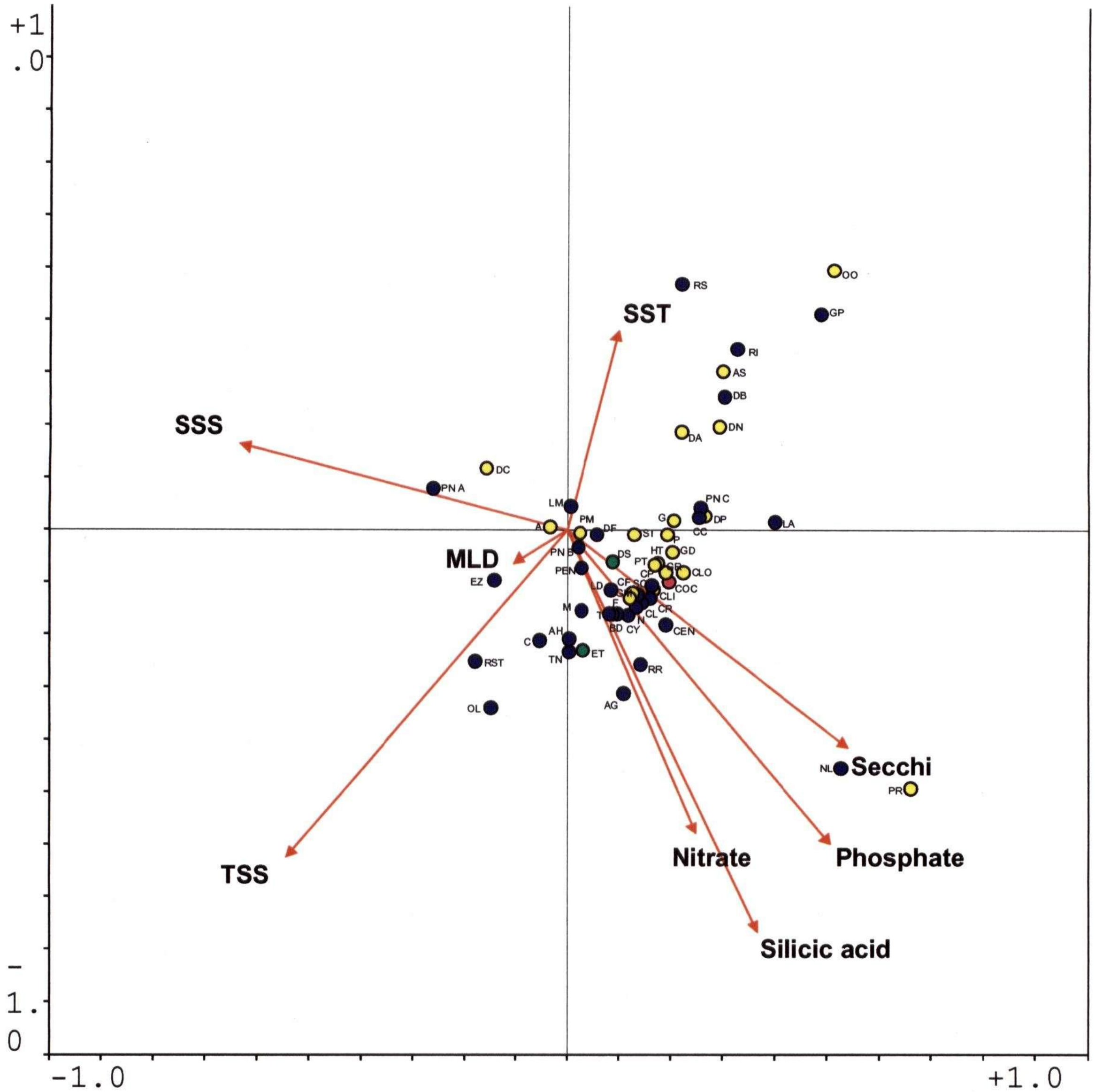

Figure 3.1: CCA ordination graph showing species or groups (points) and relationships to environmental variables (arrows). See Table 3.1 for list of species or group name abbreviations. Symbol key is; blue = diatoms, yellow = dinoflagellates, green = silicoflagellates, pink = coccolithophores. SST = sea surface temperature, SSS = sea surface salinity, TSS = concentration of total suspended solids, MLD = depth of the mixed layer.

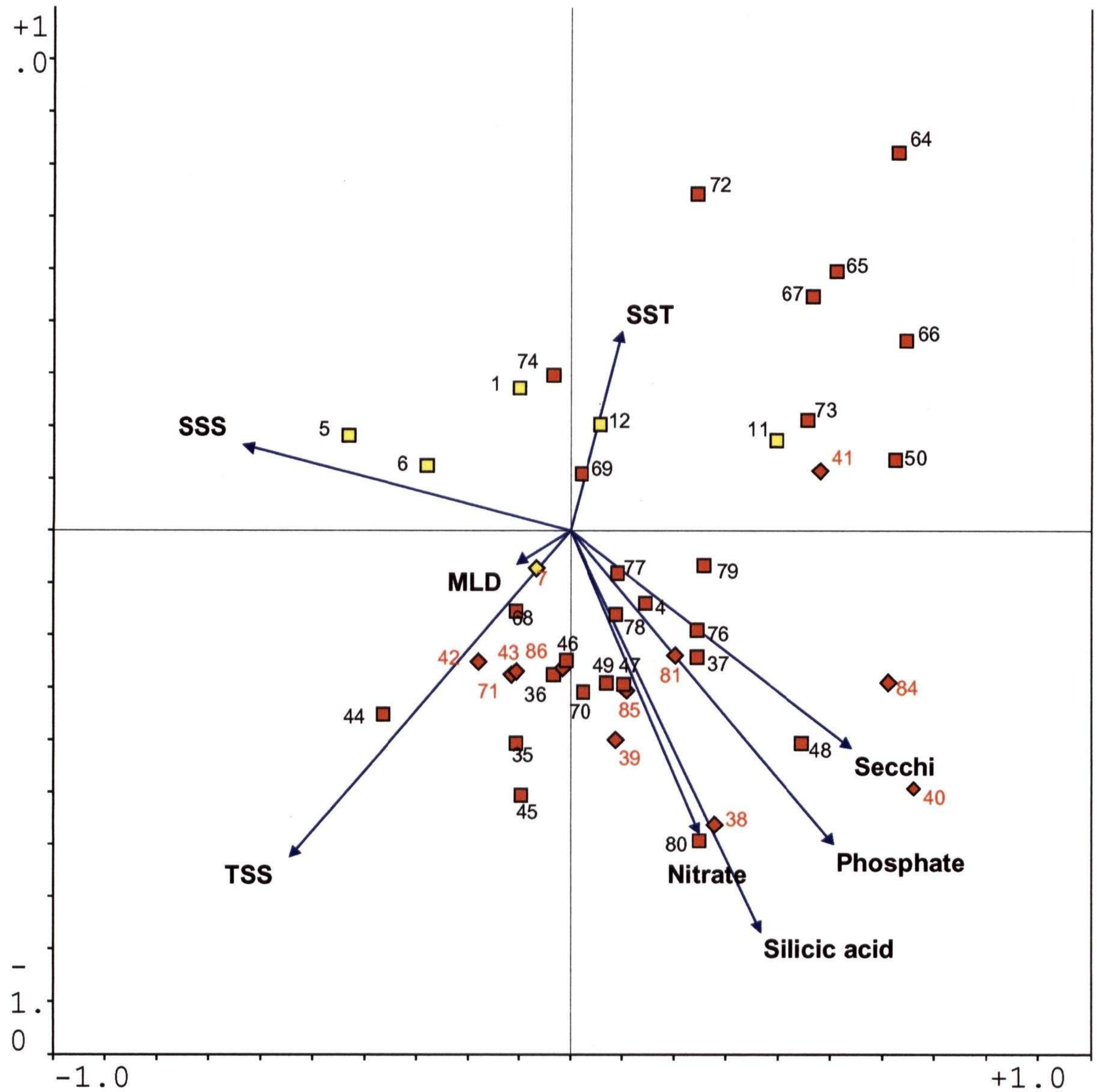

Figure 3.2: CCA ordination graph showing sites (points) and relationship to environmental variables (arrows). Colours are as follows; yellow = 2001, red = 2002. Squares indicate east coast stations while diamonds indicate west coast stations. SST = sea surface temperature, SSS = sea surface salinity, TSS = concentration of total suspended solids, MLD = depth of the mixed layer.

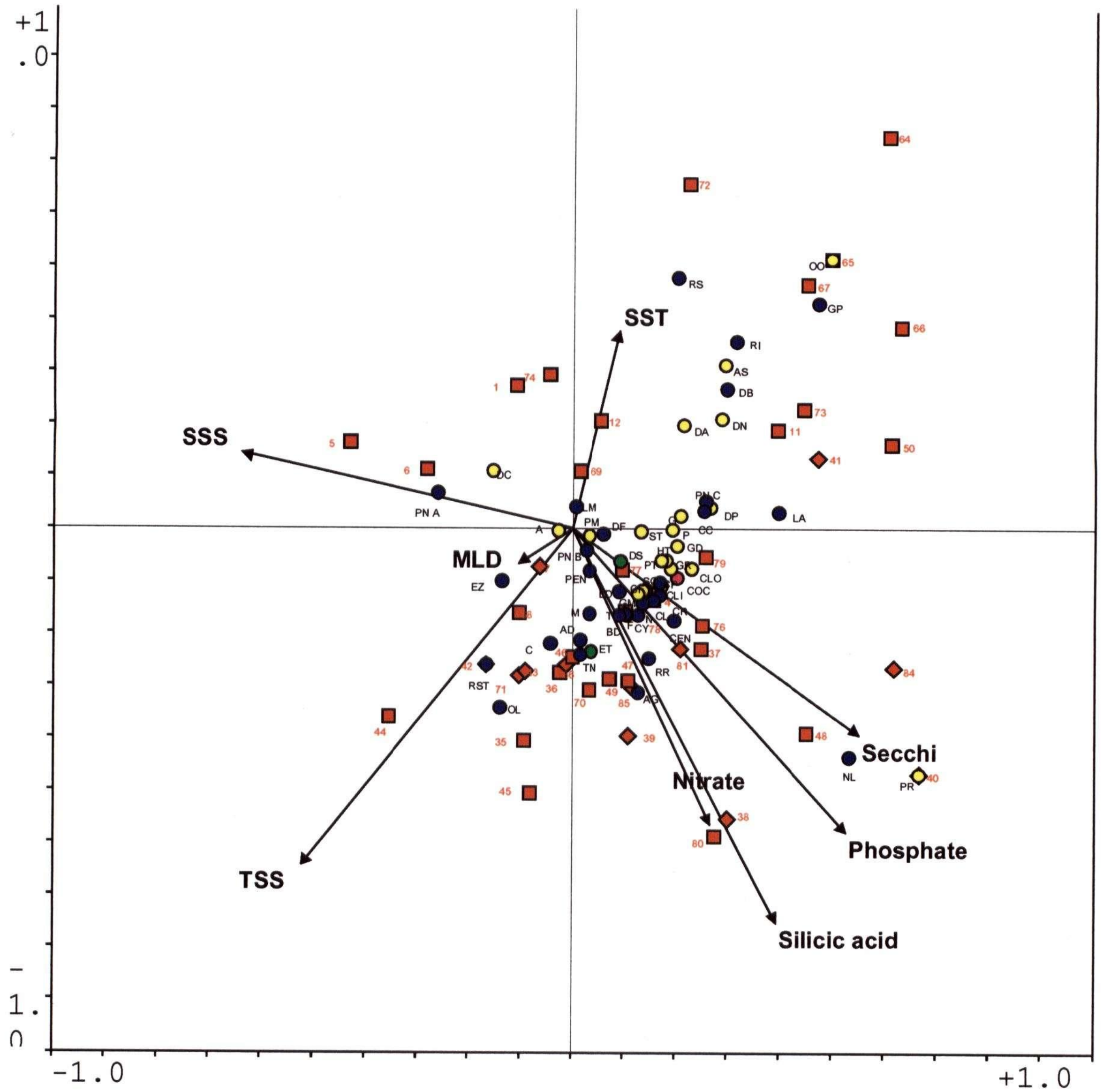

Figure 3.3: CCA ordination graph showing species or groups (circles), sites (squares and diamonds) and relationship to environmental variables (arrows). See Table 3.1 for list of species or group name abbreviations. Symbol key is; blue circles = diatoms, yellow circles = dinoflagellates, green circles = silicoflagellates, pink circles = coccolithophores, red squares = east coast stations, red diamonds = west coast stations. SST = sea surface temperature, SSS = sea surface salinity, TSS = concentration of total suspended solids, MLD = depth of the mixed layer.

average side of the axes for nutrient concentrations were stations, 1, 5, 6, 11, and 12 from 2001 as well as stations 64, 65, 66, 67, 69, 72, 73, and 74 from the 2002 sampling season.

Figure 3.3 is a triplot of the two previous biplots merged together. It shows the distributions of both sites and species or groups with respect to environmental variables. There are three occurrences where a species was found only at one location and these are seen as sites and species overlapping (Fig. 3.3). These species and stations are *Phalachroma rotundatum* at station 40, *Rhizosolenia styliformis* at station 42, and *Oxyphysis oxytoxoides* at station 65. *Pseudonitzschia* "A" was found in very high concentrations at stations 5, 6, and 7 and in Figure 3.3, it is midway between these stations. *R. setigera* was very common at stations 11, 64, 74, and 75 and the weighted average (species point) for this species was located between these stations. Coccolithophores were between stations 78, 79, and 84, where they were the most abundant (Fig. 3.3).

3.4 Discussion

CCA ordination graphs show general effects of the various environmental parameters on the distribution of the phytoplankton species or groups. This method was used by Wagey (2002) to study the phytoplankton in Ambon Bay, Indonesia. He used CCA to determine the effect of the environmental parameters temperature, salinity, water transparency, as well as ammonium, phosphate, nitrate and silicic acid concentrations on the distribution and composition of the phytoplankton. Using this method, Wagey determined that the nutrient concentrations in Ambon Bay showed a stronger correlation with the diatoms while the dinoflagellates were associated with the physical parameters (2002). Zhang and Prepas (1996) used CCA to study planktonic diatoms and cyanobacteria in eutrophic lakes in Alberta. The environmental variables used in this study were euphotic depth, water stability, temperature, pH, total phosphorus, soluble reactive silicon, and total inorganic nitrogen. They found that both groups were related strongly to total phosphorus concentrations, and that temperature and mixing patterns determined the abundance of diatoms and cyanobacteria. Diatoms were common when water stability and temperatures were low, and that cyanobacteria preferred higher temperatures than diatoms (Zhang and Prepas 1996).

In this study the distribution of phytoplankton is located largely around the center of the diagram and slightly off to the lower right hand corner (Fig. 3.1). This indicates that the distribution of a number of species is largely regulated by nutrient concentrations. This is reasonable, as the nutrients are essential for growth and sustainability of the phytoplankton community.

Most of the diatom groups or species as well as both species of silicoflagellates were found in the lower right hand quadrant clustered around the nutrient axes, inferring that the distribution of diatom communities is largely related to nutrient concentrations. The dinoflagellate groups, although still positively correlated with the nutrient axes, showed a closer relation to the surface temperature axis. This may be because the dinoflagellates are able to perform vertical migration and move up and down in the water column to where the conditions are optimal. The species found in this quadrant (upper right) may be related to higher than average surface temperatures, or lower than average concentrations of total suspended solids. The only groups or species found in the lower than average surface temperature region were diatoms and silicoflagellates, as opposed to the warmer temperatures that dinoflagellates seemed to prefer.

The depth of the mixed layer had the least influence on the phytoplankton distributions (Fig. 3.1). This is most likely due to the fact that the mixed layers were often very shallow or non-existent at many of the stations sampled. While all of the nutrients were important to the distribution of phytoplankton groups or species in this region, silicic acid had the longest vector and therefore had the greatest influence in the phytoplankton distributions. This is an interesting point as chapter 2 of this thesis found using the real data that silicic acid was not limiting at any of the stations. The concentrations of total suspended solids also had a large influence and they had a greater influence on phytoplankton distributions than sea surface temperature (Fig. 3.1).

Surface temperatures had no relation with surface salinities, but they had negative relationships with all of the other variables. Higher temperatures are due to less mixing near the surface due to stratification, and chapter 2 shows that stratification was observed at many of the stations. Without turbulence there are less suspended solids and also nutrient concentrations are lower as they are drawn down by phytoplankton and not replenished from mixing of nutrient-rich deeper waters. The Secchi disk depth also decreases as the water becomes less transparent as more phytoplankton are produced.

Figure 3.2 shows that almost all of the west coast stations had lower than average temperatures compared to the east coast stations, which is expected if upwelling is occurring on the west coast but contradicts the findings from chapter two where there were no significant differences. Figure 3.2 also shows lower than average nutrient concentrations in 2001, while almost all of the 2002 stations were found in the higher than average region for nutrient concentrations. This is consistent with the findings in Chapter 2, where nutrient concentrations were significantly higher in 2002 than in 2001.

Pseudonitzschia "A" was common at stations 5, 6, and 7 (Fig. 3.3). These stations are not very close to each other geographically (one is in the north-east; one is in the south-east, and one is in the south-west, see Fig. 2.2), but they were sampled within one day of each other (July 25 and 26, 2001) and the water parameter values were similar. *Rhizosolenia setigera* was the most common diatom found in very high abundance at stations 11, 64, 74, and 75. These stations are very close in proximity (see Fig. 2.2), but stations 64, 74, and 75 were sampled within 4 days of each other (July 30-August 02, 2002), while station 11 was sampled at the same time, but one year earlier (August 01, 2001). This shows that the conditions were similar and ideal for *R. setigera* at the same time of year during two different years at these same stations. Figure 3.3 also shows that coccolithophores were found in high abundance at stations 78, 79, and 84. While stations 78 and 79 were very close to each other in the southeast region, station 84 was on the west coast. What these stations have in common is the absence of a mixed layer and stratification extending to the surface, which leads to ideal conditions for coccolithophore growth (Brand 1994).

In summary, nutrient concentrations, especially silicic acid, and light penetration had the greatest influence on phytoplankton community composition, while the depth of the mixed layer had the least effect. Silicic acid had an important effect on phytoplankton distribution using this analysis which contradicts the real data as seen in chapter 2, where silicic acid was not found to be limiting at any station. There seems to be a problem with this analysis and the real data should be used over this analysis. Dinoflagellates were generally related to higher temperatures while diatoms were closer related to cooler temperatures. The west coast stations had lower temperatures and less nutrients than the east coast stations, where the temperatures and nutrient concentrations were higher.

FINAL CONCLUSIONS

1) There was little significant spatial variability found in nutrient and chlorophyll *a* concentrations. Some small differences were observed but only silicic acid and chlorophyll *a* cells in the large size fraction (> 5 μm) had a significant difference between coasts, with higher concentrations on the west coast than the east for silicic acid and higher concentrations on the east coast than the west for the large size chlorophyll *a* concentration.

2) Temporal variability was observed with both significantly higher nutrient concentrations of all three nutrients and integrated chlorophyll *a* concentrations in both total chlorophyll *a* and the large size fraction in 2002 compared to 2001. Surface chlorophyll *a* concentrations showed no significant differences between these two seasons.

3) The greatest effect on phytoplankton communities came from nutrient concentrations and from the depth of light penetration while the smallest effect came from the depth of the mixed layer. Dinoflagellates were generally related to areas with higher temperatures while diatoms were closer related to areas with cooler temperatures.

FUTURE RESEARCH

This thesis has provided baseline data on physical, chemical, and biological properties of the nearshore waters surrounding Gwaii Haanas National Park Reserve/Haida Heritage Site. Further research should be conducted in this region. Suggestions for future research in the Gwaii Haanas region include:

1) Investigations of areas further offshore on the west coast of Gwaii Haanas to compare with the nearshore samples taken in both the inlets on the west coast as well as the samples taken on the east coast. Also, a comparison of these data to that found on the west coast of Vancouver Island.

2) Identification of the nanoflagellates found on both the east and west coast. These small cells were seen on both coasts in this study, especially the west coast and could contribute significantly to total productivity. Further studies on size fractionation of phytoplankton should be conducted, including primary productivity measurements to determine the contribution of both picoplankton and larger cells to total productivity.

3) Several of the algal species such as *Pseudonitzschia* spp., *Dinophysis* spp., and *Alexandrium* spp. that are found in the waters of Gwaii Haanas are toxin producers and potentially harmful if found in bloom concentrations. Further studies should be conducted to determine if there is a danger of shellfish contamination in this area.

4) Satellite remote sensing of the initiation of coccolithophore blooms on the east coast, and ground truthing for species identification to determine the cause of coccolithophore blooms.

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APPENDIX A

CRUISE DETAILS

Table A.1: Duration and date of each cruise including number of stations sampled and which coast.

Cruise Number	Dates	Duration (days)	Number of Stations	East or West Coast (E/W)
1	July 10 - 17	8	3	E
2	July 25 - 27	3	4	E
3	July 31 - Aug 03	4	13	E
4	Aug 8 - 10	3	5	E
5	Aug 14 - 19	6	9	E, W
6	July 2 - 5	4	3	E
7	July 8 - 12	5	8	E, W
8	July 16 - 24	9	18	E
9	July 29 - Aug 2	5	12	E
10	Aug 13 - 20	8	11	E, W

Table A.2: Wind and weather conditions at each station, including date and time sampled.

Number	Station	Date	Time	Wind	Weather
1	Huxley Island	11-Jul-01	10:00	7kn, 90°W	sunny/cloudy
2	Tanu	17-July-01	8:30	2kn,20°NW	rain
3	Skedans	17-July-01	11:15	2kn,140°SE	overcast
4	Skedans	25-July-01	15:30		sunny patches
5	Tanu	25-July-01	18:30	0kn,30°NW	sunny patches
6	Juan Perez Sound	26-July-01	9:15	2kn,30°NE	overcast
7	S'Gaang Gwaii	26-July-01	18:45	3kn,90°E	sunny patches
8	Cumshewa 5	31-July-01	14:00	18kn,75°NE	rain
9	Cumshewa 4	31-July-01	16:00	10kn,0°N	overcast
10	Cumshewa 3	31-Jul-01	19:30	2kn,30°NW	overcast
11	Cumshewa 2	1-Aug-01	8:30	3kn,30°SE	rain
12	Logan 4	1-Aug-01	12:00	3kn,30°NE	rain
13	Logan 3	1-Aug-01	14:45	4kn,150°SW	sunny patches
14	Logan 2	1-Aug-01	16:30	15kn,30°NE	overcast
15	Logan 1	1-Aug-01	18:45	6kn,75°NE	overcast
16	Juan Perez 1	2-Aug-01	9:30	5kn,150°SE	overcast
17	Juan Perez 2	2-Aug-01	10:45	7kn,120°SW	overcast
18	Juan Perez 3	2-Aug-01	12:30	13kn,30°NW	sunny patches
19	Juan Perez 4	2-Aug-01	14:30	4kn,60°NE	overcast
20	Juan Perez 5	3-Aug-01	8:15	13kn,20°NE	overcast
21	Juan Perez Sound	9-Aug-01	10:30	4kn,90°w	sunny
22	Huxley Island	9-Aug-01	15:00	8kn,75°NW	sunny
23	Hotsprings Island	9-Aug-01	17:30	10kn,50°NW	sunny
24	Dodge Point	10-Aug-01	14:30	7kn,45°NW	sunny
25	Skedans	10-Aug-01	18:30	1kn,90°E	sunny
26	Skedans	14-Aug-01	14:15	12kn,30°NW	overcast
27	Tanu	14-Aug-01	16:30	8kn,10°NE	sunny
28	Dodge Point	15-Aug-01	9:00	1kn,90°E	overcast
29	Huxley Island	15-Aug-01	17:00	5kn,20°NE	overcast
30	Wells Cove	16-Aug-01	18:00	5kn,20°NE	overcast
31	Gowgaia Bay	17-Aug-01	9:00	3kn,90°W	overcast
32	Gowgaia Bay Head	17-Aug-01	17:00	6kn,90°W	rain
33	Barry Inlet	18-Aug-01	16:30	7kn,20°NE	sunny patches
34	Sunday Inlet	19-Aug-01	13:00	5kn,45°NW	rain
35	Goodwin Rock	5-Jul-02	10:00	4 kn, 75NW	sunny patches
36	East Ramsay	5-Jul-02	12:30	10kn, 8NW	overcast
37	Laskeek Bay	5-Jul-02	14:45	5kn, 90W	sunny patches
38	Skidegate Channel	8-Jul-02	14:45	7 kn, 60 NW	overcast
39	Tasu Head	8-Jul-02	17:00	11kn, 60NE	overcast
40	Sunday Inlet	9-Jul-02	9:00	1kn, 180S	sunny
41	Gowgaia Bay	9-Jul-02	16:15	3kn, 150SE	overcast
42	Wells Cove	10-Jul-02	12:00	11kn, 0N	overcast
43	S'Gaang Gwaii	10-Jul-02	17:15	8kn, 90E	overcast

Table A.2 continued.

Number	Station	Date	Time	Wind	Weather
44	Koya Point	11-Jul-02	10:00	1kn, 150SW	overcast
45	Scudder Point	11-Jul-02	12:30	2kn, 180S	sunny
46	Cumshewa Inlet	17-Jul-02	16:30	8kn, 40NW	rain
47	Skedans	17-Jul-02	11:00	2kn, 60NW	sunny
48	Tanu	17-Jul-02	12:45	7kn, 0N	sunny patches
49	Dodge Point	18-Jul-02	8:00	6kn, 10NW	sunny
50	Tar Islands	18-Jul-02	9:45	11kn, 40NW	sunny
51	Hotsprings	19-Jul-02	9:00	7kn, 25NE	sunny patches
52	Juan Perez Sound	19-Jul-02	9:30	3kn, 10NE	sunny patches
53	Kat Island	19-Jul-02	13:00	9kn, 60 NW	sunny patches
54	Scudder Point	19-Jul-02	14:30	3kn, 150SE	sunny patches
55	Goodwin Point	19-Jul-02	15:30	8kn, 0N	sunny patches
56	Koya Point	19-Jul-02	16:30	10kn, 45NW	sunny
57	S'Gaang Gwaii	21-Jul-02	8:00	14kn, 60 NE	overcast
58	Benjamin Point	22-Jul-02	9:15	22kn, 30NW	sunny
59	Juan Perez Sound	22-Jul-02	12:30	10kn, 0N	sunny
60	Hotsprings	23-Jul-02	17:15	3kn, 180S	sunny
61	Darwin Sound	23-Jul-02	18:00	8kn, 150SW	sunny
62	Tanu	24-Jul-02	9:15	4kn, 150Sw	rain
63	Skedans	24-Jul-02	13:30	12kn, 20NW	overcast
64	Skedans	30-Jul-02	10:30	7kn, 90W	sunny patches
65	Tanu	30-Jul-02	13:15	9kn, 40NW	sunny patches
66	Dodge Point	30-Jul-02	14:15	4kn, 70NW	sunny patches
67	Tar Islands	30-Jul-02	15:30	6kn, 150SW	overcast
68	Juan Perez Sound	31-Jul-02	8:45	2kn, 0N	sunny patches
69	Scudder Point	31-Jul-02	10:00	6kn,0N	sunny patches
70	Benjamin Point	31-Jul-02	12:00	10kn, 0N	cloudy
71	S'Gaang Gwaii	31-Jul-02	13:15	8kn, 90W	sunny
72	Darwin Sound	1-Aug-02	11:15	8kn, 10NW	overcast
73	Tanu	1-Aug-02	15:30	4kn, 30NE	sunny
74	Skedans	2-Aug-02	8:45	9kn, 30NW	sunny patches
75	Cumshewa Inlet	2-Aug-02	9:30	5kn, 50NE	sunny patches
76	Juan Perez Sound	15-Aug-02	8:00	3kn, 0N	sunny
77	Swan Bay	15-Aug-02	10:00	2kn, 20NE	sunny
78	Jedway Bay	15-Aug-02	12:00	8kn, 75NW	sunny
79	Skincuttle Inlet	15-Aug-02	15:00	9kn, 25NW	sunny
80	Koya Point	15-Aug-02	16:30	17kn, 130SE	sunny
81	S'Gaang Gwaii	16-Aug-02	13:30	18kn, 90E	sunny
82	Gowgaia Bay	17-Aug-02	14:30	12kn, 100SW	sunny
83	Puffin Cove	18-Aug-02	15:00	5kn, 70NE	overcast
84	Sunday Inlet	19-Aug-02	8:45	2kn, 180S	overcast
85	Portland Bay	19-Aug-02	11:45	15kn, 80NW	overcast
86	Kitgoro Inlet	20-Aug-02	13:15	6kn, 60NW	overcast

APPENDIX B

ORIGINAL DATA

Table B.1: Secchi disk depths and concentrations of total suspended sediments at each station.

Number	Secchi (m)	TSS (g L^{-1})	Number	Secchi (m)	TSS (g L^{-1})
1	N/A	0.0229	**44**	7.5	0.0357
2	N/A	0.034	**45**	10.5	0.0305
3	8	0.033	**46**	9	0.0309
4	7.5	0.0316	**47**	13.5	0.0308
5	3.75	0.0346	**48**	15.5	0.0310
6	5	0.0329	**49**	17	0.0294
7	6	0.028	**50**	17+	0.0089
8	7.25	0.0294	**51**	11.5	0.0067
9	7.75	0.03	**52**	10.5	0.0091
10	7.25	0.0276	**53**	9	0.0367
11	6.75	0.0291	**54**	8.5	0.0096
12	7.5	0.0285	**55**	14	0.0116
13	5.75	0.0314	**56**	9	0.0112
14	8	0.0323	**57**	10	0.0153
15	N/A	0.0293	**58**	10	0.0316
16	10.75	0.0318	**59**	13.5	0.0082
17	10	0.0285	**60**	10.75	0.0087
18	8.5	0.0325	**61**	5.5	0.0197
19	9.75	0.0312	**62**	10.5	0.0153
20	N/A	0.0262	**63**	11.5	0.0138
21	14.5	0.03	**64**	7.25	0.0109
22	11	0.0347	**65**	9.5	0.0127
23	11	0.0308	**66**	11	0.0151
24	17+	0.0313	**67**	8	0.0136
25	12.5	0.03	**68**	9	0.0356
26	9.25	0.0299	**69**	5.5	0.0338
27	9.75	0.032	**70**	10	0.0345
28	6.75	0.0325	**71**	9	0.0331
29	7.25	0.0291	**72**	5	0.0162
30	7.25	0.0302	**73**	13.5	0.0219
31	N/A	N/A	**74**	7.25	0.0327
32	N/A	0.0299	**75**	7	0.0315
33	N/A	0.0289	**76**	10	0.0303
34	N/A	0.0171	**77**	6	0.0331
35	5.5	0.0348	**78**	5	0.0338
36	8	0.0297	**79**	6	0.0355
37	8	0.0294	**80**	7	0.0341
38	4	0.0332	**81**	8	0.0282
39	5	0.0304	**82**	10	0.0311
40	10	0.0308	**83**	8	0.0334
41	9.5	0.0249	**84**	6	0.0319
42	12	0.0327	**85**	10	0.0316

Table B.2: List of stations with missing S4 data including date sampled and problem encountered.

Station Number	Date	Problem	Station Number	Date	Problem
2	17-07-01	Time constraint	**29**	15-08-01	Machine shutdown
3	17-07-01	Time constraint	**30**	16-08-01	Machine shutdown
8	31-07-01	Machine shutdown	**31**	17-08-01	Machine shutdown
9	31-07-01	Machine shutdown	**32**	17-08-01	Machine shutdown
10	31-07-01	Machine shutdown	**33**	18-08-01	Machine shutdown
13	1/8/2001	Machine shutdown	**34**	19-08-01	Machine shutdown
14	1/8/2001	Machine shutdown	**51**	19-07-02	Broken cord
15	1/8/2001	Machine shutdown	**52**	19-07-02	Broken cord
16	2/8/2001	Machine shutdown	**53**	19-07-02	Broken cord
17	2/8/2001	Machine shutdown	**54**	19-07-02	Broken cord
18	2/8/2001	Machine shutdown	**55**	19-07-02	Broken cord
19	2/8/2001	Machine shutdown	**56**	19-07-02	Broken cord
20	3/8/2001	Machine shutdown	**57**	21-07-02	Broken cord
21	9/8/2001	Machine shutdown	**58**	22-07-02	Broken cord
22	9/8/2001	Machine shutdown	**59**	22-07-02	Broken cord
23	9/8/2001	Machine shutdown	**60**	23-07-02	Broken cord
24	10/8/2001	Machine shutdown	**61**	23-07-02	Broken cord
25	10/8/2001	Machine shutdown	**62**	24-07-02	Broken cord
26	14-08-01	Machine shutdown	**63**	24-07-02	Broken cord
27	14-08-01	Machine shutdown	**75**	2/8/2002	Infected file
28	15-08-01	Machine shutdown	**82**	17-08-02	Infected file

Table B.3: Temperature (°C) and salinity at the surface at each station.

Station	Temperature	Salinity
1	11.24	31.17
4	12.56	31.84
5	13.92	32.03
6	13.05	31.58
7	11.40	31.85
11	14.41	31.48
12	12.79	31.71
35	10.69	31.53
36	11.19	31.70
37	11.66	31.61
38	12.54	30.60
39	12.37	31.43
40	12.52	30.39
41	13.89	31.28
42	12.33	32.03
43	11.21	32.04
44	9.89	32.00
45	9.95	31.91
46	10.91	31.95
47	11.04	31.85
48	12.42	31.51
49	11.28	31.84
50	10.14	32.02
64	12.65	31.62
65	13.67	31.66
66	14.06	31.35
67	12.11	31.66
68	13.20	31.56
69	13.92	31.39
70	12.86	31.45
71	11.83	31.81
72	13.07	31.65
73	14.43	31.44
74	13.87	31.47
76	13.45	31.05
77	13.65	31.51
78	14.25	31.61
79	13.40	31.51
80	13.90	31.29
81	11.76	31.71
83	11.69	31.84
84	13.79	31.02
85	11.69	31.86
86	10.95	31.93

Table B.4: Nutrient concentrations (µM) and chlorophyll *a* concentrations (µg L^{-1}) in two size fractions for each depth. Nitrate concentrations denoted as zero, are undetectable.

Number	Depth (m)	PO_4	NO_3	$Si(OH)_4$	Chl a (>0.7µm)	Chl a (>5 µm)
1	0	0.38	0	6.3	1.2	0.58
	2	0.40	0	7.8	1.8	0.31
	5	0.24	0	3.6	2.2	0.75
	10	0.57	1.1	6.1	2.8	1.8
2	0	0.10	0	3.3	6.5	4.18
	2	0.16	0	1.3	3.1	3.4
	5	0.21	0	4.5	8.3	3.6
	10	0.46	1.6	6.7	6.8	2.5
3	0	0.53	1.4	7.5	4.1	2.3
	5	0.34	0.76	4.9	5.3	2.4
	10	0.58	1.9	9.5	5.9	2.2
	20	0.61	2.4	8.5	4.5	2.1
4	0	0.50	1.7	9.7	1.4	0.36
	5	0.67	2.2	11.7	2.1	0.56
	10	0.51	1.8	9.7	0.58	0.59
	20	0.67	2.4	12.0	1.1	0.41
5	0	0.24	0	5.4	11.0	3.1
	2	0.17	0	4.5	8.3	3.1
	5	0.24	0	5.2	1.3	2.7
	10	0.24	0	5.8	6.3	3.4
6	0	0.05	0	3.1	14.6	3.7
	5	0.09	0	1.5	3.3	4.5
	10	0.16	0	1.2	5.5	4.7
	20	0.40	1.0	7.0	9.4	6.2
7	0	0.61	6.1	13.3	1.6	2.1
	5	0.71	7.3	14.8	3.8	1.8
	10	0.69	7.5	14.8	3.5	1.4
	15	0.84	9.3	18.3	3.3	1.2
8	0	0.60	2.6	10.2	3.3	0.57
	5	0.53	2.2	10.1	5.8	0.63
	10	0.68	3.0	11.3	3.1	0.38
	15	0.71	3.3	11.4	3.0	0.48
9	0	0.33	0.67	6.5	5.9	1.8
	5	0.44	0.83	7.7	7.7	1.7
	10	0.68	1.3	10.3	3.3	1.6
	20	0.63	1.3	11.3	3.6	0.76
10	0	0.26	0	3.1	4.0	0.51
	2	0.28	0	3.1	1.6	0.68
	5	0.29	0	4.4	2.7	0.79
	10	0.44	0	6.0	3.1	1.6
11	0	0.26	0	1.8	2.3	0.26
	5	0.48	0	5.9	4.0	1.8
	10	0.43	0	6.3	4.1	0.71
	20	0.48	0.70	6.6	3.7	1.2

Table B.4 continued.

Number	Depth (m)	PO_4	NO_3	$Si(OH)_4$	Chl a (>0.7μm)	Chl a (>5 μm)
12	0	0.36	0	6.6	5.0	0.97
	5	0.35	0.86	5.4	6.6	1.8
	10	0.41	1.1	5.6	4.4	0.54
	20	0.68	2.7	9.5	1.9	0.26
13	0	0.24	0	4.7	6.0	1.4
	5	0.30	0	4.3	7.9	2.4
	10	0.56	0.98	7.2	2.0	0.51
	20	0.61	0.81	6.7	1.9	0.22
14	0	0.26	0	3.9	4.2	0.44
	5	0.47	0.04	4.8	1.7	0.54
	10	0.57	0.39	6.5	2.6	0.28
	20	0.64	1.2	6.5	0.58	0.29
15	0	0.30	0	3.7	4.3	1.1
	5	0.23	0	1.9	15.8	5.5
	10	0.15	0	1.7	9.6	2.6
	15	0.45	0	3.5	2.0	0.32
16	0	0.54	0.68	4.7	2.0	0.30
	5	0.44	1.5	4.7	2.4	0.27
	10	0.64	2.1	6.3	3.0	0.37
	20	0.69	2.3	6.5	2.1	0.03
17	0	0.30	0	2.2	2.6	0.18
	5	0.38	0	2.5	2.5	0.32
	10	0.29	0	2.1	2.3	0.33
	20	0.52	0	5.0	0.91	0.12
18	0	0.28	0	3.6	2.4	0.22
	5	0.40	0	3.9	2.3	0.22
	10	0.54	1.1	5.6	1.7	0.02
	20	0.60	1.4	7.3	1.8	0.17
19	0	0.28	0	3.6	1.7	0.12
	5	0.30	0	2.7	3.6	0.97
	10	0.42	0	1.9	4.4	0.55
	20	0.43	0	2.6	0.80	0.10
20	0	0.57	2.1	6.9	2.1	0.24
	5	0.39	1.0	6.1	3.5	0.20
	10	0.59	2.3	7.2	0.98	0.20
	20	0.67	2.4	7.4	1.4	0.17
21	0	0.34	0.08	4.2	1.4	0.22
	5	0.49	0.19	5.4	4.0	0.53
	10	0.57	0.92	5.8	4.5	0.57
	20	0.66	1.4	5.9	1.6	0.15
22	0	0.47	1.0	8.4	1.7	0.27
	5	0.60	1.7	9.4	3.8	0.84
	10	0.66	1.9	8.4	3.5	0.78
	20	0.57	1.7	6.7	1.8	0.43

Table B.4 continued.

Number	Depth (m)	PO_4	NO_3	$Si(OH)_4$	Chl a (>0.7µm)	Chl a (>5 µm)
23	0	0.76	4.9	11.3	1.8	0.34
	5	0.56	4.2	11.0	1.3	0.32
	10	0.85	6.6	14.8	0.67	0.31
	20	0.85	8.5	16.1	2.0	0.17
24	0	0.60	2.2	11.3	2.0	0.43
	5	0.87	6.2	13.5	0.76	0.37
	10	4.2	8.6	15.8	1.3	0.24
	20	1.1	11.2	18.6	0.68	0.12
25	0	0.85	7.4	17.3	6.02	2.1
	5	0.85	7.6	15.4	4.0	2.0
	10	0.47	3.6	8.0	2.5	2.0
	20	0.87	7.8	15.9	3.7	1.9
26	0	0.55	1.0	10.6	13.4	3.8
	5	0.55	1.4	12.4	10.1	3.7
	10	0.29	1.3	7.1	5.2	2.5
	20	0.76	5.2	13.7	6.3	2.3
27	0	0.17	0	4.4	1.2	0.97
	2	0.32	0	9.1	1.2	1.0
	5	0.38	0	9.3	9.5	2.5
	10	0.64	4.4	14.3	5.5	1.8
28	0	0.19	0	4.5	1.8	1.0
	5	0.16	0	4.0	2.7	2.0
	10	1.1	1.0	7.3	N/A	2.1
	20	0.66	5.0	13.5	7.7	2.2
29	0	0.20	0	7.7	1.5	0.70
	5	0.32	0	8.0	4.0	4.0
	10	0.44	0	9.8	1.4	2.3
	20	0.79	3.6	11.2	0.50	0.32
30	0	0.20	0	7.2	3.0	0.32
	5	0.43	0.09	10.6	2.4	0.38
	10	0.28	2.1	12.0	6.9	0.29
31	0	0.31	0	11.2	1.6	0.32
	5	0.37	0	9.7	2.1	0.34
	10	0.34	0.51	9.5	3.3	0.53
32	0	0.13	0	7.8	11.1	0.91
	5	0.41	2.1	10.6	3.2	0.27
	10	0.49	0.78	12.9	2.3	0.68
	15	0.37	0	11.2	1.7	0.47
33	0	0.22	0	10.6	7.1	0.18
	5	0.24	0	8.4	2.8	0.21
	10	0.28	0	11.0	6.8	0.36
	20	0.36	0	13.3	3.2	0.35

Table B.4 continued.

Number	Depth (m)	PO_4	NO_3	$Si(OH)_4$	Chl a (>0.7µm)	Chl a (>5 µm)
34	0	0	0.33	5.9	7.8	1.3
	5	0.15	0	4.9	7.1	0.99
	10	0.34	0	9.5	2.6	0.65
	15	0.31	0	7.2	4.2	0.76
35	0	0.49	4.0	12.0	7.0	2.6
	5	0.48	3.1	11.4	7.2	0.41
	10	0.56	4.1	12.0	7.1	6.8
	20	1.1	12.9	18.9	2.7	NA
36	0	0.53	3.4	11.3	4.5	0.68
	5	0.49	2.7	11.0	2.6	1.0
	10	0.34	1.9	7.8	5.3	0.61
	20	0.80	8.9	15.7	3.5	0.28
37	0	0.41	2.7	9.0	3.8	0.62
	5	0.66	5.9	14.5	5.3	1.6
	10	0.83	8.5	15.9	2.7	1.1
	20	0.94	10.6	18.4	6.8	2.2
38	0	0.24	0.21	10.9	6.0	0.33
	5	0.41	2.1	11.6	6.2	0.67
	10	0.42	3.0	11.8	5.0	0.58
	20	0.78	6.5	17.3	1.6	0.09
39	0	0.41	1.7	15.3	3.7	0.43
	5	0.50	2.1	15.3	6.8	0.22
	10	0.41	2.2	12.3	6.5	0.08
	20	0.44	3.2	9.5	2.2	0.13
40	0	0.39	2.9	7.9	2.0	0.28
	5	0.78	6.7	15.6	0.76	0.18
	10	0.84	8.4	17.1	1.9	0.11
	20	0.95	10.7	18.8	1.2	0.11
41	0	0.43	0	1.1	1.4	0.33
	5	0.30	0.47	3.6	1.5	0.51
	10	0.36	1.8	8.1	3.3	1.4
	20	0.91	10.9	18.6	6.5	2.8
42	0	0.53	4.2	11.0	2.6	0.17
	5	0.48	3.9	10.7	2.3	0.12
	10	0.34	2.9	8.1	2.1	0.18
	20	0.51	4.5	11.7	2.3	0.28
43	0	0.62	4.4	15.7	4.2	1.1
	5	0.41	2.6	8.4	3.3	1.5
	10	0.57	4.6	13.8	3.6	1.6
	20	0.74	7.2	16.5	4.3	1.9
44	0	0.86	10.1	18.1	6.1	1.2
	5	0.80	10.0	17.3	3.3	0.95
	10	0.62	6.8	12.5	3.2	1.1
	20	0.98	11.3	19.4	2.8	1.2

Table B.4 continued.

Number	Depth (m)	PO_4	NO_3	$Si(OH)_4$	Chl a (>0.7μm)	Chl a (>5 μm)
45	0	0.79	8.8	15.8	2.3	0.54
	5	0.63	5.7	15.8	3.6	0.67
	10	0.72	7.4	16.5	6.5	N/A
	20	0.57	5.8	10.4	2.6	0.59
46	0	0.70	5.8	13.8	3.0	0.43
	5	0.62	4.9	12.4	3.0	0.91
	10	0.81	6.7	15.9	3.3	1.3
	20	0.82	6.9	16.1	4.4	1.2
47	0	0.86	7.7	17.0	2.3	0.56
	5	0.67	5.8	11.8	2.2	0.81
	10	0.83	7.5	15.3	3.5	0.82
	20	0.89	8.3	16.8	0.77	0.93
48	0	0.61	4.4	11.4	3.6	1.3
	5	0.77	6.8	14.2	2.6	0.85
	10	0.81	7.4	14.9	2.4	0.59
	20	0.90	8.6	17.3	1.1	0.53
49	0	0.65	4.9	10.7	1.7	0.69
	5	0.37	2.4	5.8	2.1	0.57
	10	0.73	6.0	12.7	3.9	0.32
	20	0.46	3.2	6.3	1.0	0.22
50	0	0.86	9.4	17.5	3.6	0.89
	5	0.86	9.4	16.8	3.8	0.88
	10	0.89	9.4	17.8	4.6	0.55
	20	0.87	9.8	18.1	3.4	1.1
51	0	0.58	4.6	14.1	3.6	1.0
	5	0.68	6.4	13.1	4.4	0.75
	10	0.58	5.8	10.3	2.5	0.75
	20	0.98	11.2	18.0	0.49	0.75
52	0	0.48	2.9	13.8	2.3	0.19
	5	0.51	3.9	13.6	2.6	0.28
	10	0.61	5.6	14.2	3.0	0.22
	20	0.87	10.4	16.9	2.2	0.14
53	0	0.15	0	1.8	2.0	0.42
	5	0.19	0	1.9	1.3	0.39
	10	0.32	0	1.5	1.5	1.0
	20	0.90	5.9	4.5	6.0	2.8
54	0	0.18	0.44	4.1	2.1	0.84
	5	0.27	1.1	5.8	1.3	0.42
	10	0.56	5.0	10.2	3.2	0.51
	20	1.1	13.3	20.5	0.65	0.23
55	0	0.78	6.9	14.1	2.5	0.19
	5	0.78	7.2	14.3	1.3	0.31
	10	0.65	6.9	12.3	2.6	0.50
	20	1.0	11.9	19.7	1.7	1.0

Table B.4 continued.

Number	Depth (m)	PO_4	NO_3	$Si(OH)_4$	Chl a (>0.7μm)	Chl a (>5 μm)
56	0	0.91	10.5	19.3	2.3	0.46
	5	0.93	10.8	19.7	2.4	0.70
	10	0.67	7.8	14.2	4.1	0.64
	20	0.99	12.1	21.0	2.0	0.49
57	0	0.62	4.5	14.4	2.4	0.47
	5	0.53	4.9	12.3	4.0	0.83
	10	0.57	5.5	13.0	3.5	1.1
	20	0.84	9.1	18.4	1.7	1.1
58	0	0.52	3.8	11.8	5.2	0.47
	5	0.75	7.7	17.2	4.3	0.96
	10	0.76	8.1	17.8	4.9	1.2
	20	0.84	9.4	18.8	2.8	1.2
59	0	0.51	3.9	9.6	3.8	0.92
	5	0.33	2.4	5.9	10.5	0.76
	10	0.42	3.5	7.8	5.1	1.6
	20	0.61	6.0	11.0	6.3	2.0
60	0	0.31	1.3	6.7	3.1	2.3
	5	0.27	1.3	4.9	5.3	3.9
	10	0.49	3.6	9.4	5.4	2.5
	20	0.61	5.9	11.0	4.6	3.7
61	0	0.16	0.70	6.5	4.9	1.4
	5	0.19	0.94	8.4	5.2	1.6
	10	0.19	1.2	7.3	5.9	4.1
	20	0.60	6.1	12.5	11.2	2.9
62	0	0.57	3.6	10.5	3.9	1.9
	5	0.60	4.3	11.3	6.1	2.0
	10	0.62	5.0	11.5	5.8	2.9
	20	0.80	7.5	14.4	5.7	1.4
63	0	0.66	5.4	11.5	5.4	2.1
	5	0.69	5.4	12.7	7.7	2.3
	10	0.74	5.7	12.9	4.1	2.5
	20	0.69	5.7	13.0	9.6	1.4
64	0	0.33	0.97	3.2	5.8	2.1
	5	0.55	2.2	7.1	5.7	3.0
	10	0.54	2.1	7.4	5.5	4.1
	20	0.59	3.0	8.3	3.6	4.3
65	0	0.33	0.42	5.7	4.3	0.33
	5	0.32	0.57	6.4	4.0	1.0
	10	0.25	0.52	5.8	4.6	1.2
	20	0.23	0.57	4.1	2.1	2.7
66	0	0.16	0.26	3.2	5.3	1.1
	5	0.24	0.50	4.3	12.1	1.4
	10	0.39	1.9	7.4	6.2	3.2
	20	0.42	2.2	7.7	10.8	3.2

Table B.4 continued.

Number	Depth (m)	PO_4	NO_3	$Si(OH)_4$	Chl a (>0.7μm)	Chl a (>5 μm)
67	0	0.29	1.4	4.0	10.8	2.6
	5	0.49	3.0	8.3	5.6	2.5
	10	0.48	2.9	8.4	6.4	2.4
	20	0.57	4.3	9.4	5.5	1.9
68	0	0.13	0.15	1.8	5.3	1.4
	5	0.30	0.76	4.9	5.5	0.91
	10	0.33	1.4	5.7	3.9	1.9
	20	0.46	3.2	8.0	3.2	1.8
69	0	0.21	0	1.8	2.6	1.1
	5	0.13	0	2.0	4.9	1.3
	10	0.36	2.3	5.4	4.7	2.8
	20	0.73	7.6	12.0	6.2	1.3
70	0	0.42	2.9	9.7	8.2	1.9
	5	0.43	4.0	10.3	5.5	2.0
	10	0.37	2.6	6.5	3.5	1.4
	20	0.70	7.5	15.0	3.5	1.8
71	0	0.49	3.4	9.6	4.5	1.2
	5	0.63	5.4	14.9	3.9	1.1
	10	0.50	4.2	10.5	4.7	1.3
	20	0.64	6.0	14.2	2.8	1.1
72	0	0.15	0.14	2.7	5.9	2.4
	5	0.05	0	0.84	3.7	1.9
	10	0.19	0.32	1.1	9.3	3.9
	20	0.62	4.8	8.5	7.7	2.3
73	0	0.17	0	4.0	0.36	0.54
	5	0.20	0.12	4.5	1.9	0.41
	10	0.43	1.7	6.6	2.2	1.4
	20	0.27	1.3	3.0	3.8	3.5
74	0	0.37	0.07	1.8	4.8	2.8
	5	0.25	0.11	1.3	2.7	2.1
	10	0.32	0.18	1.7	9.0	1.6
	20	0.27	0.39	2.4	13.0	3.3
75	0	0.41	0	0.71	3.3	0.92
	5	0.44	0.05	1.1	5.5	2.4
	10	0.43	0	1.0	7.5	2.5
	20	0.32	0	0.79	8.5	2.6
76	0	0.43	2.1	9.6	4.5	1.9
	5	0.42	2.0	10.0	5.2	1.7
	10	0.39	1.7	7.4	6.3	4.1
	20	0.33	2.1	6.6	4.8	3.7
77	0	0.39	0.89	8.8	5.6	2.1
	5	0.30	1.1	6.2	6.0	2.6
	10	0.46	2.9	8.7	7.0	3.3
	20	0.49	3.5	9.7	3.5	3.4

Table B.4 continued.

Number	Depth (m)	PO_4	NO_3	$Si(OH)_4$	Chl a (>0.7μm)	Chl a (>5 μm)
78	0	0.22	0	6.5	3.3	0.38
	5	0.31	0	7.8	5.3	1.9
	10	0.31	0	8.9	10.5	4.7
	20	0.48	2.2	9.5	5.7	2.1
79	0	0.31	1.0	6.6	6.2	2.0
	5	0.45	2.2	9.3	5.9	2.7
	10	0.92	2.5	8.8	12.5	4.0
	20	0.49	3.3	8.6	7.3	4.1
80	0	0.42	1.3	11.6	4.9	0.70
	5	0.50	2.8	26.3	4.7	0.79
	10	0.43	3.0	10.7	3.7	0.89
	20	0.60	7.3	14.1	2.6	1.1
81	0	0.85	10.6	20.2	3.0	0.49
	5	0.86	10.7	19.5	4.0	0.62
	10	0.87	10.9	20.4	4.6	0.74
	20	0.67	7.4	14.2	4.1	0.78
82	0	0.70	7.1	17.2	1.4	0.70
	5	0.82	9.7	19.1	3.9	0.63
	10	0.91	12.0	21.2	2.2	0.76
	20	0.95	12.5	21.0	5.0	0.77
83	0	0.84	9.5	17.3	3.2	0.51
	5	0.88	10.6	17.7	2.0	0.49
	10	0.91	11.0	18.7	4.6	0.63
	20	0.99	13.1	20.2	3.5	0.75
84	0	0.26	0.11	9.9	5.3	2.3
	5	0.75	6.2	16.3	13.1	1.9
	10	0.79	7.1	17.1	4.3	0.61
	20	1.2	13.7	22.5	0.51	0.22
85	0	0.65	6.8	14.4	2.8	0.38
	5	0.85	9.8	18.5	2.8	0.46
	10	0.80	9.6	17.4	2.6	0.62
	20	0.87	11.0	16.4	2.4	0.31
86	0	0.81	8.7	15.5	4.4	0.40
	5	0.78	10.7	16.5	4.7	0.32
	10	0.68	7.4	13.5	3.2	0.49
	20	1.0	13.2	22.4	4.4	0.45

APPENDIX C

VERTICAL PROFILES OF PHYSICAL PROPERTIES

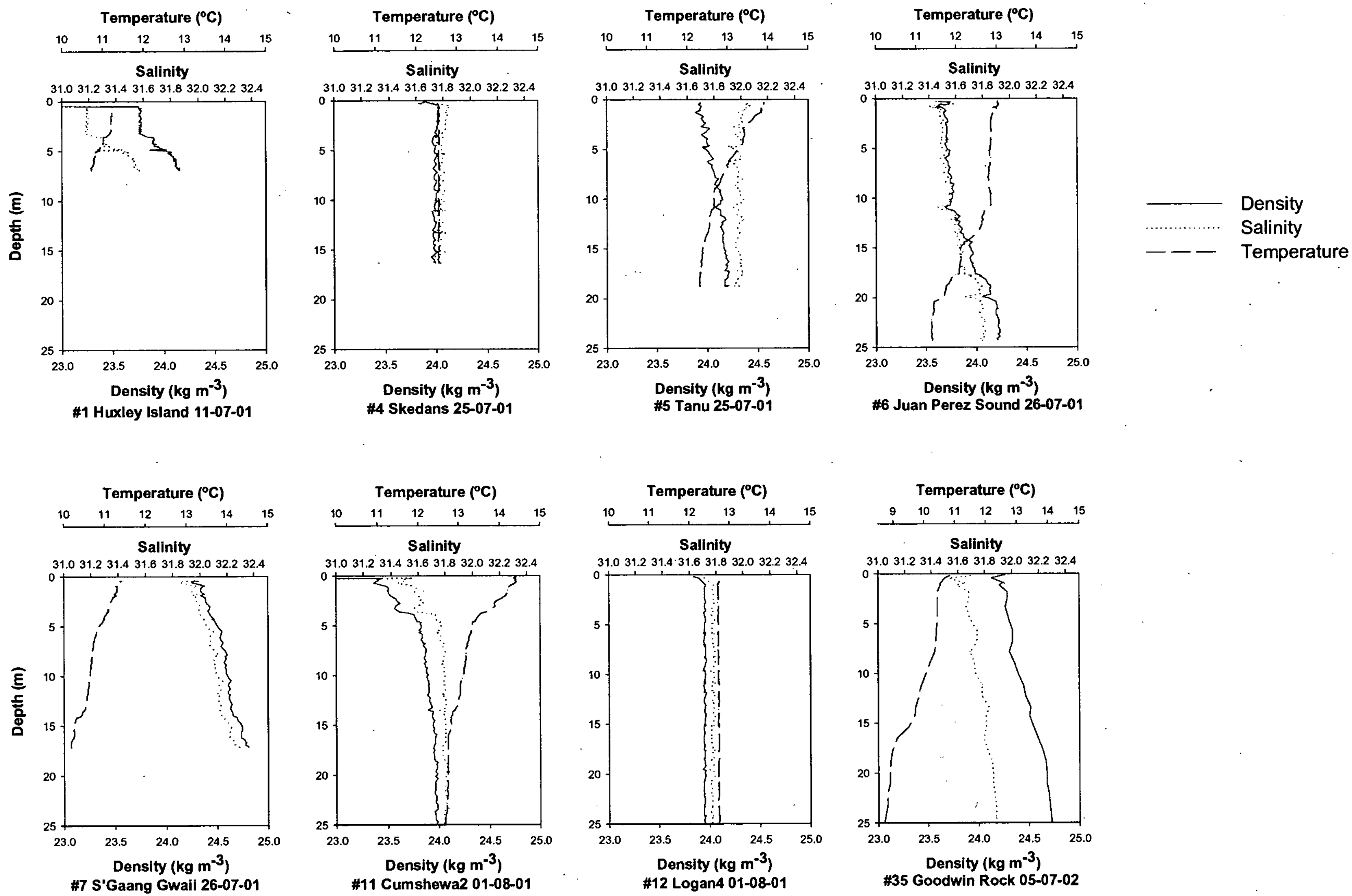

Figure C.1: Vertical profiles of temperature, salinity, and density for each of the stations sampled

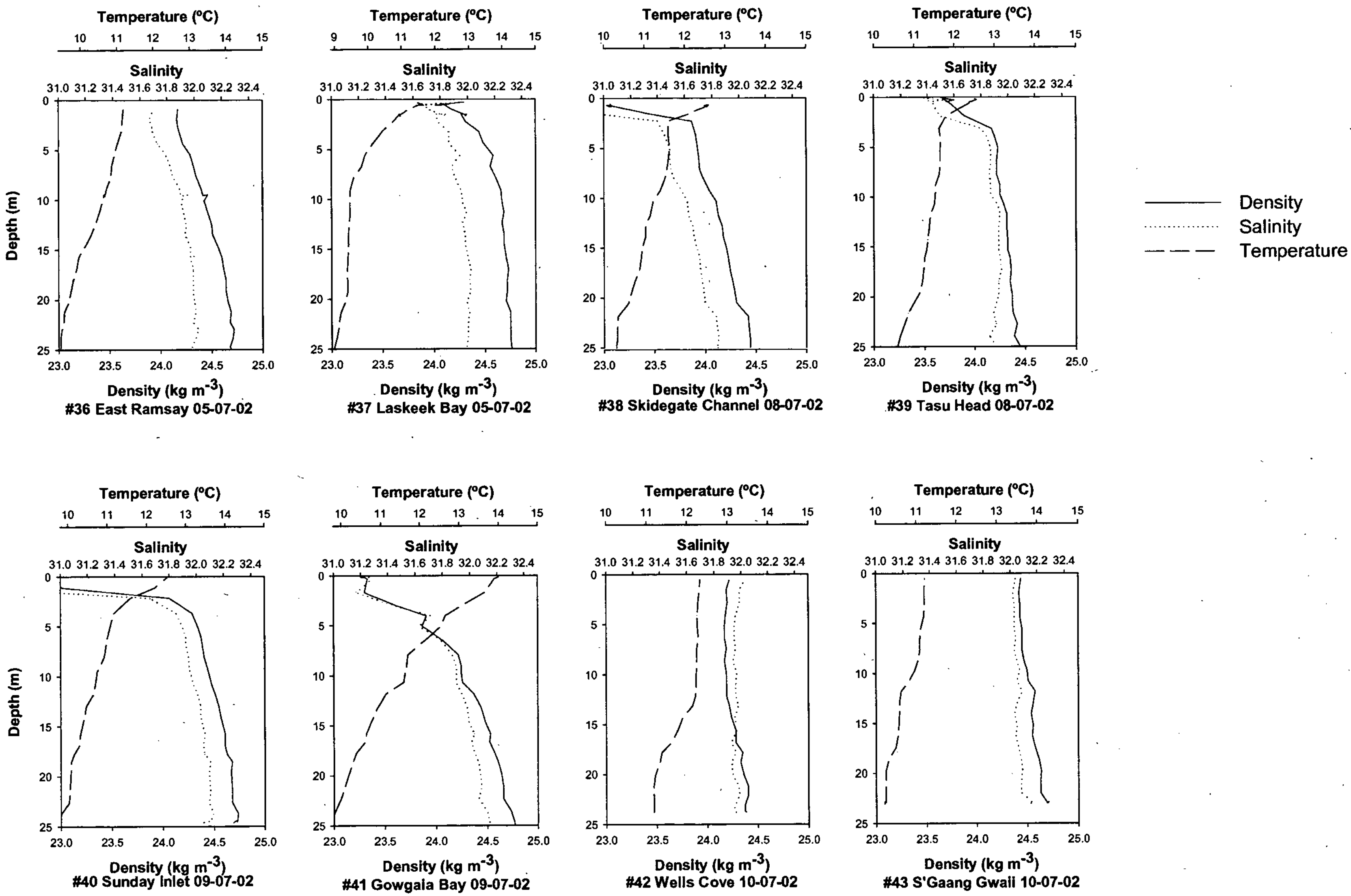

Figure C.1: Vertical profiles of temperature, salinity, and density for each of the stations sampled

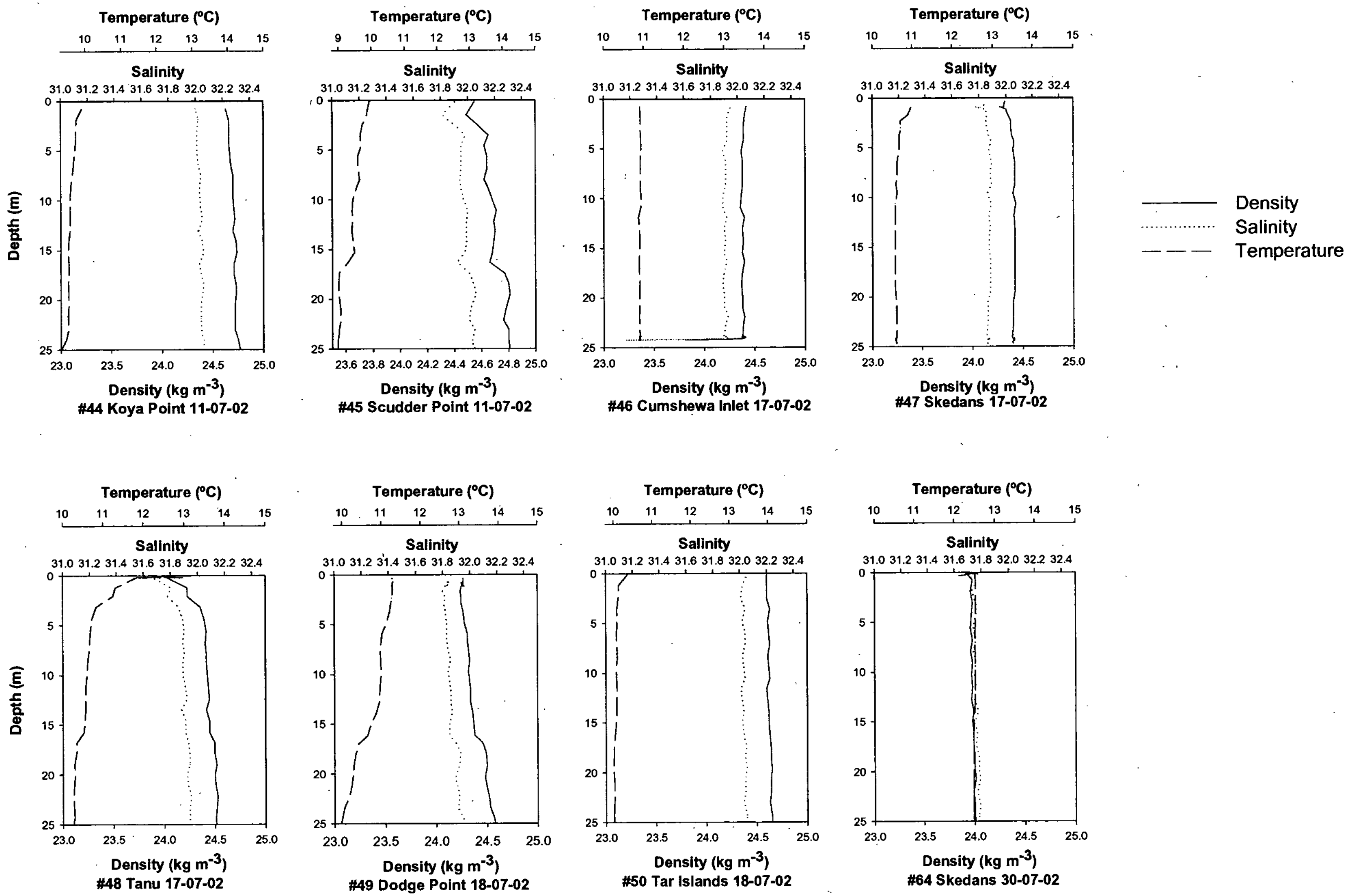

Figure C.1: Vertical profiles of temperature, salinity, and density for each of the stations sampled

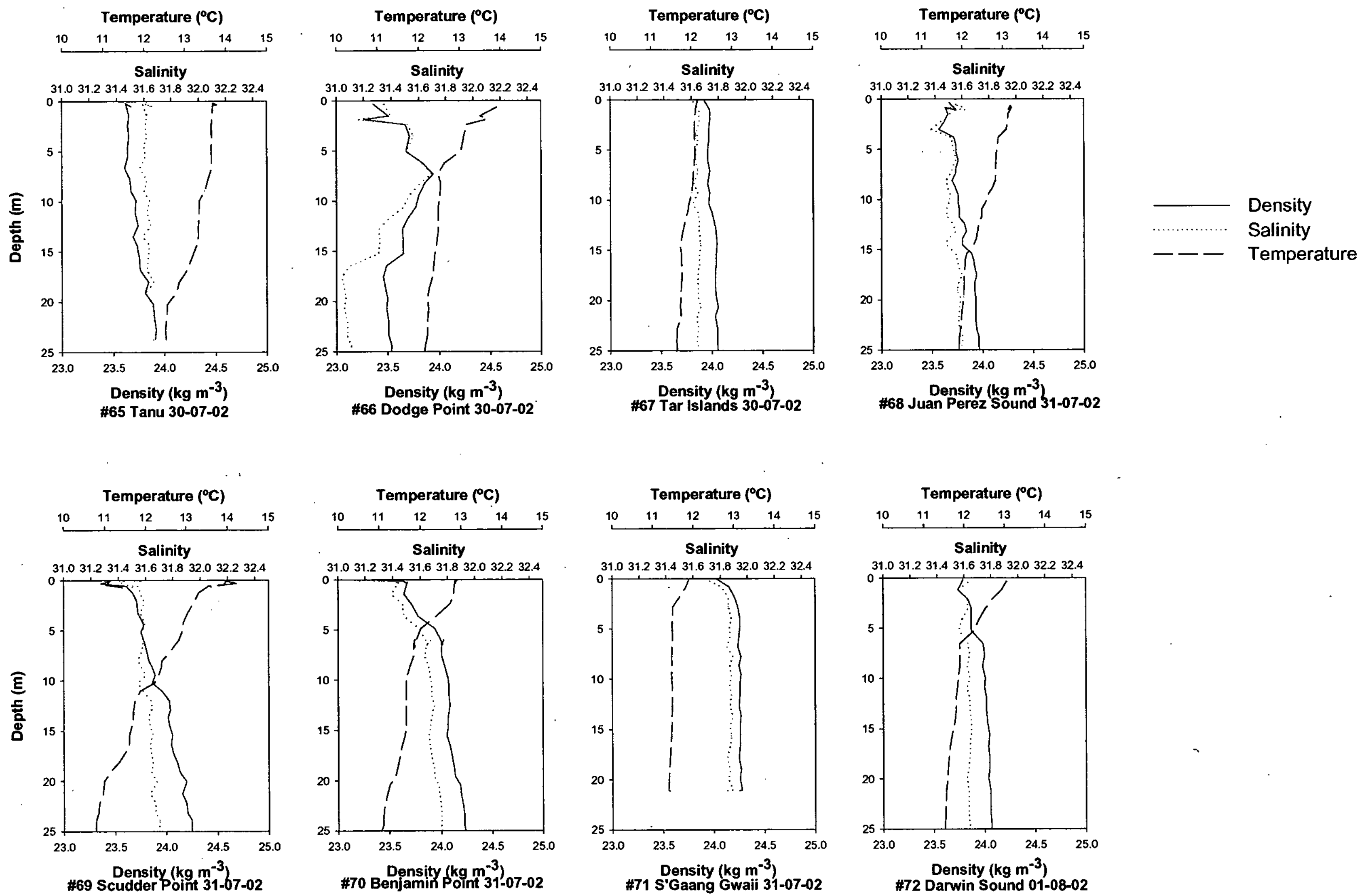

Figure C.1: Vertical profiles of temperature, salinity, and density for each of the stations sampled

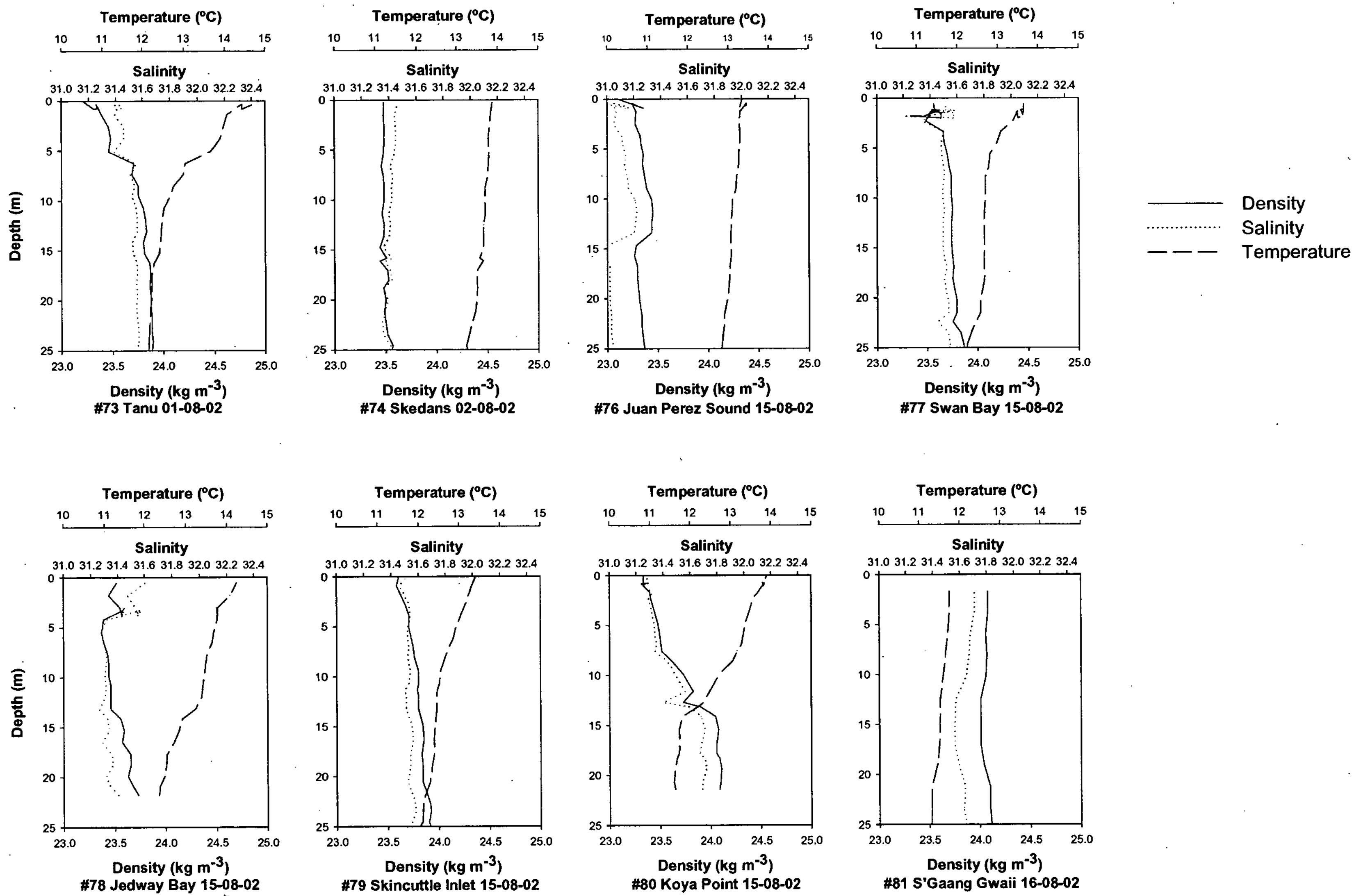

Figure C.1: Vertical profiles of temperature, salinity, and density for each of the stations sampled

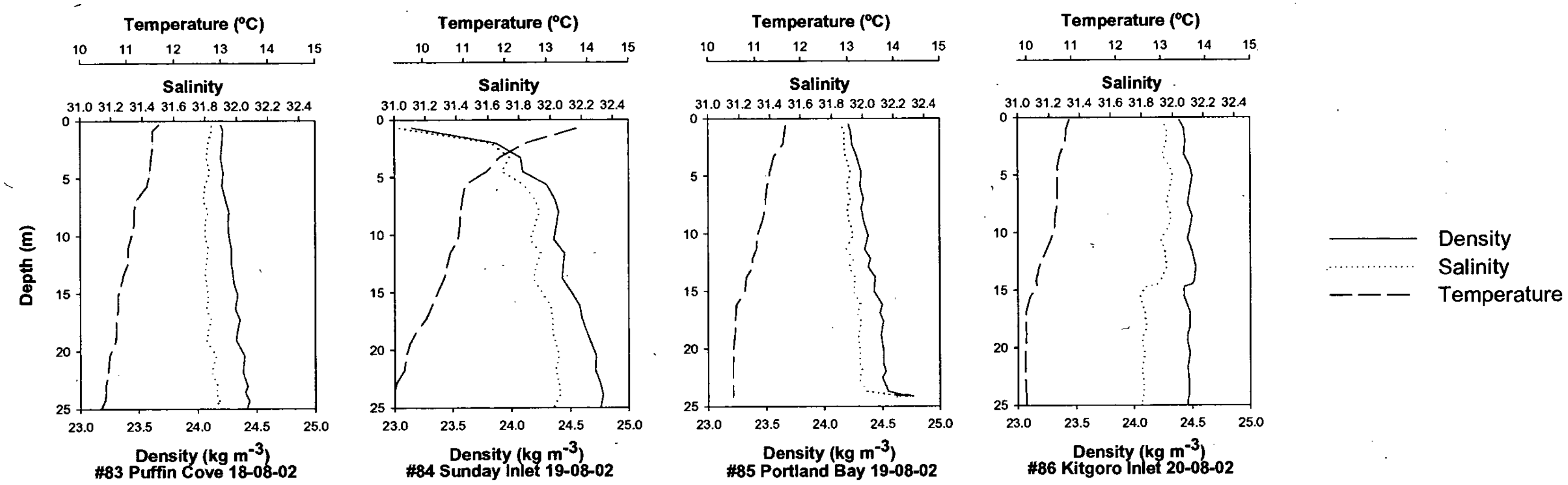

Figure C.1: Vertical profiles of temperature, salinity, and density for each of the stations sampled

APPENDIX D

VERTICAL PROFILES OF CHEMICAL PARAMETERS

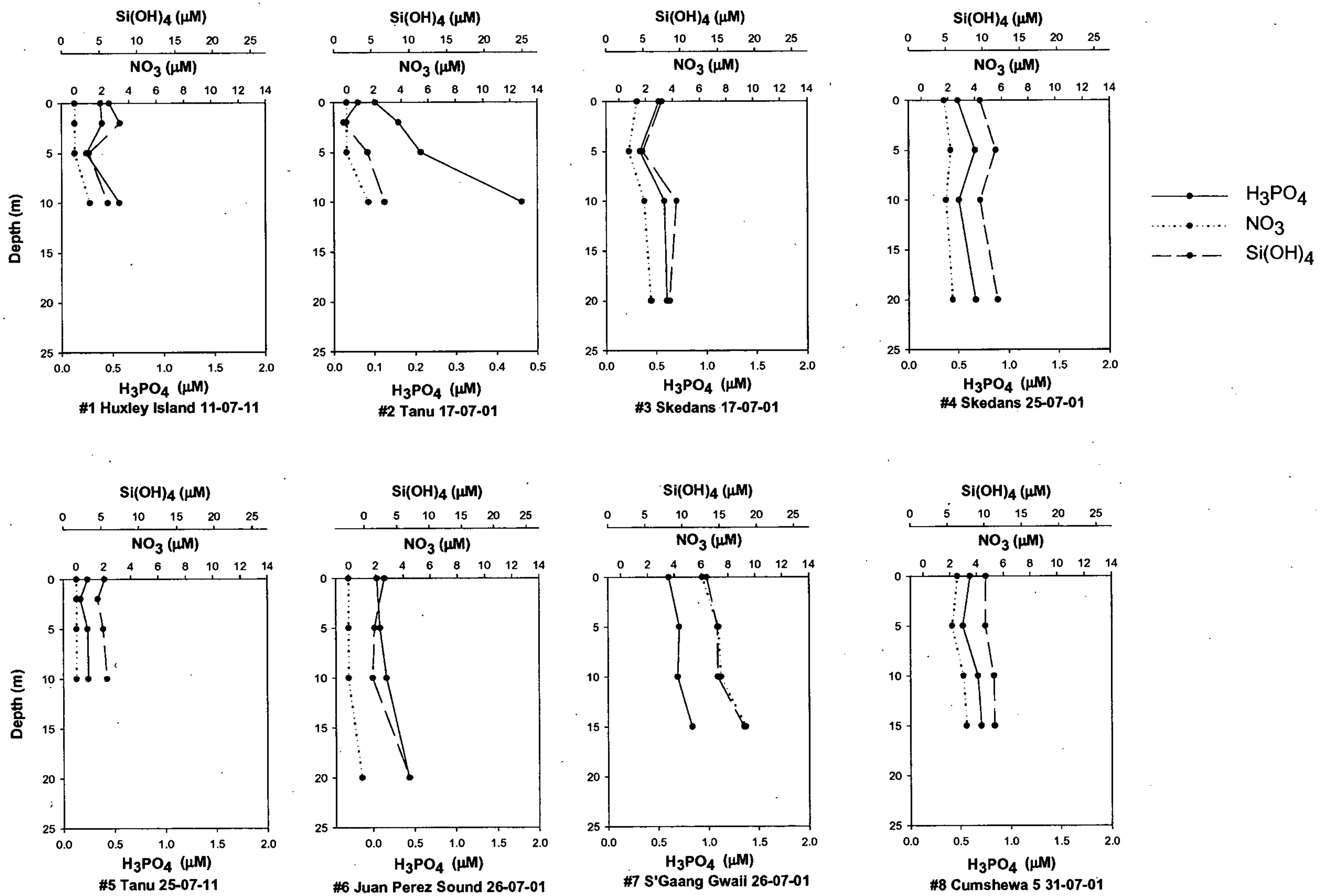

Figure D.1: Vertical profiles of nitrate, phosphate, and silicic acid for each of the stations sampled.

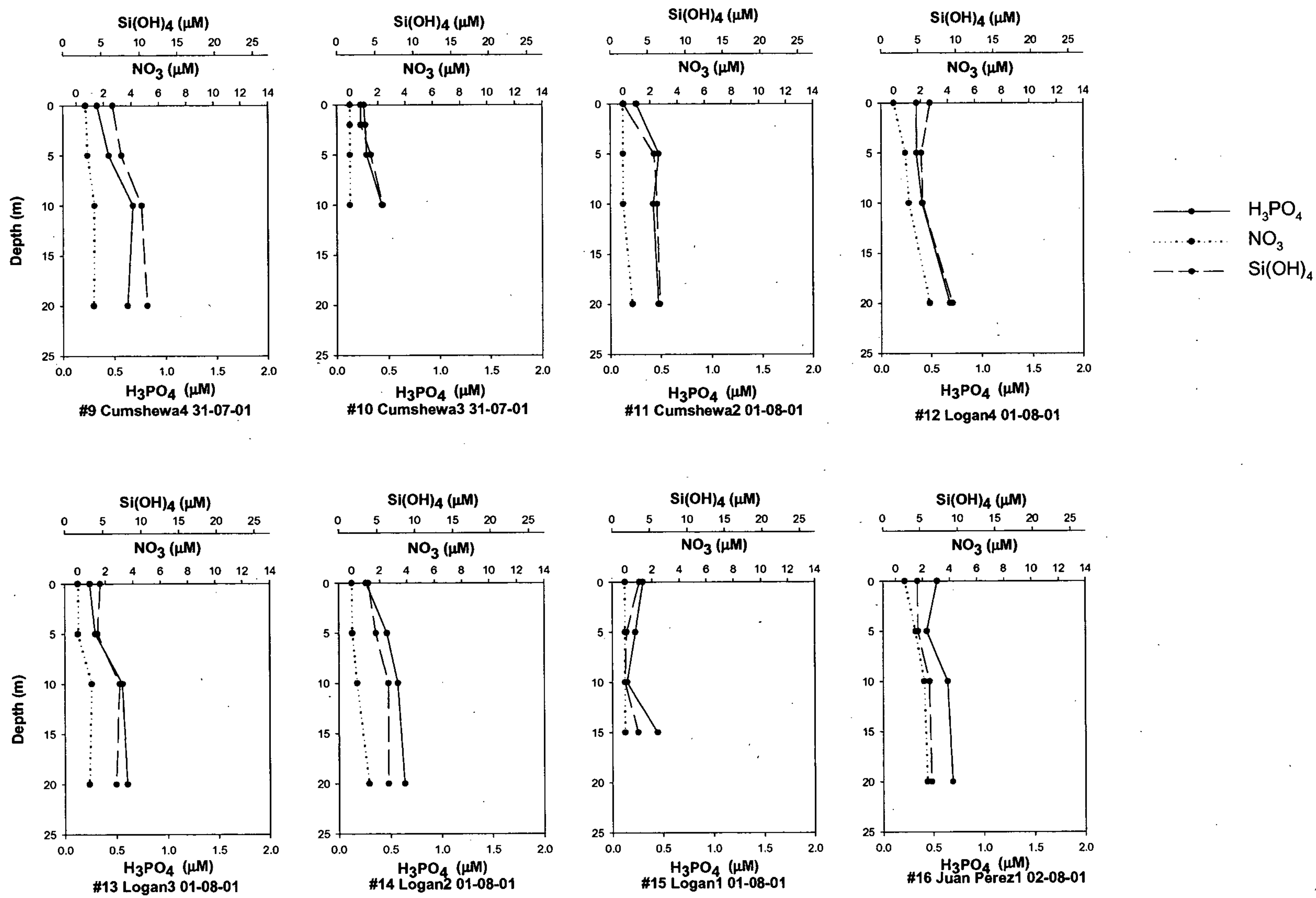

Figure D.1: Vertical profiles of nitrate, phosphate, and silicic acid for each of the stations sampled.

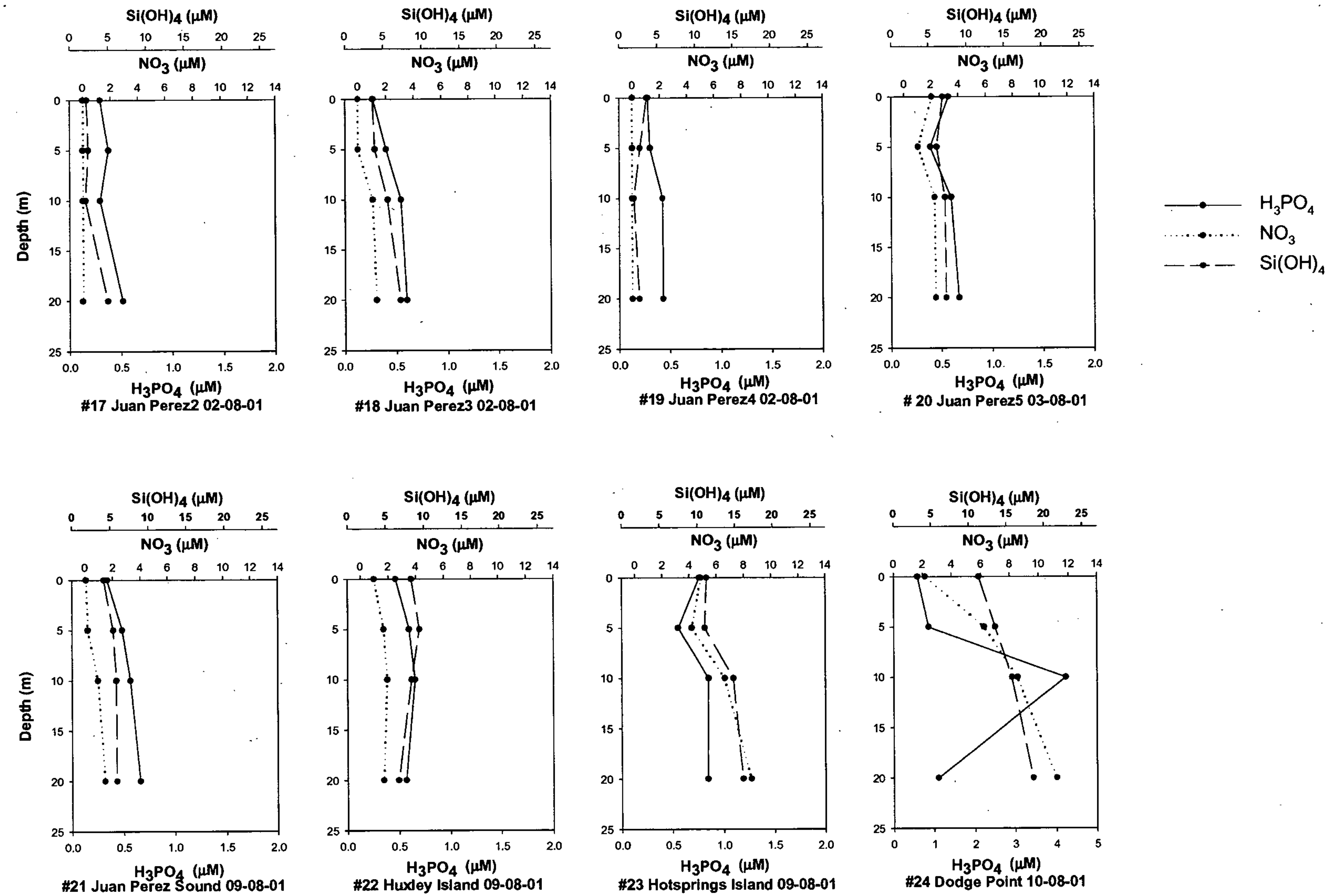

Figure D.1: Vertical profiles of nitrate, phosphate, and silicic acid for each of the stations sampled.

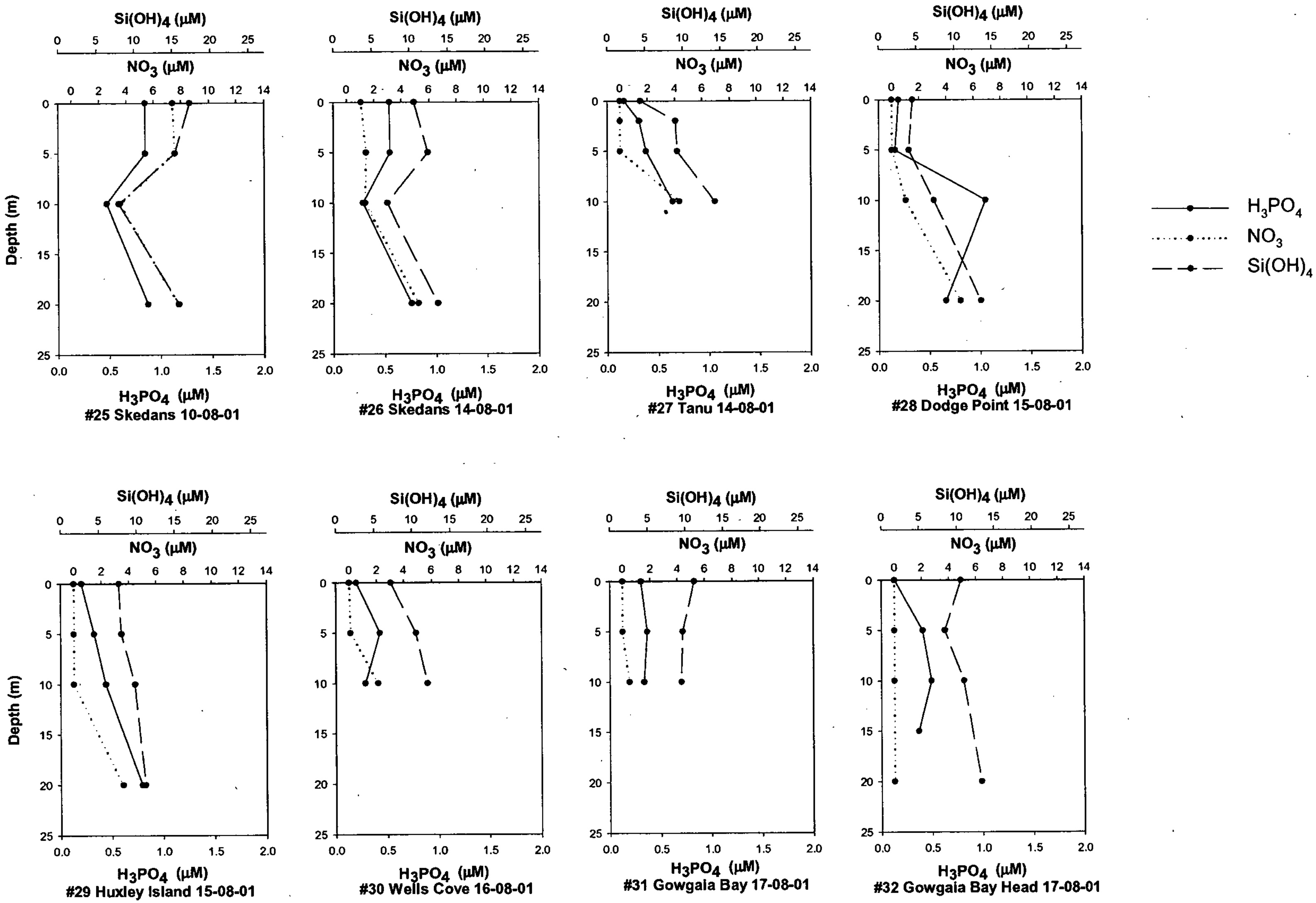

Figure D.1: Vertical profiles of nitrate, phosphate, and silicic acid for each of the stations sampled.

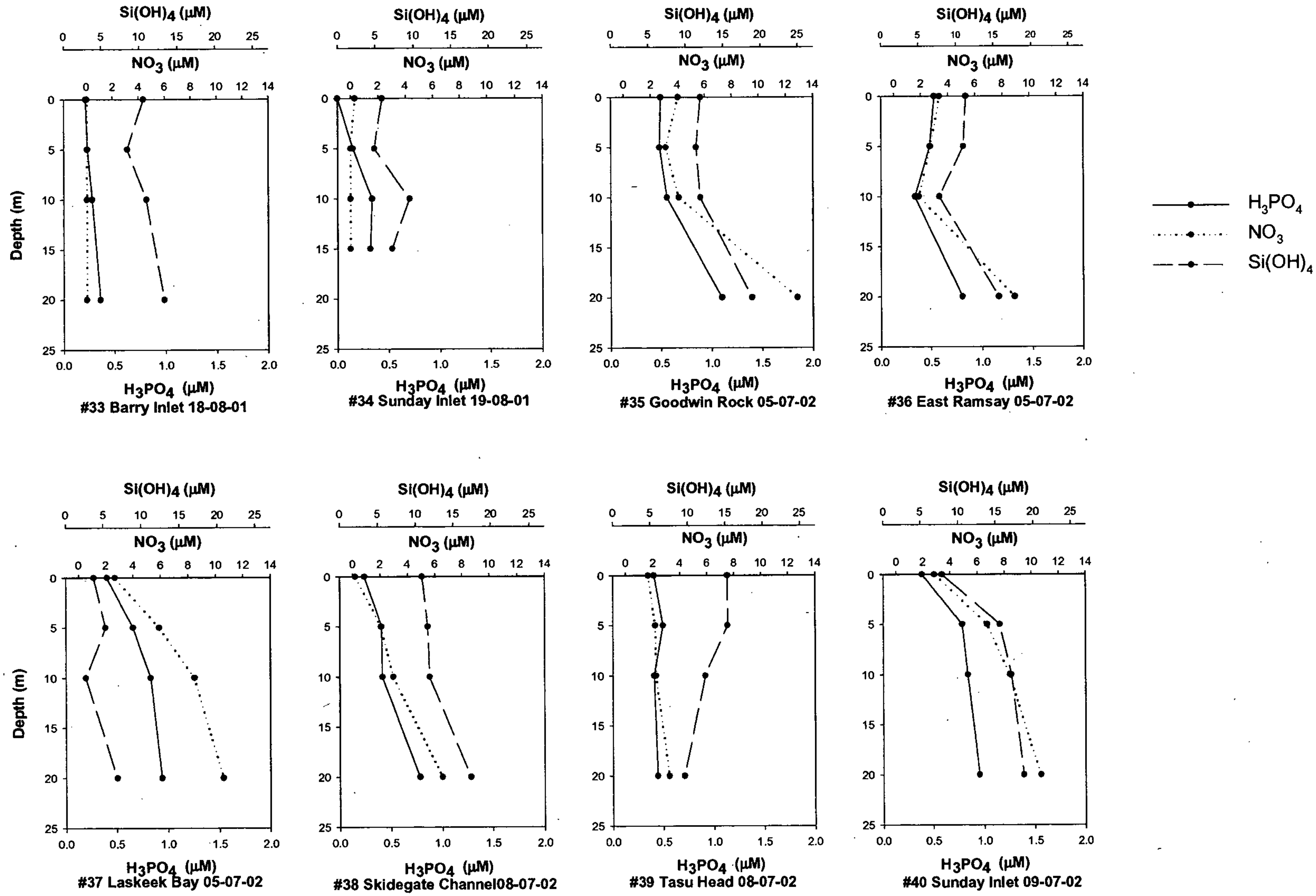

Figure D.1: Vertical profiles of nitrate, phosphate, and silicic acid for each of the stations sampled.

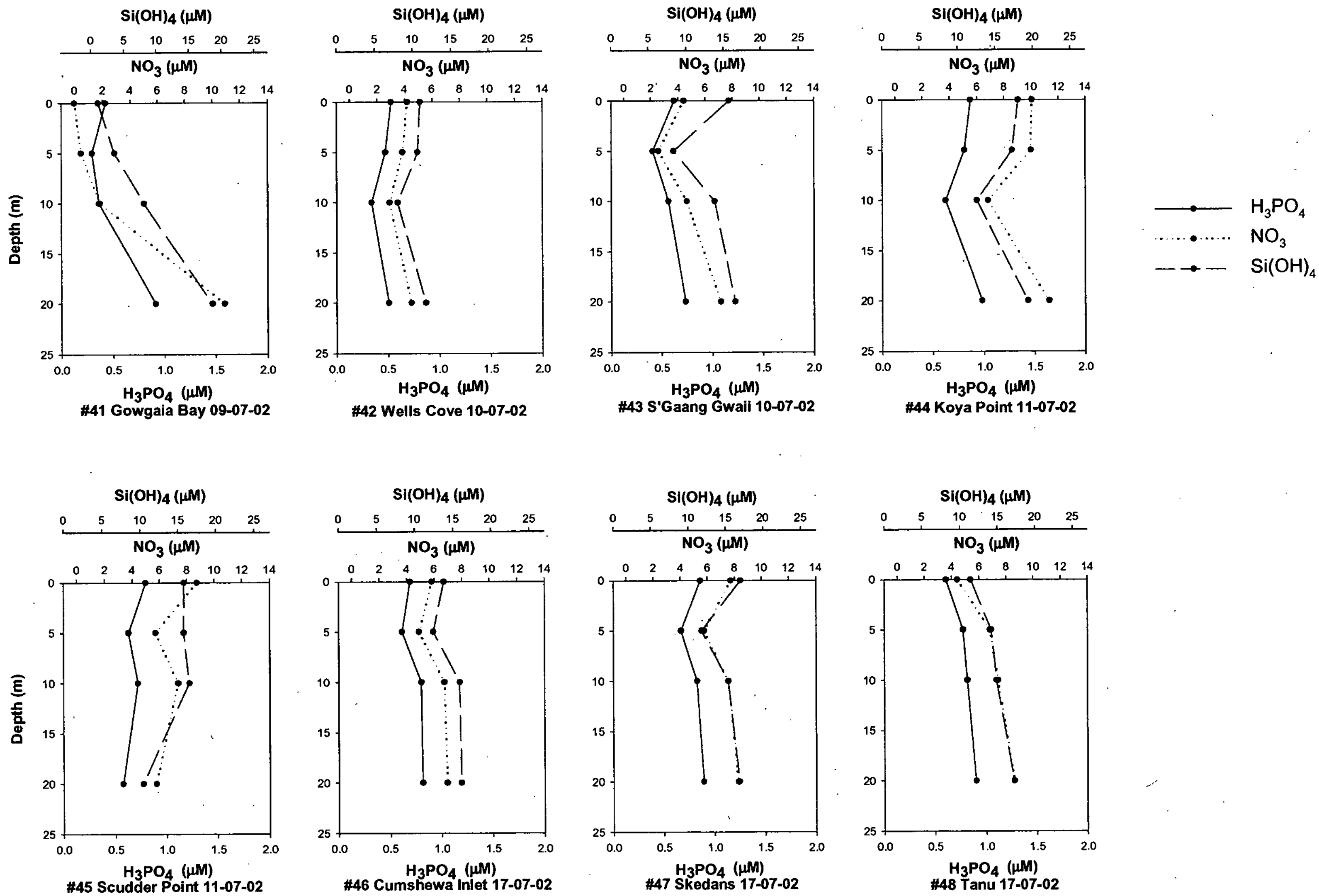

Figure D.1: Vertical profiles of nitrate, phosphate, and silicic acid for each of the stations sampled.

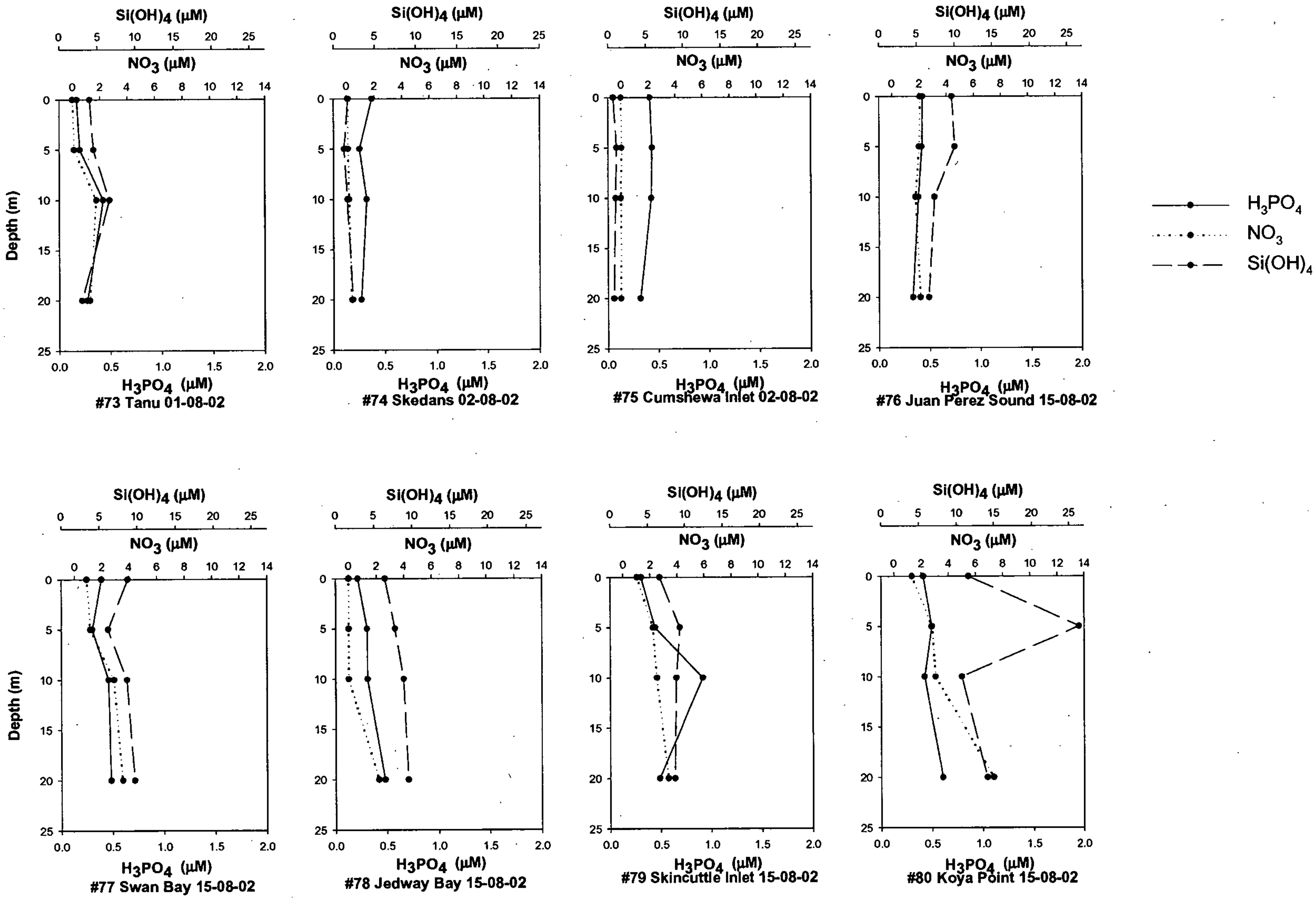

Figure D.1: Vertical profiles of nitrate, phosphate, and silicic acid for each of the stations sampled.

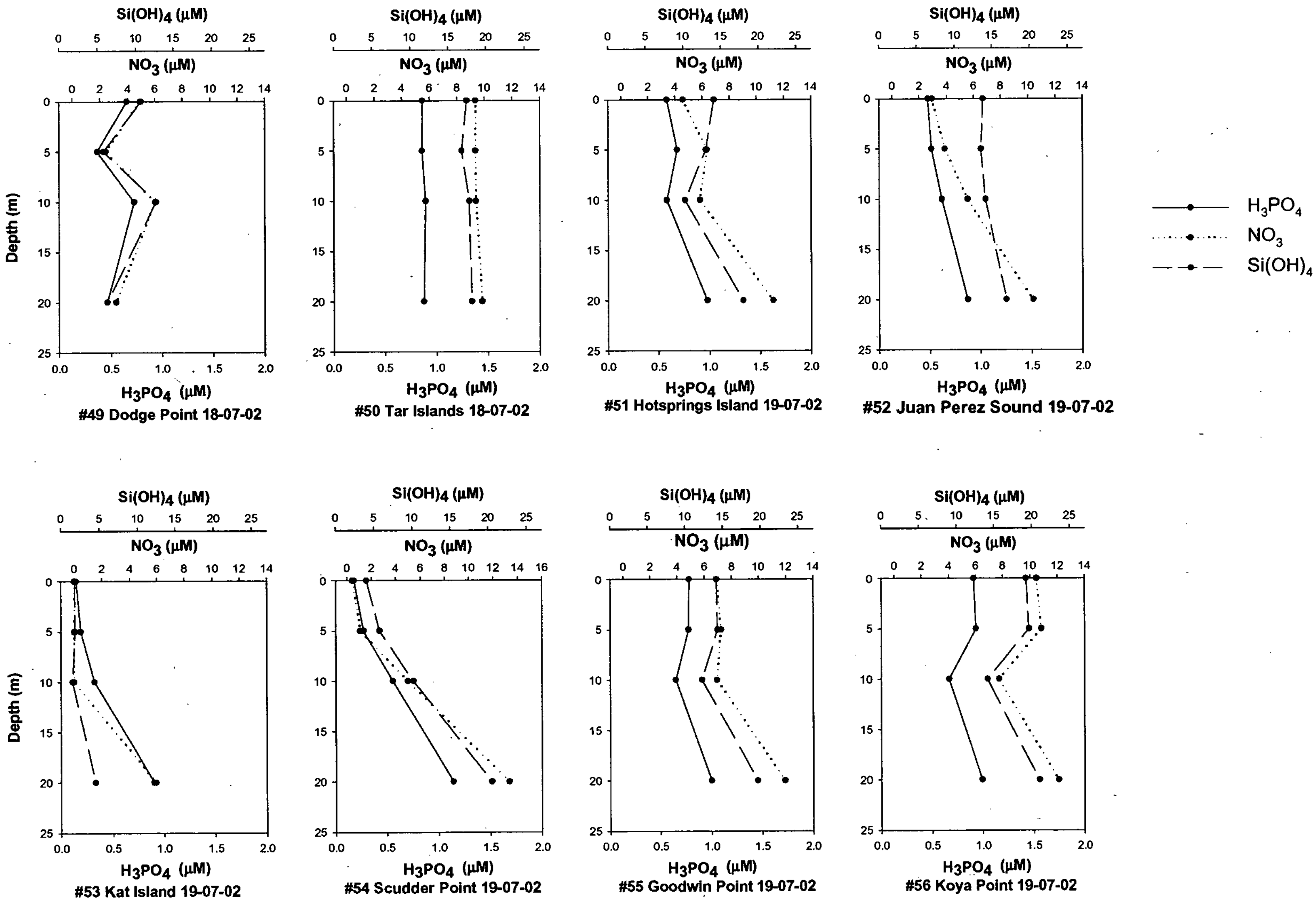

Figure D.1: Vertical profiles of nitrate, phosphate, and silicic acid for each of the stations sampled.

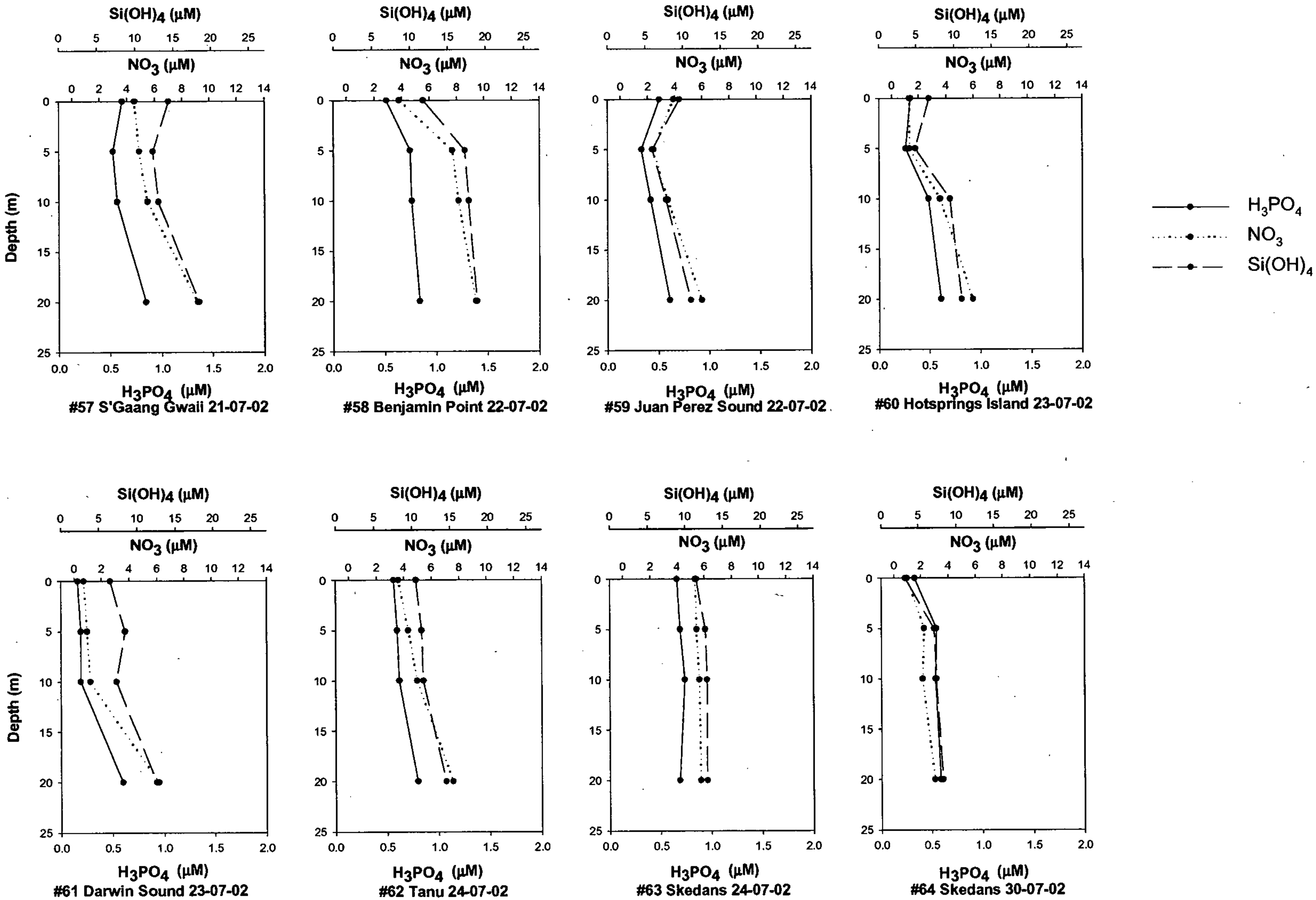

Figure D.1: Vertical profiles of nitrate, phosphate, and silicic acid for each of the stations sampled.

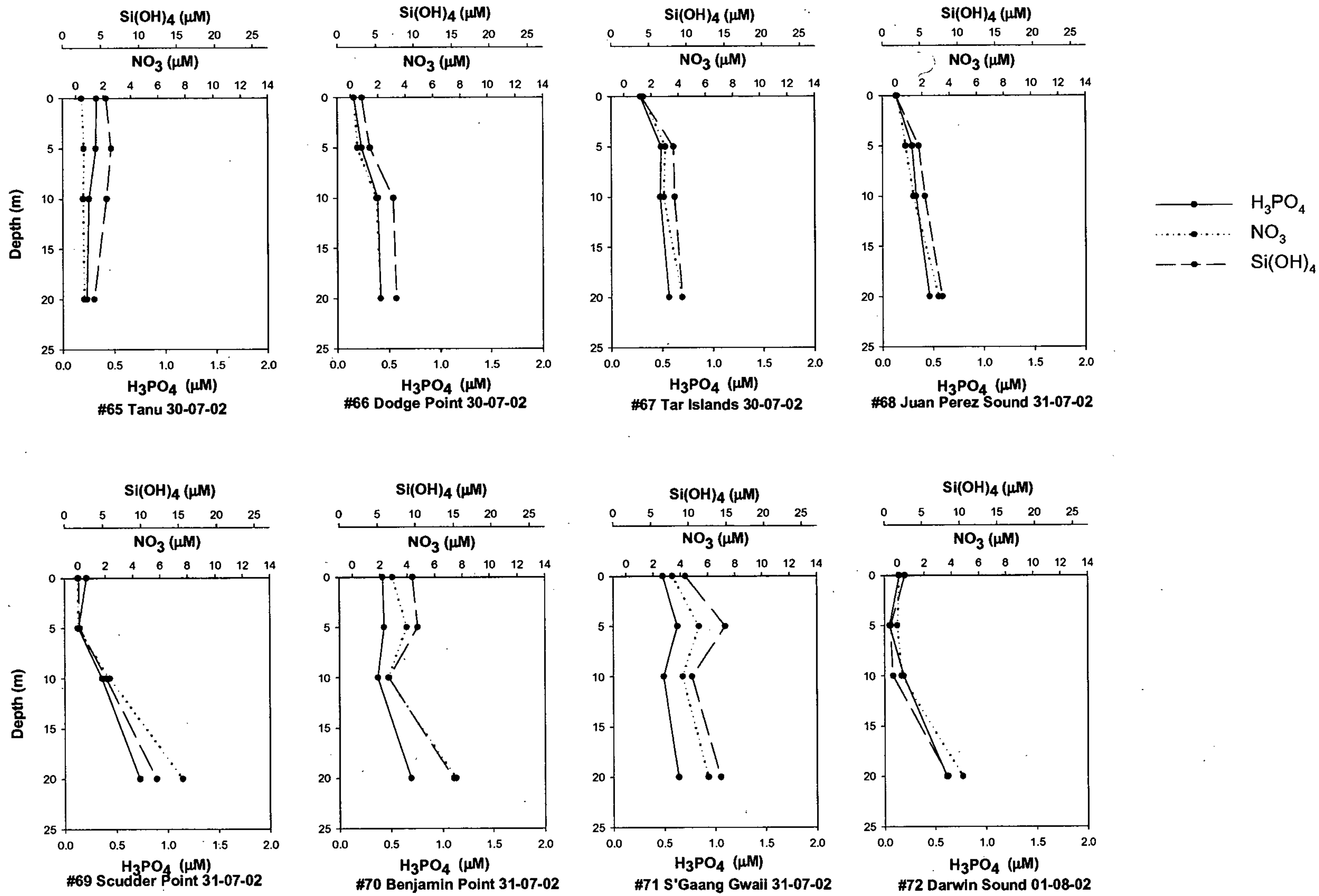

Figure D.1: Vertical profiles of nitrate, phosphate, and silicic acid for each of the stations sampled.

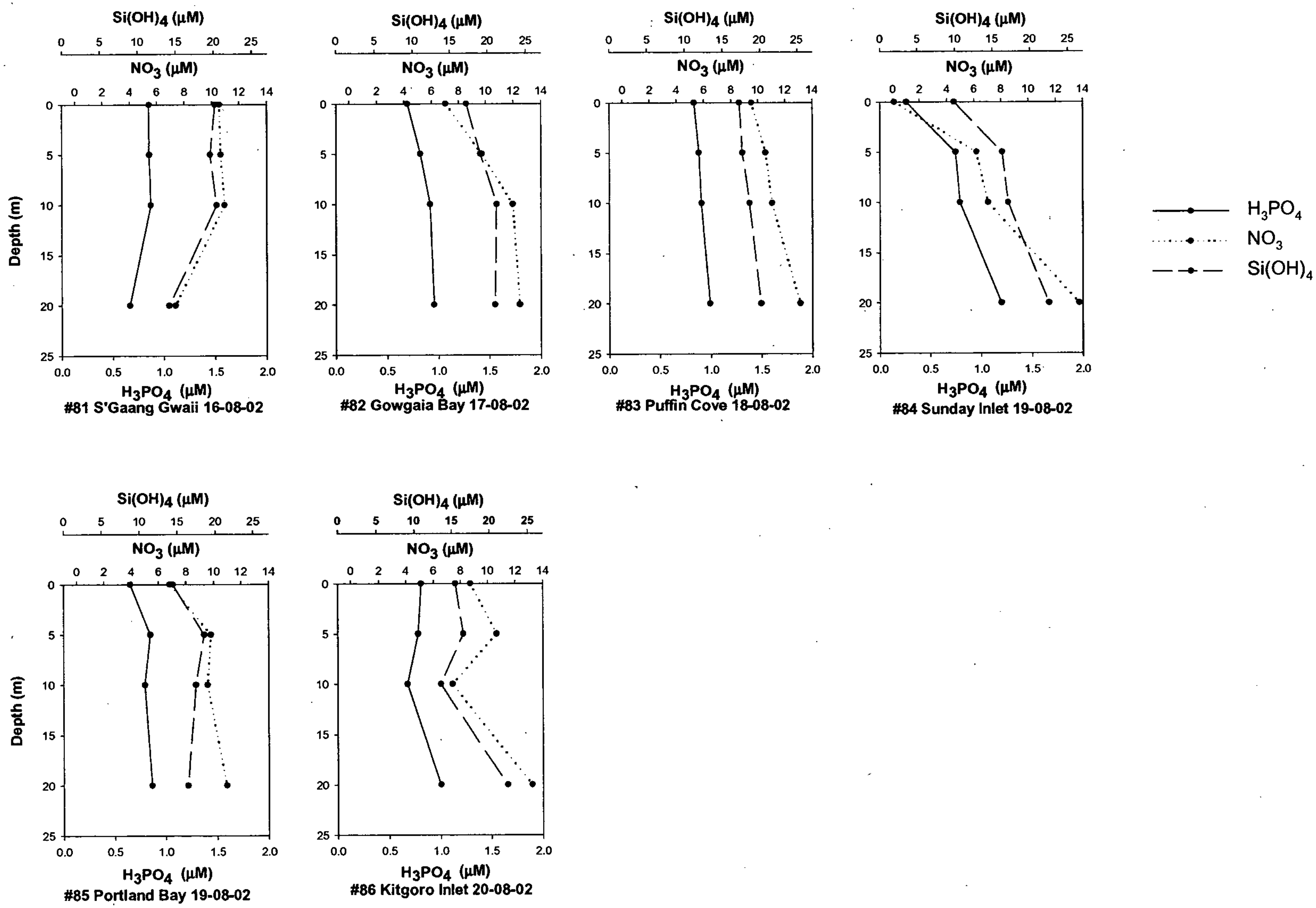

Figure D.1: Vertical profiles of nitrate, phosphate, and silicic acid for each of the stations sampled.

APPENDIX E

VERTICAL PROFILES OF BIOLOGICAL PARAMETERS

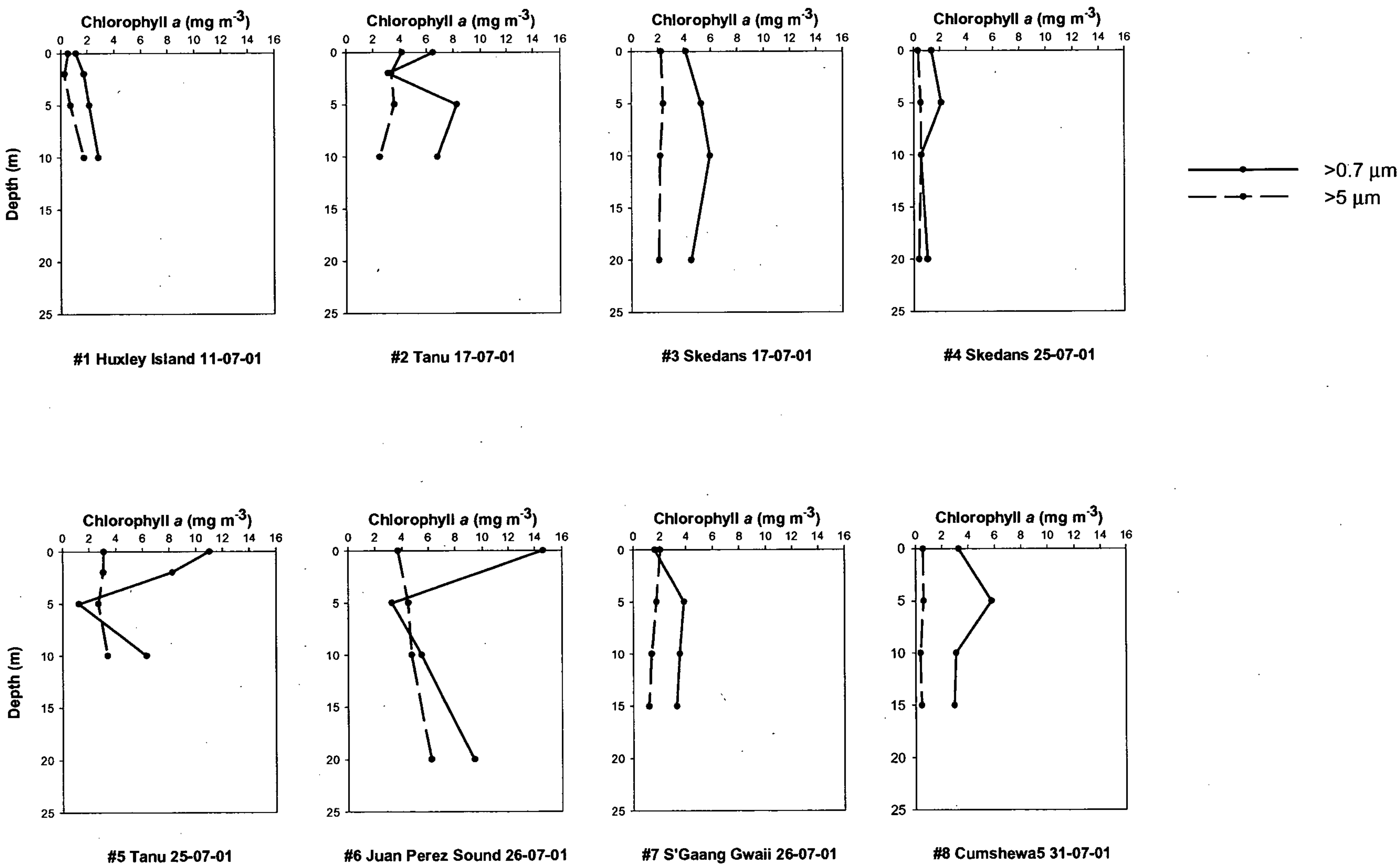

Figure E.1: Vertical profiles of chlorophyll a for both the total chlorophyll (> 0.7 µm) and the large size fraction (> 5 µm) for each of the stations sampled.

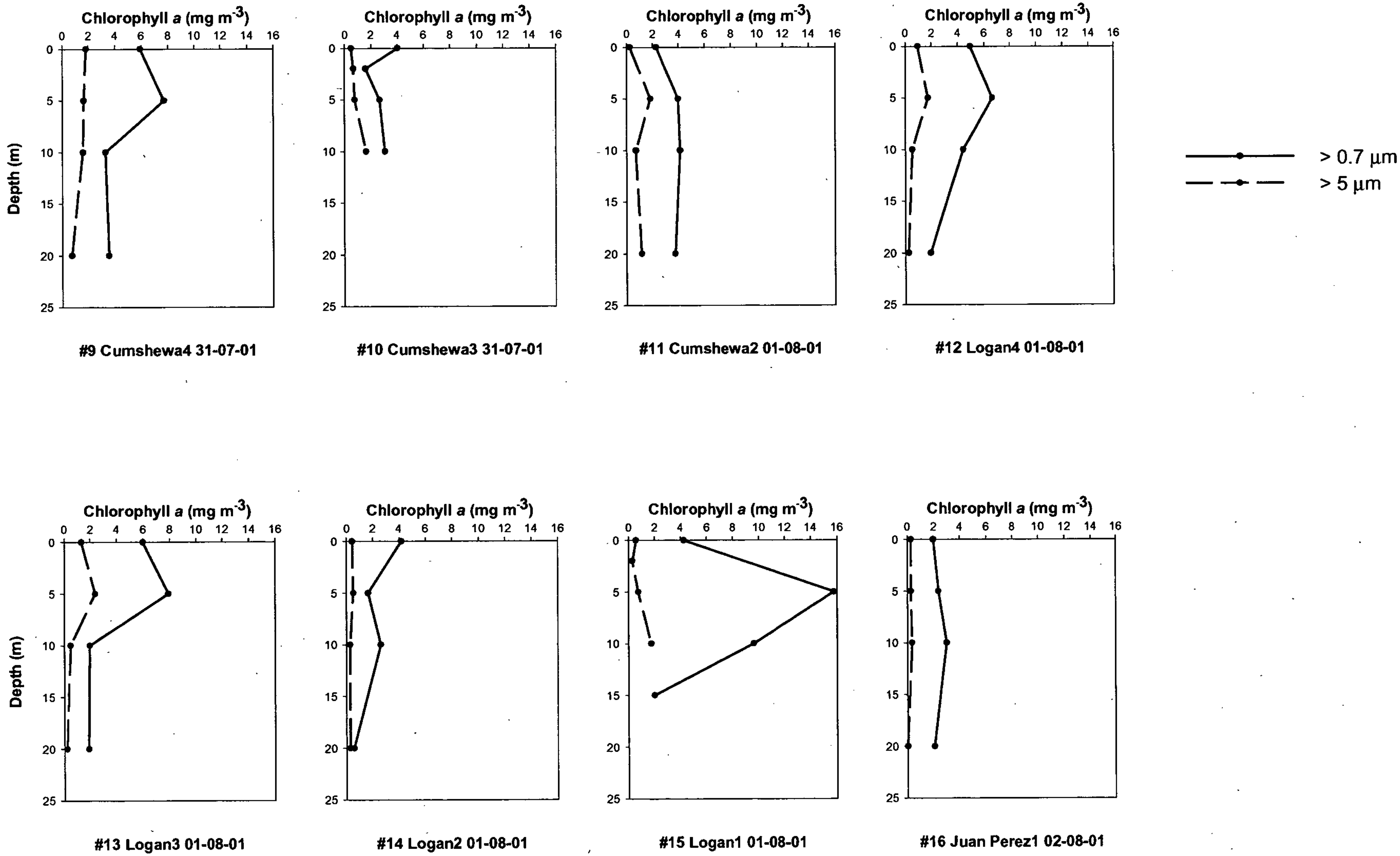

Figure E.1: Vertical profiles of chlorophyll a for both the total chlorophyll (> 0.7 µm) and the large size fraction (> 5 µm) for each of the stations sampled.

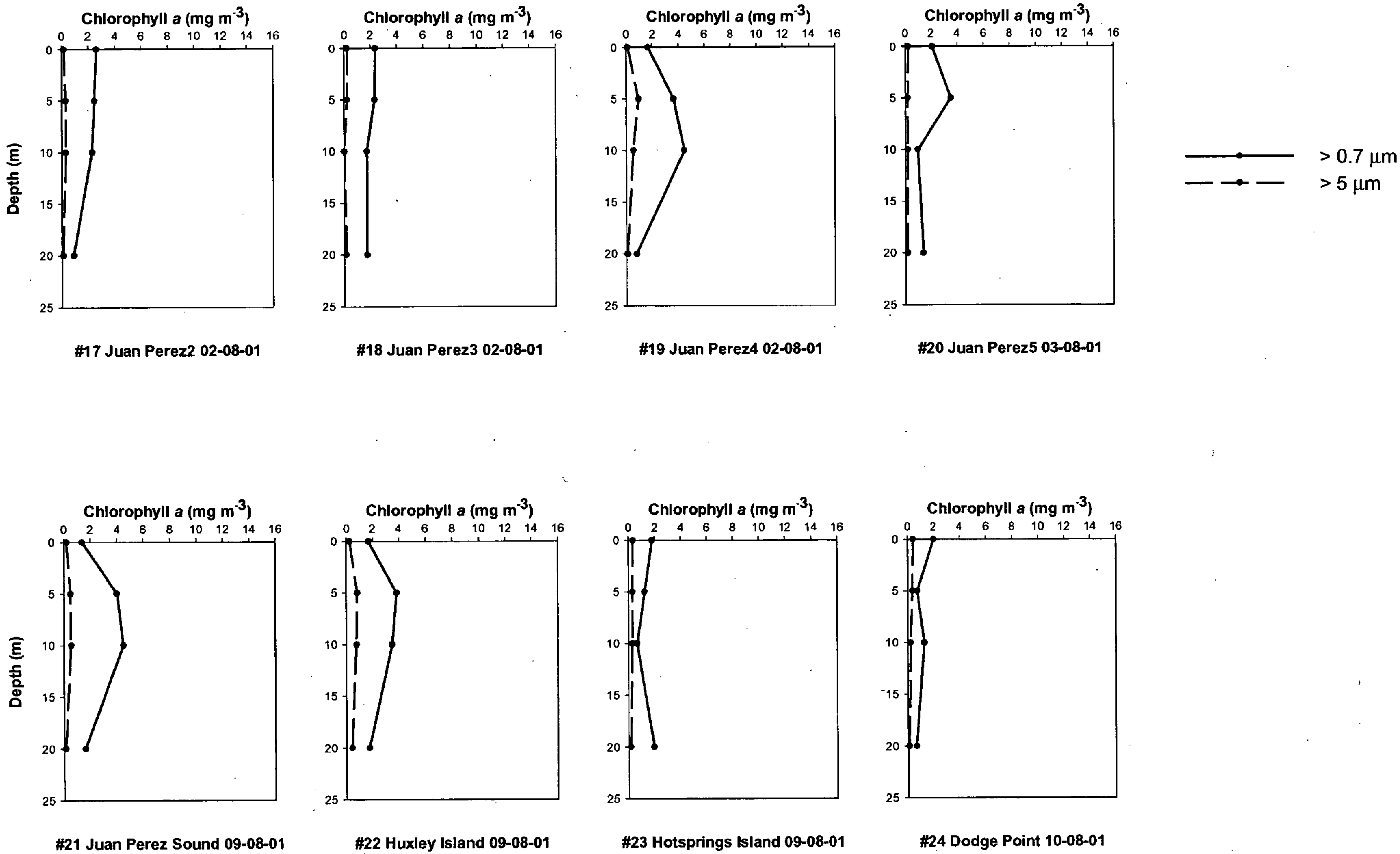

Figure E.1: Vertical profiles of chlorophyll a for both the total chlorophyll (> 0.7 µm) and the large size fraction (> 5 µm) for each of the stations sampled.

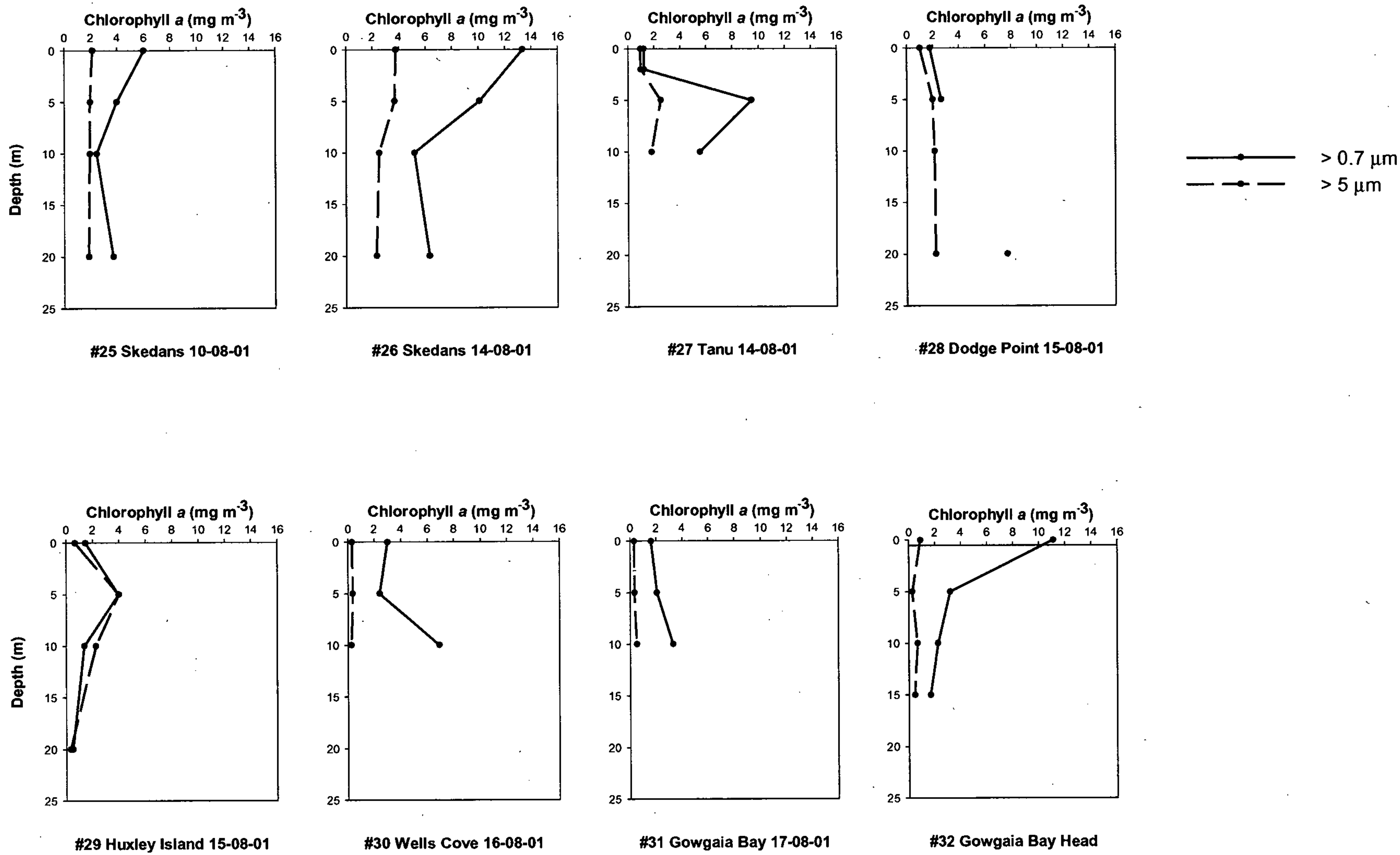

Figure E.1: Vertical profiles of chlorophyll a for both the total chlorophyll (> 0.7 µm) and the large size fraction (> 5 µm) for each of the stations sampled.

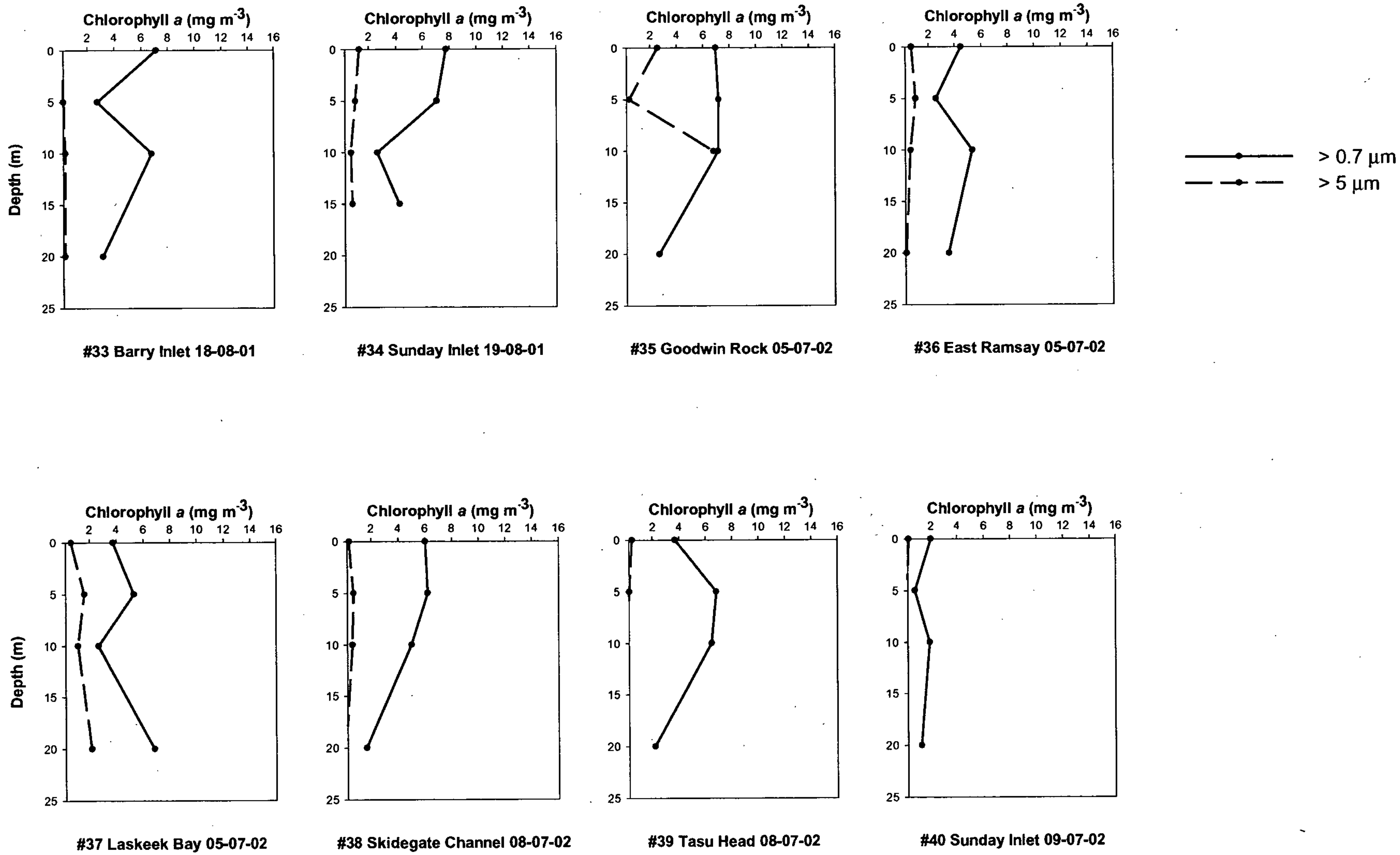

Figure E.1: Vertical profiles of chlorophyll a for both the total chlorophyll (> 0.7 µm) and the large size fraction (> 5 µm) for each of the stations sampled.

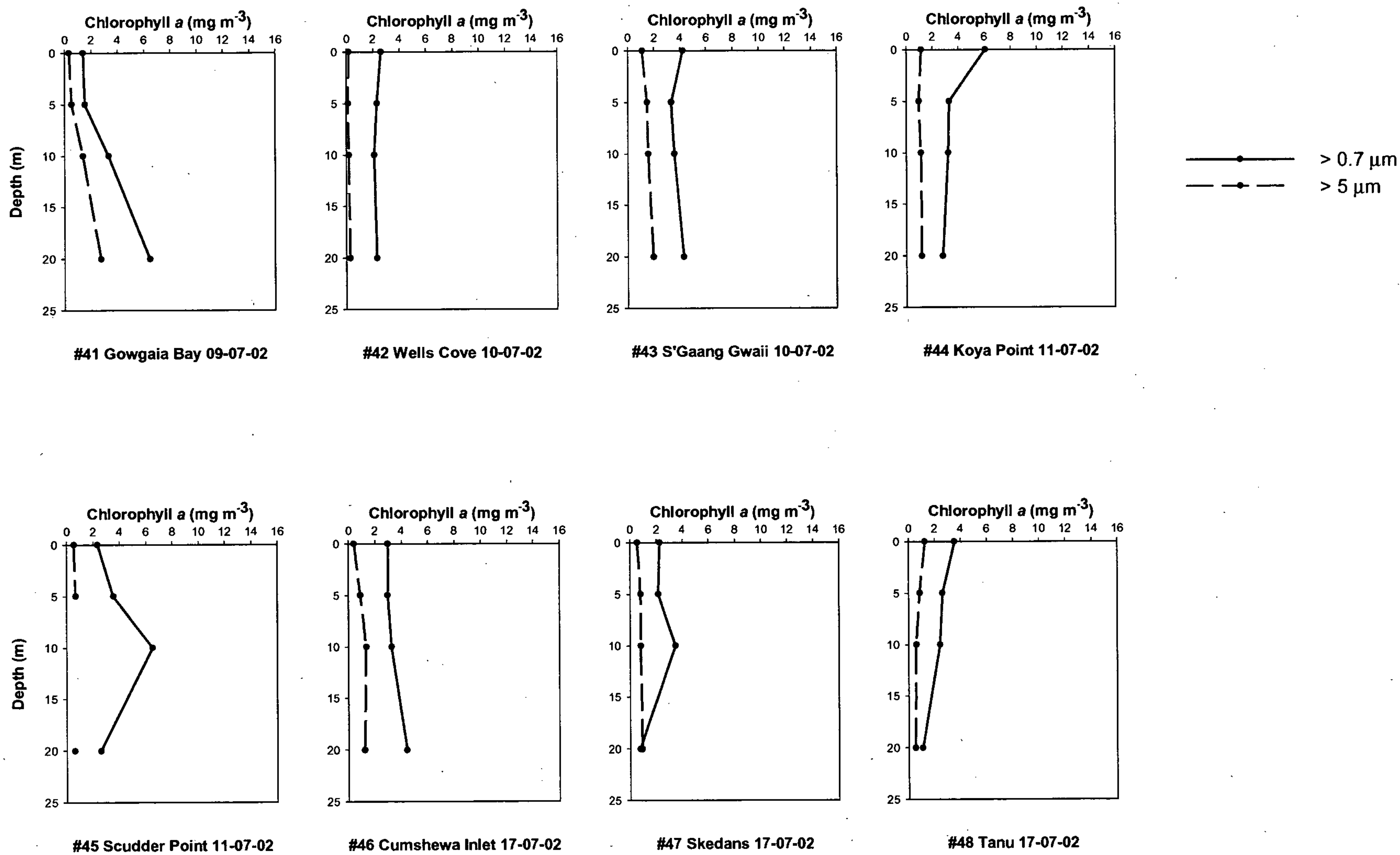

Figure E.1: Vertical profiles of chlorophyll a for both the total chlorophyll (> 0.7 µm) and the large size fraction (> 5 µm) for each of the stations sampled.

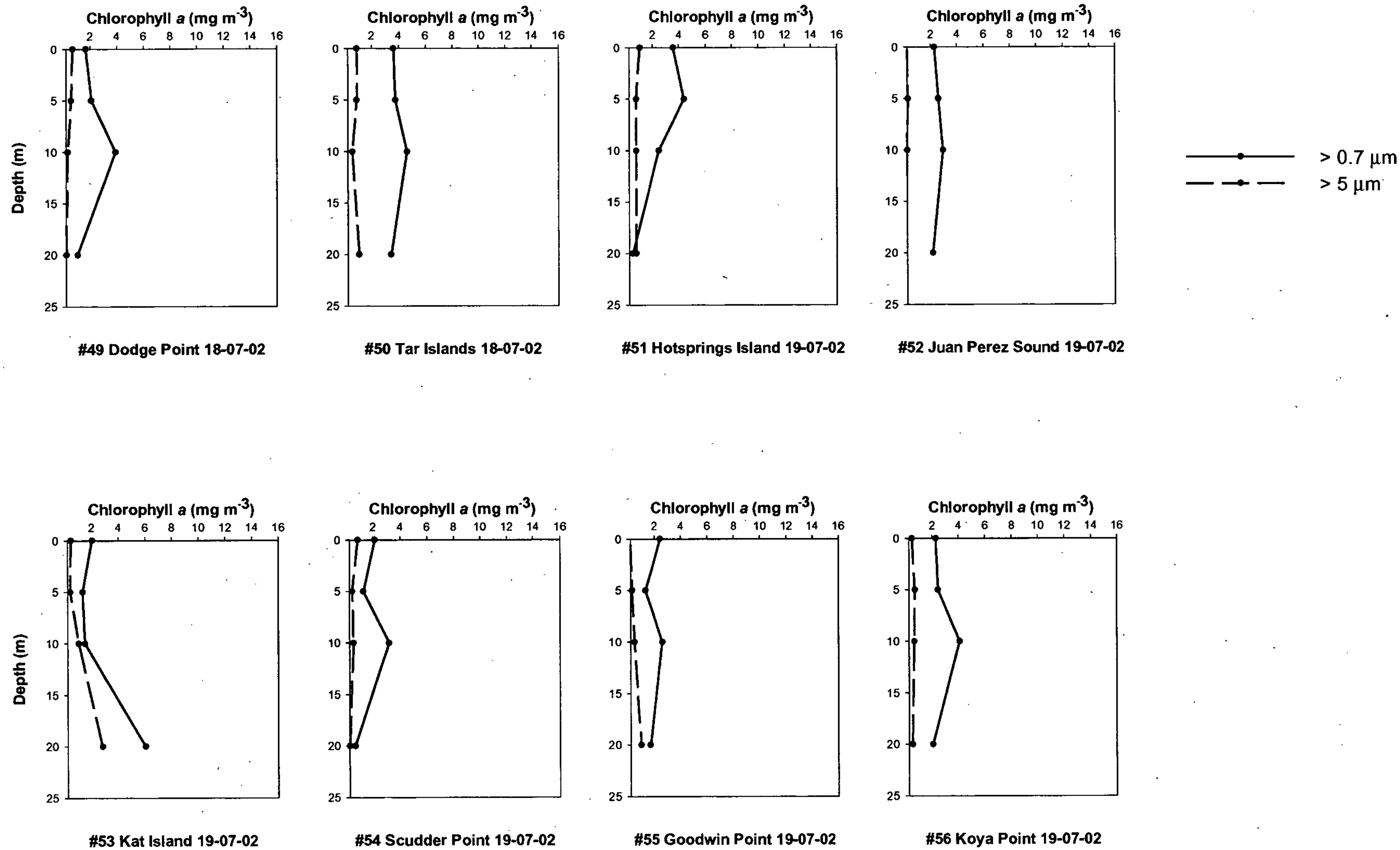

Figure E.1: Vertical profiles of chlorophyll a for both the total chlorophyll (> 0.7 µm) and the large size fraction (> 5 µm) for each of the stations sampled.

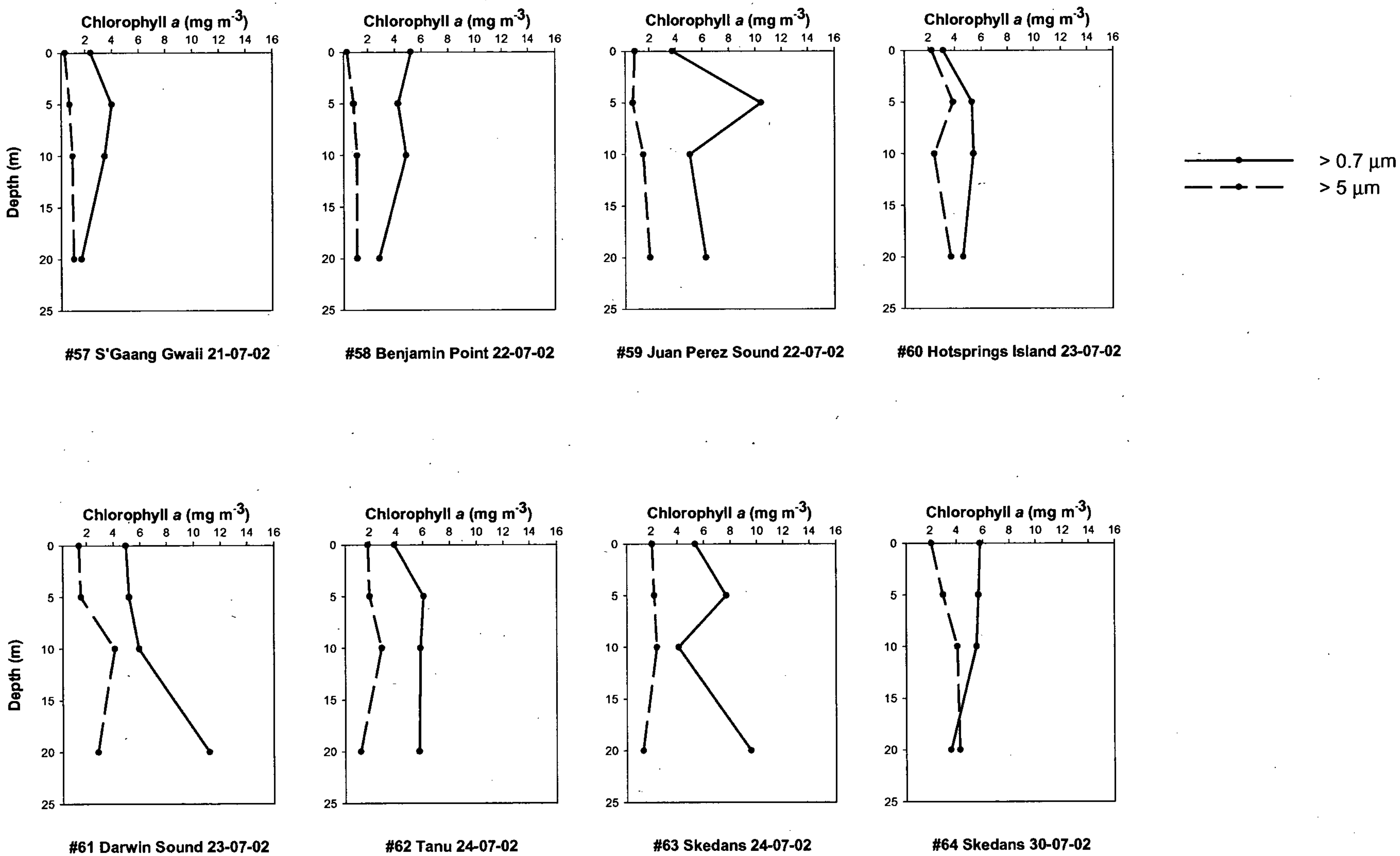

Figure E.1: Vertical profiles of chlorophyll a for both the total chlorophyll (> 0.7 µm) and the large size fraction (> 5 µm) for each of the stations sampled.

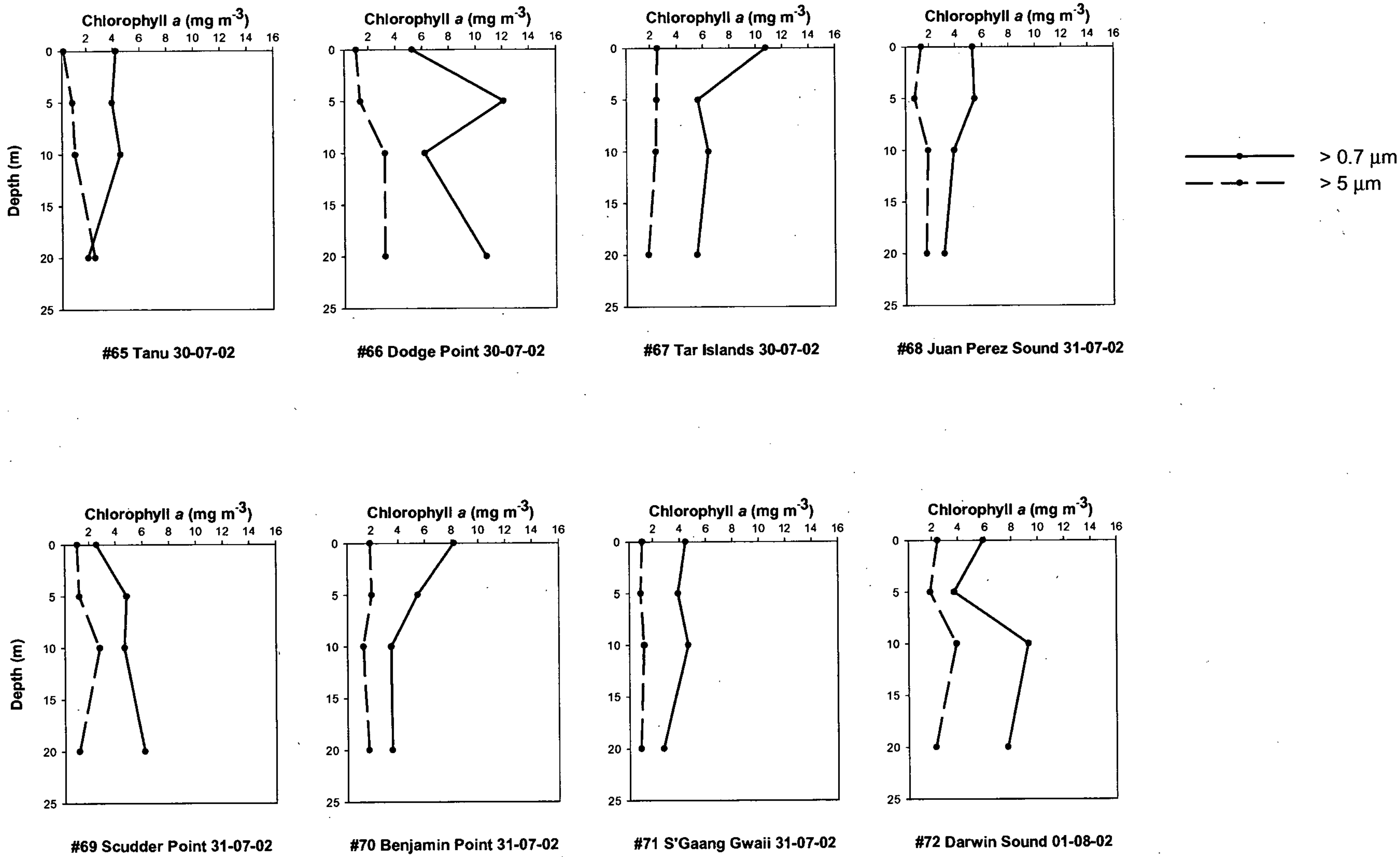

Figure E.1: Vertical profiles of chlorophyll a for both the total chlorophyll (> 0.7 µm) and the large size fraction (> 5 µm) for each of the stations sampled.

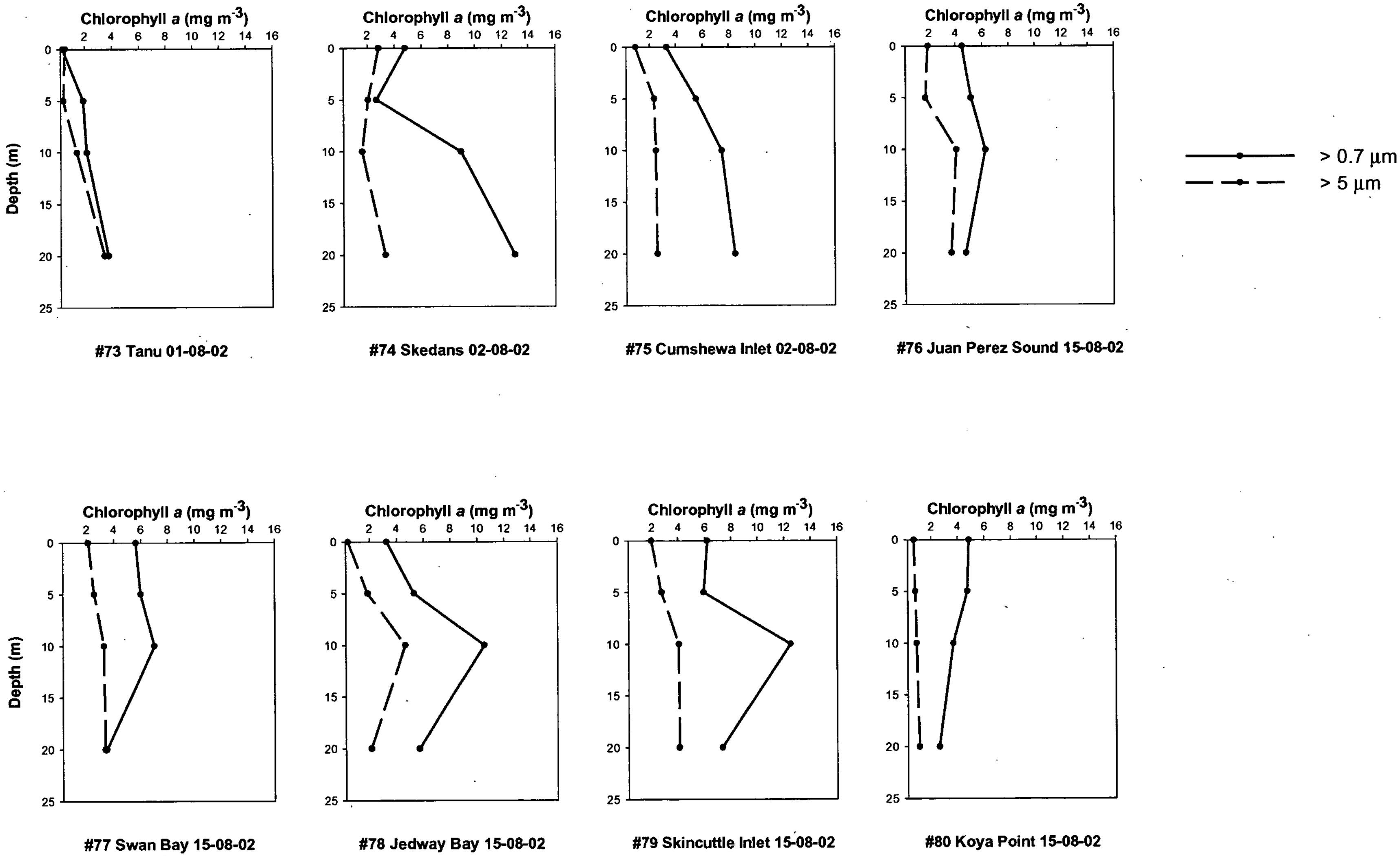

Figure E.1: Vertical profiles of chlorophyll a for both the total chlorophyll (> 0.7 µm) and the large size fraction (> 5 µm) for each of the stations sampled.

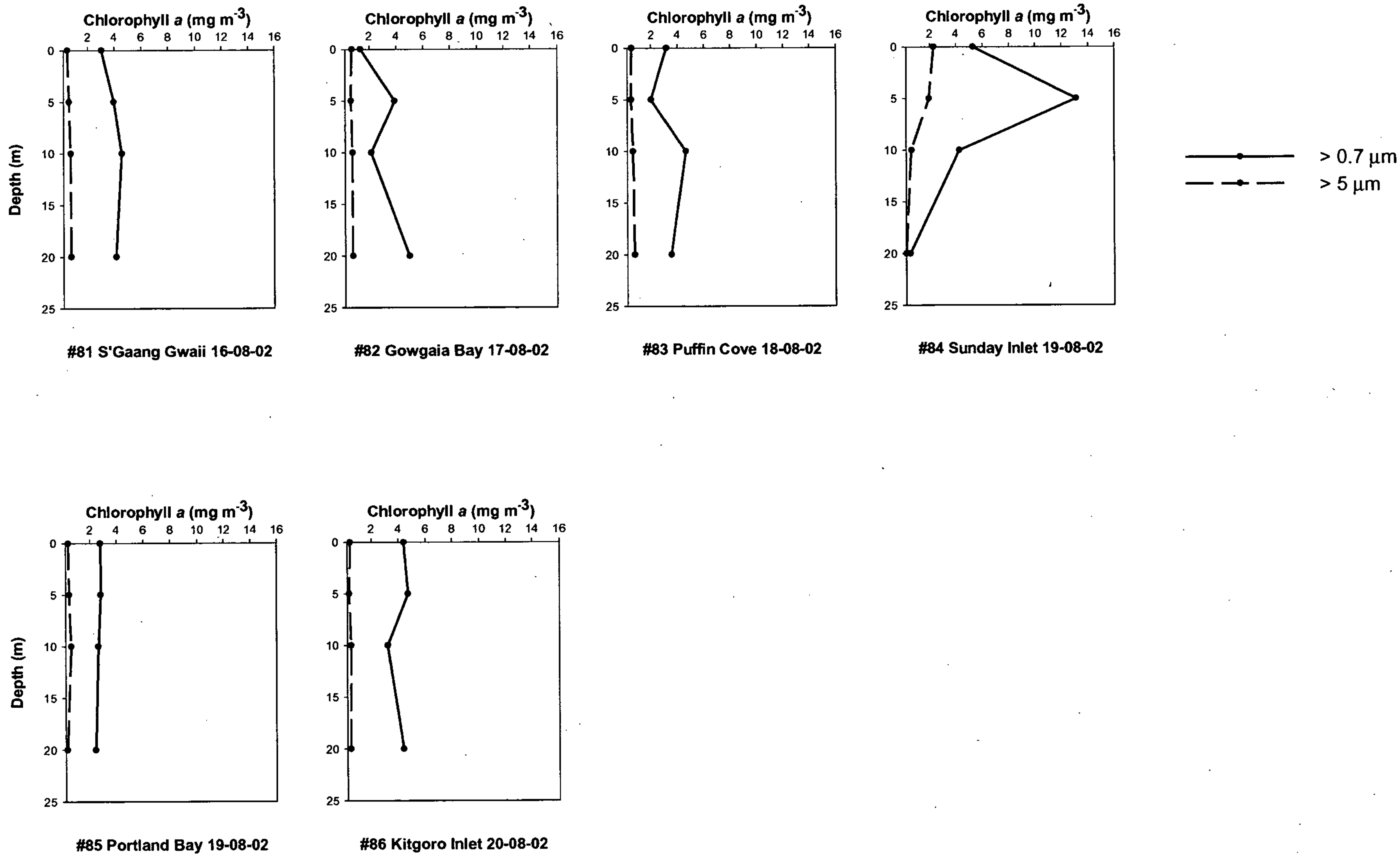

Figure E.1: Vertical profiles of chlorophyll a for both the total chlorophyll (> 0.7 µm) and the large size fraction (> 5 µm) for each of the stations sampled.

APPENDIX F

PHYTOPLANKTON CELL COUNTS

Table F.1: Concentration of phytoplankton (cells L^{-1}) at each station. A value of zero means the species was not observed.

Station	*Asterionella glacialis*	*Asteromphalus heptactis*	*Bacteriastrum delicatulum*	*Ceratulina pelagica*	*Chaetoceros* spp.	*Coscinodiscus centralis*	*Coscinodiscus lineatus*	*Coscinodiscus perforatus*
1	0	0	0	0	5800	0	0	0
2	0	0	0	11700	0	0	0	0
3	0	1230	0	0	1230	3080	0	0
4	0	759	0	759	0	0	3040	0
5	0	0	0	0	0	0	0	0
6	0	0	0	0	8350	0	0	0
7	1460	0	0	0	7310	0	0	0
8	0	1290	0	0	2390	0	0	736
9	0	0	0	0	0	0	0	440
10	0	0	0	0	2490	0	0	0
11	0	0	0	1430	5710	0	0	0
12	0	588	0	0	588	0	0	0
13	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0
17	0	483	0	0	0	0	0	0
18	0	936	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0
20	0	119	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0
23	0	0	0	0	0	1420	0	0
30	0	399	0	0	0	0	0	0
31	0	0	0	0	0	0	210	0
32	0	0	0	0	0	0	0	0
33	0	290	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0
35	0	1270	0	0	77500	0	0	0
36	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0
38	0	0	0	0	21600	665	0	0
39	0	0	0	0	0	0	0	0
40	0	0	0	0	5730	0	0	0
41	0	0	0	0	44500	0	0	0
42	0	179	0	0	986	0	0	0
43	0	0	0	0	609000	0	0	0
44	0	0	0	0	341000	0	0	0
45	0	0	0	0	90700	0	0	0
46	0	0	0	496	42100	0	0	0

Table F.1 continued.

Station	*Asterionella glacialis*	*Asteromphalus heptactis*	*Bacteriastrum delicatulum*	*Ceratulina pelagica*	*Chaetoceros* spp.	*Coscinodiscus centralis*	*Coscinodiscus lineatus*	*Coscinodiscus perforatus*
47	0	248	0	1240	10900	248	0	0
48	0	0	0	0	9090	1610	0	0
49	0	137	0	0	1330	2150	0	0
50	0	0	0	0	2170	3070	0	0
51	0	0	0	0	0	1810	0	0
52	0	0	0	0	0	0	0	0
53	3660	0	0	0	183000	0	0	0
54	0	0	0	0	258000	0	0	0
55	0	0	0	0	39900	1240	0	0
56	0	0	0	0	35900	0	0	0
57	0	0	0	0	211000	0	0	0
58	0	0	0	0	60100	0	0	547
59	0	0	0	0	13200	3770	0	0
60	0	0	0	0	24700	5910	0	219
61	0	0	0	0	43900	1900	0	0
62	0	0	0	0	7800	3050	0	0
63	0	0	0	0	46400	0	0	0
64	0	0	0	0	13200	2210	0	0
65	0	0	0	0	0	3020	0	0
66	0	0	0	0	4900	3200	0	0
67	0	0	0	0	4790	6040	0	0
68	0	0	0	0	10800	4140	0	0
69	0	0	0	0	0	3440	0	0
70	0	0	0	0	9620	2960	0	0
71	0	0	0	0	375000	1890	0	0
72	0	0	0	0	102000	0	0	0
73	0	0	0	0	2410	1750	0	0
74	0	0	0	0	9750	1950	0	0
75	0	0	0	0	1360	2720	0	0
76	0	0	0	0	29200	0	0	0
77	0	0	0	15900	85100	10600	0	0
78	0	0	3900	0	0	0	0	0
79	0	0	0	9000	130000	27000	0	0
80	1410	0	0	1410	9860	0	0	0
81	680	0	0	1360	46200	0	0	0
82	0	0	0	0	19200	0	0	0
84	0	0	0	0	1240	1240	0	0
85	0	0	0	0	0	0	0	0
86	0	0	0	0	5720	0	0	0

Table F.1 continued.

Station	*Coscinodiscus radiatus*	*Cylindrotheca closterium*	*Dactylisolen fragilissimus*	*Ditylum brightwellii*	*Eucampia zodiacus*	*Fragilaria* spp.	*Gyrosigma/Pleurosigma*	*Leptocylindrus danicus*
1	0	0	6700	1340	8930	0	0	26800
2	0	0	0	0	0	0	0	0
3	0	1850	0	0	0	0	0	5540
4	1520	2280	0	0	0	0	0	7590
5	0	0	0	0	0	0	0	8350
6	0	0	0	0	16700	0	0	16700
7	0	1460	0	0	5850	0	0	4390
8	0	2210	0	0	0	736	0	1840
9	0	2640	0	1760	0	0	0	13200
10	0	622	0	1240	0	0	8710	2490
11	0	1430	1430	3570	0	0	713	7130
12	0	0	294	0	0	0	0	10600
13	0	2420	0	0	483	0	0	3870
14	0	0	0	0	0	0	0	2960
15	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	354	2840
17	0	0	0	0	0	0	0	0
18	0	0	0	0	936	0	0	234
19	0	0	0	0	0	0	0	0
20	0	0	0	0	1070	0	0	1900
21	0	0	0	0	0	0	0	613
22	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	2020
30	0	0	266	0	0	0	0	133
31	0	0	0	0	0	0	0	6730
32	0	0	0	0	0	0	0	828
33	0	0	290	0	0	0	0	0
34	0	1210	0	0	0	0	0	0
35	0	6360	0	0	0	0	0	29200
36	0	696	0	0	0	0	0	1390
37	0	0	0	0	0	0	0	36900
38	0	1990	0	0	0	665	0	9640
39	0	0	0	0	0	0	0	249
40	0	0	628	0	0	235	0	549
41	0	0	0	0	0	0	0	0
42	0	0	0	0	0	269	0	179
43	0	2440	0	0	29200	0	0	14600
44	0	1460	0	0	0	0	0	2920
45	0	4180	0	0	1190	0	0	16100
46	0	0	6940	496	0	0	0	4460

Table F.1 continued.

Station	*Coscinodiscus radiatus*	*Cylindrotheca closterium*	*Dactylisolen fragilissimus*	*Ditylum brightwellii*	*Eucampia zodiacus*	*Fragilaria* spp.	*Gyrosigma/Pleurosigma*	*Leptocylindrus danicus*
47	0	0	0	0	0	0	248	1980
48	0	0	713	0	89	0	0	1690
49	0	0	0	0	0	0	0	871
50	47	0	849	0	0	0	0	1370
51	0	0	0	0	0	0	0	360
52	0	0	0	0	0	0	0	0
53	0	3660	25600	0	0	0	0	21900
54	0	0	0	0	0	0	0	21900
55	0	0	0	0	0	0	0	1240
56	0	0	0	0	0	0	0	4450
57	0	4330	1080	0	0	2170	0	2170
58	0	1640	0	0	0	0	0	2190
59	0	1130	0	0	0	0	0	0
60	0	0	0	0	0	657	0	657
61	0	3480	0	0	0	0	0	0
62	0	0	0	170	0	0	0	2880
63	1270	636	0	0	0	0	0	27300
64	0	0	0	1100	0	0	1100	5520
65	0	275	0	0	0	0	0	2750
66	0	0	0	0	0	0	0	1280
67	0	0	0	0	0	0	0	2080
68	0	552	552	0	2210	0	0	4140
69	0	0	0	0	0	3440	0	18300
70	0	0	0	0	0	0	0	3700
71	0	3770	0	0	7550	0	0	5660
72	0	3660	0	0	0	0	0	0
73	0	438	0	0	0	0	0	3720
74	0	0	0	0	0	0	0	6820
75	0	1360	0	0	0	0	0	2720
76	0	11700	0	0	0	0	0	35100
77	0	37200	0	0	0	0	0	10600
78	0	7800	0	0	0	0	0	46800
79	0	9000	0	0	0	0	0	36000
80	0	2820	0	0	0	0	0	11300
81	0	2720	0	0	0	2040	0	680
82	0	3280	0	0	0	0	0	5610
84	0	3700	0	0	0	0	0	0
85	0	4090	0	0	0	1750	0	1750
86	0	2860	0	0	0	1270	0	0

Table F.1 continued.

Station	*Leptocylindrus mediterraneus*	*Leptocylindrus minimus*	*Licmorpha abbreviata*	*Melosira* spp.	*Navicula* spp.	*Nitzschia longissima*	*Odontella longicruris*	*Pseudonitzschia* "A"
1	0	4460	0	0	893	0	0	4020
2	0	0	0	0	0	0	0	1070000
3	0	0	1230	0	1230	0	1850	24000
4	0	0	0	0	1520	0	0	90400
5	0	0	0	0	0	0	0	2360000
6	0	0	0	0	0	0	0	2280000
7	0	0	0	0	0	0	0	227000
8	0	0	1100	0	1290	0	0	2020
9	0	0	0	0	440	0	0	0
10	0	0	622	0	0	0	0	0
11	0	0	0	0	0	0	0	0
12	0	0	0	0	294	0	0	1760
13	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0
17	0	967	0	0	0	0	0	0
18	3280	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0
20	1190	0	0	595	119	0	0	357
21	0	0	0	1230	0	0	0	0
22	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0
30	0	0	399	0	266	0	0	0
31	0	631	421	0	421	210	0	0
32	0	0	0	0	0	0	0	0
33	0	290	290	0	0	0	0	0
34	0	0	0	1520	0	0	0	0
35	0	0	0	0	2540	0	0	97900
36	0	0	0	0	6270	0	0	71000
37	0	0	0	0	5130	0	0	137000
38	0	0	332	0	0	0	0	9300
39	0	125	0	0	0	0	0	187
40	0	0	1100	0	157	471	0	2200
41	0	0	0	5090	0	0	0	20300
42	0	0	538	0	358	90	0	2690
43	0	0	0	0	0	0	0	29200
44	0	0	0	5850	0	0	4390	19000
45	0	0	0	0	0	0	0	29800
46	0	0	0	0	1980	0	0	4460

Table F.1 continued.

Station	*Leptocylindrus mediterraneus*	*Leptocylindrus minimus*	*Licomorpha abbreviata*	*Melosira* spp.	*Navicula* spp.	*Nitzschia longissima*	*Odontella longicruris*	*Pseudonitzschia* "A"
47	0	0	0	0	496	0	0	2730
48	0	1980	0	0	89	0	0	0
49	0	624	89	0	183	0	0	0
50	0	0	0	0	330	0	0	0
51	0	0	236	0	0	0	0	0
52	0	0	0	0	0	0	0	0
53	0	0	532	0	0	0	0	0
54	0	0	0	0	0	21900	0	12200
55	0	46300	0	4870	0	309	0	4330
56	0	1550	0	619	1270	0	0	6040
57	0	3810	0	0	0	0	1080	15200
58	0	0	0	0	1640	0	0	3830
59	0	0	547	0	377	0	0	0
60	0	0	0	0	219	0	0	657
61	0	0	0	0	0	0	0	0
62	0	0	0	0	1360	0	0	0
63	0	0	0	0	1910	0	0	0
64	0	0	636	0	1100	0	0	0
65	0	0	1100	0	0	0	0	0
66	0	0	0	0	1070	0	0	0
67	0	0	427	0	1040	0	0	0
68	0	0	0	0	0	0	0	1100
69	0	0	0	0	0	0	0	0
70	0	0	1150	0	740	0	0	3700
71	0	0	0	1480	0	0	0	28300
72	0	0	0	0	0	0	0	3660
73	0	0	0	0	657	0	0	2850
74	0	0	0	0	0	0	0	0
75	0	0	0	0	1360	0	0	13600
76	0	0	0	0	0	0	0	40900
77	0	0	0	0	15900	0	0	128000
78	0	0	0	0	0	0	0	78000
79	0	0	0	0	4500	0	0	121000
80	0	0	0	0	705	0	0	4230
81	0	0	0	0	0	0	0	19700
82	0	0	0	0	0	0	0	41200
84	0	0	936	0	824	0	1240	21800
85	0	0	412	0	7600	0	0	78400
86	0	0	0	0	2540	0	0	25700

Table F.1 continued.

Station	*Pseudonitzschia* "B"	*Pseudonitzschia* "C"	*Rhizosolenia robusta*	*Rhizosolenia styliformis*	*Rhizosolenia setigera*	*Rhizosolenia imbricata*	*Skeletonema costatum*	*Thalassionema nitzschiodes*
1	16500	0	0	0	2680	0	26800	1790
2	339000	257000	0	0	58500	0	29200	5850
3	30200	16600	0	0	67700	2460	2460	2460
4	12900	4560	0	0	53200	2280	0	0
5	194000	0	0	0	50100	0	0	0
6	284000	33400	0	0	66800	0	125000	8350
7	48200	42400	0	0	0	0	76000	2920
8	0	0	0	0	919	184	0	368
9	0	440	0	0	103000	879	0	440
10	0	0	0	0	121000	0	10600	4360
11	1430	0	0	0	155000	1430	0	713
12	8230	0	0	0	15900	0	0	2060
13	18400	0	0	0	10600	0	0	0
14	1620	0	0	0	5120	0	0	0
15	0	0	0	0	527	0	0	527
16	15200	19850	0	0	2130	354	0	1060
17	9180	0	0	0	0	0	0	242
18	21100	0	0	0	5150	0	0	1870
19	4180	1620	0	0	696	0	0	0
20	1080	3570	0	0	1900	0	0	833
21	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0
30	399	0	0	0	0	0	0	1070
31	421	0	841	0	1680	4840	0	841
32	0	0	0	0	0	1380	0	0
33	0	0	0	0	0	0	0	870
34	3330	0	0	0	4240	0	0	606
35	5090	0	0	0	0	0	12700	21600
36	2790	0	0	0	0	0	0	0
37	10300	0	3080	0	2050	0	0	15400
38	0	0	0	0	0	0	12300	3660
39	125	0	125	0	0	0	0	62
40	1330	628	0	0	0	78	785	785
41	61000	243000	0	0	7630	1270	0	1270
42	90	5820	448	179	0	0	0	986
43	0	0	0	0	0	2440	0	12200
44	0	0	0	0	0	0	117000	4390
45	9550	0	0	0	0	0	4180	0
46	0	0	0	0	1980	496	65900	2480

Table F.1 continued.

Station	*Pseudonitzschia* "B"	*Pseudonitzschia* "C"	*Rhizosolenia robusta*	*Rhizosolenia styliformis*	*Rhizosolenia setigera*	*Rhizosolenia imbricata*	*Skeletonema costatum*	*Thalassionema nitzschiodes*
47	496	0	0	0	496	0	36200	991
48	89	0	0	0	178	179	2140	267
49	137	0	0	0	0	0	412	137
50	236	0	0	0	189	0	0	330
51	0	0	0	0	0	0	0	0
52	0	0	0	0	0	0	0	0
53	0	11000	0	0	0	0	844000	0
54	0	29200	0	0	0	0	324000	2440
55	1240	0	0	0	0	0	18600	928
56	0	0	0	0	0	0	11800	636
57	3250	0	0	0	0	0	45500	3250
58	2190	0	0	0	0	547	63400	3830
59	0	0	0	0	0	0	2450	566
60	438	438	0	0	0	1100	3290	876
61	0	2210	0	0	316	0	11700	0
62	2030	4070	0	0	3050	170	6780	0
63	0	0	0	0	64800	1270	14700	636
64	0	0	0	0	216000	8830	21000	0
65	824	0	0	0	1650	0	4120	0
66	1920	8960	0	0	640	0	5340	0
67	0	9780	0	0	3120	0	5200	0
68	8000	4410	0	0	0	0	16600	0
69	12600	4590	0	0	2290	0	266000	0
70	0	3700	0	0	0	0	164000	5180
71	32000	0	0	0	1890	0	49000	3770
72	29200	102000	0	0	925000	3660	0	0
73	1310	3070	0	0	0	219	7670	219
74	3900	0	0	0	258000	2920	0	1950
75	0	0	0	0	385000	2720	0	1360
76	298000	23400	0	0	0	0	1260000	0
77	255000	53200	0	0	31900	0	851000	0
78	109000	46800	0	0	11700	0	129000	7800
79	170000	99000	0	0	18000	0	315000	0
80	21100	64800	0	0	6340	705	52800	2110
81	16300	15000	2040	0	4080	0	51000	1360
82	15000	0	468	0	0	468	4680	2340
84	0	0	0	0	824	0	0	824
85	15800	1750	1170	0	0	0	0	585
86	11100	5100	1590	0	0	0	9220	2860

Table F.1 continued.

Station	*Thalassiosira* spp.	Centric < 10 µm	Pennate < 25 µm	Coccolithophore	*Dictyocha speculum*	*Ebria tripartita*	*Alexandrium* spp.	*Amphidinium spheniodes*
1	2230	3130	893	0	3570	446	0	0
2	5850	0	0	0	0	0	0	0
3	13500	0	2460	0	0	0	1850	0
4	15900	0	3800	0	0	0	5320	0
5	25100	0	16700	0	0	0	25100	0
6	0	0	0	0	0	0	16700	0
7	7310	5850	0	0	1460	0	0	0
8	6620	1840	2390	0	1100	368	1290	736
9	3520	879	879	0	0	0	0	0
10	9330	1240	0	0	0	0	622	622
11	0	0	713	0	0	0	2140	713
12	2350	1470	2940	0	1180	0	2650	2350
13	1930	0	3380	0	0	0	5800	0
14	808	0	0	1890	0	0	808	0
15	1580	1580	1050	0	0	0	1580	527
16	1770	0	0	0	0	0	0	0
17	242	483	0	725	0	0	1450	242
18	1170	936	234	468	234	0	468	234
19	0	0	0	0	0	0	0	0
20	1790	714	0	2740	0	0	595	238
21	818	0	0	0	0	0	1230	0
22	0	0	0	737	0	0	2950	0
23	2430	607	1420	1620	0	0	1620	0
30	1200	1070	7320	1460	0	799	266	0
31	4420	3160	2950	3160	841	0	631	631
32	552	0	276	0	0	0	1100	0
33	0	580	2320	0	0	870	0	0
34	909	0	2120	2420	0	0	0	0
35	71200	24200	11400	12700	1270	0	0	0
36	114000	0	0	0	696	0	0	0
37	89300	5130	0	0	0	0	0	0
38	9970	6650	0	15300	332	0	1330	0
39	436	1060	249	5480	623	249	187	0
40	1180	942	1100	314	471	157	0	0
41	6360	0	0	0	0	0	0	0
42	1880	1430	1340	1340	0	0	0	0
43	31700	0	0	0	2440	0	19500	0
44	30700	1460	2920	0	0	1460	0	0
45	5970	2390	1790	4180	2390	0	0	0
46	14400	496	991	0	0	0	496	0

Table F.1 continued.

Station	*Thalassiosira* spp.	Centric < 10 µm	Pennate < 25 µm	Coccolithophore	*Dictyocha speculum*	*Ebria tripartita*	*Alexandrium* spp.	*Amphidinium spheniodes*
47	6690	1240	1490	0	0	743	0	0
48	1430	178	357	0	446	178	178	0
49	550	412	275	0	229	92	0	0
50	896	236	0	0	330	94	0	94
51	0	361	0	83400	5420	2890	361	0
52	0	0	0	132000	3720	3190	0	0
53	0	0	0	0	0	0	0	0
54	0	2440	4870	0	2440	0	0	0
55	619	2480	1240	4330	309	1240	0	0
56	5720	3500	0	2540	0	1590	0	0
57	23800	4330	0	0	0	0	0	0
58	4370	5470	3830	3280	2730	0	0	0
59	2080	1890	943	19200	1890	377	566	0
60	1750	2630	438	10500	2850	0	0	0
61	3790	0	2530	12300	2530	632	0	0
62	4070	1360	2200	2370	1870	0	1360	0
63	19700	3180	5090	9530	1270	0	636	0
64	21000	4410	2200	30100	0	0	1100	0
65	4120	2200	0	9060	549	0	0	1920
66	2560	1490	2560	9180	427	0	640	0
67	4580	1250	1250	4370	624	0	1670	0
68	3310	3310	0	3310	2210	0	0	0
69	9170	3440	2290	5730	0	0	0	0
70	4440	4440	1480	0	1480	0	0	0
71	26400	0	3770	17000	5660	0	0	0
72	14600	0	3660	0	7310	0	7310	0
73	1310	1970	219	3940	0	219	657	438
74	7800	1950	0	0	0	0	0	0
75	10900	0	1360	0	0	0	1360	0
76	40900	0	0	40900	0	0	0	0
77	31900	15900	5320	63800	0	0	0	0
78	81900	0	7800	292000	0	0	31200	0
79	94500	36000	0	220000	4500	0	9000	0
80	10600	4230	0	3520	2110	0	0	0
81	12200	5440	0	3400	2040	1360	0	0
82	1870	6550	2340	9820	1870	0	0	0
84	5350	27200	7410	32500	0	0	2880	0
85	3510	17500	4090	5260	4090	0	0	0
86	5400	7630	3180	2540	953	0	0	0

Table F.1 continued.

Station	*Ceratium fusus*	*Ceratium lineatum*	*Ceratium longipipes*	*Dinophysis acuminata*	*Dinophysis acuta*	*Dinophysis fortii*	*Dinophysis norwegica*	*Dinophysis parva*
1	0	0	0	4020	0	0	446	0
2	0	0	0	17500	0	0	0	0
3	0	0	0	1850	0	0	0	0
4	0	0	759	0	68340	0	1520	0
5	0	0	0	0	33400	0	0	0
6	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0
8	0	919	0	4780	1840	0	736	552
9	0	0	0	440	0	0	0	0
10	1240	0	0	1240	1240	0	3730	0
11	2140	0	0	1430	2140	0	0	713
12	0	1180	0	3820	5580	0	1180	0
13	483	1930	0	13500	4350	0	967	483
14	0	1620	0	7820	5660	0	3500	269
15	47900	12100	0	16900	11100	2630	2630	2630
16	1060	1060	0	6030	7090	0	0	354
17	242	1210	0	5800	5560	0	725	725
18	0	468	234	2340	1170	0	234	468
19	1390	2790	696	7190	5110	0	928	2320
20	119	238	0	2620	1310	0	119	238
21	0	1640	0	2660	4290	0	818	613
22	983	2950	0	3930	2950	0	1970	0
23	0	2430	202	3240	1620	0	0	0
30	0	0	0	0	0	0	0	0
31	0	841	0	421	0	0	0	0
32	0	552	0	0	0	0	6070	0
33	0	290	0	0	0	0	0	0
34	0	1210	0	1210	0	0	0	0
35	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0
39	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	78	0
41	0	0	0	0	0	0	0	0
42	0	0	0	269	0	0	0	0
43	0	0	0	0	0	0	0	0
44	0	0	0	0	0	0	0	0
45	0	0	0	0	0	0	0	597
46	0	0	0	0	0	0	0	0

Table F.1 continued.

Station	*Ceratium fusus*	*Ceratium lineatum*	*Ceratium longipipes*	*Dinophysis acuminata*	*Dinophysis acuta*	*Dinophysis fortii*	*Dinophysis norwegica*	*Dinophysis parva*
47	0	0	248	0	0	0	0	0
48	0	0	0	624	0	0	178	0
49	0	0	0	687	0	0	321	0
50	0	0	0	330	0	0	189	0
51	0	0	0	1440	0	0	0	0
52	0	0	0	2130	0	0	0	0
53	0	0	0	0	0	0	0	0
54	0	0	0	0	0	0	0	0
55	0	0	0	619	0	0	309	0
56	0	0	0	0	0	0	0	0
57	0	0	0	0	0	0	0	0
58	0	0	0	0	0	0	0	0
59	0	377	0	1130	0	0	943	0
60	0	0	0	438	0	0	657	0
61	0	0	0	632	0	0	0	0
62	0	0	0	678	0	0	678	0
63	0	0	0	0	0	0	0	0
64	0	0	0	0	0	0	0	0
65	0	0	0	3020	1370	0	1370	0
66	0	0	213	1070	640	0	1490	0
67	0	0	0	1460	624	0	416	416
68	0	2210	0	1100	0	0	1380	0
69	0	0	0	0	0	0	2290	0
70	0	0	0	0	0	0	0	0
71	0	0	0	0	0	0	0	0
72	0	0	0	0	0	0	7310	0
73	0	219	0	1310	0	0	0	219
74	0	0	0	0	0	0	0	0
75	0	0	0	0	0	0	0	0
76	0	5850	0	0	0	0	0	0
77	0	0	0	0	0	0	0	0
78	15600	7800	0	0	3900	0	0	0
79	0	9000	0	0	4500	0	0	0
80	0	0	0	705	0	0	705	0
81	0	0	0	0	0	0	0	0
82	0	0	0	0	0	0	0	0
84	0	0	0	0	0	0	4120	0
85	0	0	0	0	0	0	0	0
86	0	0	0	318	0	0	0	0

Table F.1 continued.

Station	*Glenodinium danicum*	*Gonyaulax* spp.	*Gymnodinium* spp.	*Gyrodinium* spp.	*Heterocapsa triquetra*	*Oxyphysis oxytoxoides*	*Peridinium* spp.	*Phalachroma rotundatum*
1	0	0	11600	893	0	0	1340	0
2	0	0	0	0	0	0	0	0
3	2460	1850	616	0	0	0	0	0
4	0	0	1520	0	0	0	759	0
5	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0
7	2920	0	4390	1460	0	0	0	0
8	2570	1100	3130	2390	2210	0	0	0
9	0	2640	440	0	0	0	0	0
10	8090	2490	4360	0	622	0	622	0
11	5710	4280	4990	0	9980	0	0	0
12	0	2940	6760	0	5880	0	0	0
13	6770	9670	15000	3870	20300	0	0	0
14	5120	7000	8890	4310	9700	808	3503	0
15	12100	4740	14200	0	9480	0	2630	0
16	1420	4960	14900	10300	3900	354	5670	0
17	3380	4830	12800	7490	8700	0	2660	242
18	1640	5380	7020	4210	3280	234	1400	0
19	0	6730	16500	8820	3710	0	2090	0
20	595	2140	2380	1190	5240	0	238	0
21	6340	6540	11900	6130	3890	0	5730	0
22	2210	9830	21400	6630	5650	0	5160	0
23	1620	8300	10100	3040	8300	202	4650	0
30	799	665	3330	1200	5320	0	932	0
31	2310	841	12200	8840	1680	0	1260	0
32	0	1100	61000	3860	1660	0	0	0
33	4060	4060	10400	2320	2320	0	1160	0
34	3330	29700	19100	1820	7270	0	0	0
35	0	1270	7630	0	0	0	0	0
36	2790	0	6960	0	0	0	0	0
37	0	0	5130	0	0	0	0	0
38	332	0	4650	0	0	0	332	0
39	872	0	7350	1180	187	0	62	0
40	785	0	3220	1650	0	0	0	78
41	0	1270	1270	0	0	0	0	0
42	896	448	3940	896	269	0	896	0
43	0	0	0	0	0	0	0	0
44	0	1460	5850	2920	0	0	0	0
45	6560	0	0	0	0	0	0	0
46	0	496	2480	0	0	0	0	0

Table F.1 continued.

Station	*Glenodinium danicum*	*Gonyaulax* spp.	*Gymnodinium* spp.	*Gyrodinium* spp.	*Heterocapsa triquetra*	*Oxyphysis oxytoxoides*	*Peridinium* spp.	*Phalachroma rotundatum*
47	1490	991	2730	991	0	0	0	0
48	624	624	2590	2410	0	0	178	0
49	596	642	1830	1600	183	0	458	0
50	519	896	0	755	189	0	472	0
51	0	0	8300	3970	0	0	0	0
52	532	0	12800	5320	0	0	532	0
53	0	0	14600	14600	0	0	0	0
54	0	0	2440	0	0	0	0	0
55	1240	0	6810	2480	0	0	619	0
56	0	318	10500	6360	0	0	953	0
57	3250	1080	5420	0	0	0	0	0
58	1090	1090	1640	0	0	0	0	0
59	943	566	1890	0	0	0	566	0
60	657	219	2630	2630	0	0	657	0
61	0	632	3790	0	0	0	0	0
62	0	170	1870	0	509	0	678	0
63	0	636	0	0	0	0	0	0
64	0	2210	1100	0	0	0	0	0
65	8510	5220	9330	8240	6040	824	1920	0
66	0	1490	5980	0	2990	0	0	0
67	5830	624	3330	0	2080	0	624	0
68	1380	0	6340	3030	276	0	2210	0
69	0	0	5730	4590	0	0	0	0
70	4440	740	7400	2960	0	0	0	0
71	3770	0	11300	0	0	0	0	0
72	0	7310	0	0	0	0	0	0
73	3940	3070	9200	5480	4820	0	2410	0
74	0	0	0	0	0	0	0	0
75	0	0	0	0	0	0	0	0
76	0	0	0	0	0	0	0	0
77	0	0	10600	0	0	0	0	0
78	0	39000	89700	0	101000	0	0	0
79	0	4500	9000	0	0	0	0	0
80	705	1410	6340	2820	0	0	705	0
81	680	2040	7480	4080	1360	0	2040	0
82	5150	936	10800	6550	1400	0	0	0
84	0	1240	1240	0	4120	0	0	0
85	4680	0	19900	4680	0	0	0	0
86	953	0	3500	2540	0	0	1270	0

Table F.1 continued.

Station	*Prorocentrum compressum*	*Prorocentrum micans*	*Protoperidinium* spp.	*Scrippsiella trochoidea*
1	0	0	1790	0
2	0	0	11700	0
3	0	0	616	0
4	0	3800	6080	759
5	0	8350	0	0
6	0	0	0	16700
7	0	0	1460	0
8	0	1660	2570	1840
9	0	0	1320	440
10	0	0	0	1240
11	0	0	713	3570
12	0	2640	1760	4110
13	0	14500	4350	3870
14	0	2700	5120	1890
15	0	0	7900	5270
16	0	354	3900	2130
17	0	242	3140	1210
18	0	1400	3040	702
19	0	1390	2550	1390
20	0	357	0	595
21	0	818	3270	3270
22	0	983	1470	4670
23	0	1210	809	4250
30	13700	133	0	133
31	0	421	210	1260
32	0	552	1660	3310
33	57100	0	0	2320
34	0	3640	7270	1210
35	0	0	1271	1270
36	0	0	3480	1390
37	0	0	4100	2050
38	0	0	0	1330
39	0	0	0	130
40	0	0	0	0
41	0	0	1270	0
42	0	0	0	896
43	0	0	0	0
44	0	0	0	0
45	0	0	597	1190
46	0	0	0	0

Table F.1 continued.

Station	*Prorocentrum compressum*	*Prorocentrum micans*	*Protoperidinium* spp.	*Scrippsiella trochoidea*
47	0	0	0	0
48	0	0	0	267
49	0	0	92	229
50	0	0	141	141
51	0	0	722	361
52	0	0	532	532
53	0	0	7310	0
54	0	0	0	2440
55	0	0	309	619
56	0	0	953	636
57	0	0	0	0
58	0	0	547	547
59	0	0	2080	566
60	0	0	1310	0
61	0	1580	4430	0
62	0	339	848	1190
63	0	0	0	636
64	0	0	0	2210
65	0	0	3020	4120
66	0	0	2990	2780
67	0	0	832	1250
68	0	276	828	0
69	0	0	3440	0
70	0	0	0	0
71	0	0	0	0
72	0	0	0	7310
73	0	0	219	2190
74	0	0	0	0
75	0	0	0	0
76	0	0	5850	0
77	0	0	10600	21300
78	0	3900	15600	50700
79	0	9000	4500	13500
80	0	0	0	0
81	0	0	2040	0
82	0	0	468	936
84	0	1650	1240	3710
85	0	0	0	585
86	0	0	0	0

APPENDIX G

DATA FROM PREVIOUS STUDIES

Table G.1: Surface data for samples taken in Hecate Strait July 2-6, 2000. Nutrient concentrations are in µM and chlorophyll a concentrations are in mg m^{-3}. Data from C.L.K. Robinson.

Latitude	Longitude	Nitrate	Silicate	Phosphate	Chlorophyll *a*
51.210	128.873	0.0	7.3	0.40	0.40
51.293	129.037	0.1	5.6	0.34	0.38
51.403	129.232	0.9	7.9	0.46	1.24
51.517	129.423	0.0	2.7	0.33	0.91
51.627	129.587	0.0	2.8	0.33	1.05
51.737	129.760	0.0	9.5	0.35	0.32
51.838	129.950	0.1	7.9	0.34	0.36
51.962	130.205	0.2	6.0	0.33	0.32
52.042	130.380	2.7	12.1	0.62	1.35
52.145	130.555	0.4	9.3	0.45	1.10
52.301	130.652	0.2	7.3	0.37	0.52
52.417	130.742	0.1	5.9	0.29	0.36
52.546	130.824	0.1	8.3	0.27	0.43
52.712	130.882	0.1	3.8	0.23	0.64
52.887	130.118	1.0	9.4	0.50	1.67
53.072	131.010	0.1	2.8	0.67	1.06
53.260	131.015	0.1	0.8	0.24	0.39
53.432	131.032	0.1	2.6	0.23	0.67
53.575	131.018	0.1	3.9	0.20	0.85
53.657	130.940	0.1	4.5	0.26	1.14
53.760	130.936	0.9	3.4	0.22	1.56
53.835	130.941	0.1	6.5	0.27	2.00
54.000	131.086	0.2	4.3	0.35	4.54
54.128	131.232	0.1	9.2	0.42	4.39
52.994	130.367	0.1	2.1	0.27	0.69
52.690	130.028	0.1	8.3	0.31	0.35
52.390	129.690	0.3	1.5	0.33	0.72
52.080	129.442	0.1	0.6	0.31	0.40
51.809	129.029	0.1	2.3	0.18	0.52
51.503	128.699	0.2	2.1	0.35	2.28
51.137	128.530				0.81
51.130	128.308	0.2	4.8	0.27	0.48

Table G.2: Surface data for samples taken in Hecate Strait August 25 – September 6, 2000. Nutrient concentrations are in μM and chlorophyll a concentrations are in mg m^{-3}. Data from C.L.K. Robinson.

Latitude	Longitude	Nitrate	Silicate	Phosphate	Chlorophyll *a*
51.212	128.85	2.1	9.7		1.36
51.52	130.443	2.4	13.7	0.6	1.61
51.761	130.666	2.1	13.8	0.52	0.91
50.77	129.456	0.1	9.1	0.38	0.4
51.198	130.094	0.2	7.1	0.4	0.53
51.17	130.134	0.2	7.3	0.4	0.61
51.22	130.218	0.2	6.5	0.38	0.48
52.05	131.53	1.5	11.3	0.54	1.46
52.05	131.49	2.6	12.3	0.63	1.32
51.681	130.55	4.8	16.5	0.74	1.09
51.597	130.582	6.5	17.3	0.87	0.97
51.422	130.62	3.6	14.7	0.7	1.13
51.541	130.448	4.6	17.1	0.75	1.6
51.239	130.342	0.2	5.9	0.4	0.32
51.308	130.183	0.2	7.2	0.42	0.35
51.212	130.071	0.5	7	0.46	0.28

Table G.3: Surface data for samples taken in Hecate Strait August 9-11, 2000. Chlorophyll a concentrations are in mg m^{-3}. Data from T.D. Peterson.

Latitude	Longitude	Chlorophyll *a*
52.09	131.388	0.89
52.12	131.358	1.11
52.14	131.323	0.52
52	131.497	1.78
52	131.33	3.23
52	131.235	8.10
52	131.154	2.86
52	130.95	0.19
52	130.85	0.53
52	130.733	0.13

Table G.4: Surface data for samples taken on the west coast of the Queen Charlotte Islands July 4-11, 2000. Chlorophyll a concentrations are in mg m^{-3}. Data from C.L.K. Robinson.

Latitude	Longitude	Chlorophyll *a*
54 10.5	133 08.9	0.98
53 32.6	133 04.5	0.92
53 17.82	132 50.124	0.6
53 07.28	132 40.91	1.43
52 57.29	132 31.24	0.9
52 47.8	132 19.06	0.4
52 40.43	132 07.17	1.08
52 32.29	131 54.24	1.55
52 24.8	131 41.17	1.37
52 23.44	131 41.17	1
52 14.4	131 31.4	0.95
52 05.78	131 19.67	1.58
51 57.22	131 06.41	0.75

Table G.5: Surface data for samples taken off of the west coast of the Queen Charlotte Islands June 13-21, 2000. Chlorophyll a concentrations are in mg m^{-3}. Data from F. Whitney.

Latitude	**Longitude**	**Chlorophyll *a***
51	135.43	0.22
50.99	134.31	0.33
50.99	133.46	0.42
51	132.67	0.35
51	131.86	0.77
50.99	131.04	1.02
51	130.26	0.27
51.26	130.91	0.62
51.37	132.06	0.12
51.49	133.29	0.24
51.63	134.56	0.09
51.75	135.84	0.21
52	135.83	0.11
52.25	135.83	0.16
52.51	135.74	0.20
52.75	135.83	0.20
53	135.83	0.20
53.25	135.83	0.17
53.5	135.83	0.242
53.75	135.83	0.164
54	135.83	0.22
53.25	135.42	0.26
53	135.41	0.27
52.75	135.41	0.29
52.75	135.83	0.37
52.62	135.83	0.36
52.5	135.84	0.36
52.37	135.83	0.31

Table G.6: Surface data for samples taken on the west coast of the Queen Charlotte Islands September 1999. Chlorophyll a concentrations are in mg m^{-3}. Data from F. Whitney.

Latitude	Longitude	Chlorophyll *a*
56.50143	135.6519	0.60
55.71717	135.6492	0.53
55.50183	135.6508	0.45
54.99305	135.6517	0.94
54.49248	135.6508	0.85
54.00707	135.6496	0.68
53.79833	135.6473	0.69
53.60017	135.6485	1.00
53.50067	135.6497	0.88
53.40033	135.6495	0.89
53.3004	135.6506	0.87
53.20317	135.6512	0.82
53.103	135.6548	0.87
52.9985	135.656	0.77
52.8	135.653	0.69
53.298	135.0014	0.28
53.30167	134.504	0.40
53.30007	134	0.44
53.29955	133.4984	0.90
53.25045	133.012	0.73
52.77678	132.7222	0.52
52.25873	131.8867	0.61
52.09535	131.1952	0.74
51.63273	130.8917	0.97
51.12117	130.088	1.04
51.00003	129.9011	1.14
51.00058	129.0305	0.26
51.00057	128.2747	0.17

APPENDIX H

CCA ORDINATION BIPLOTS

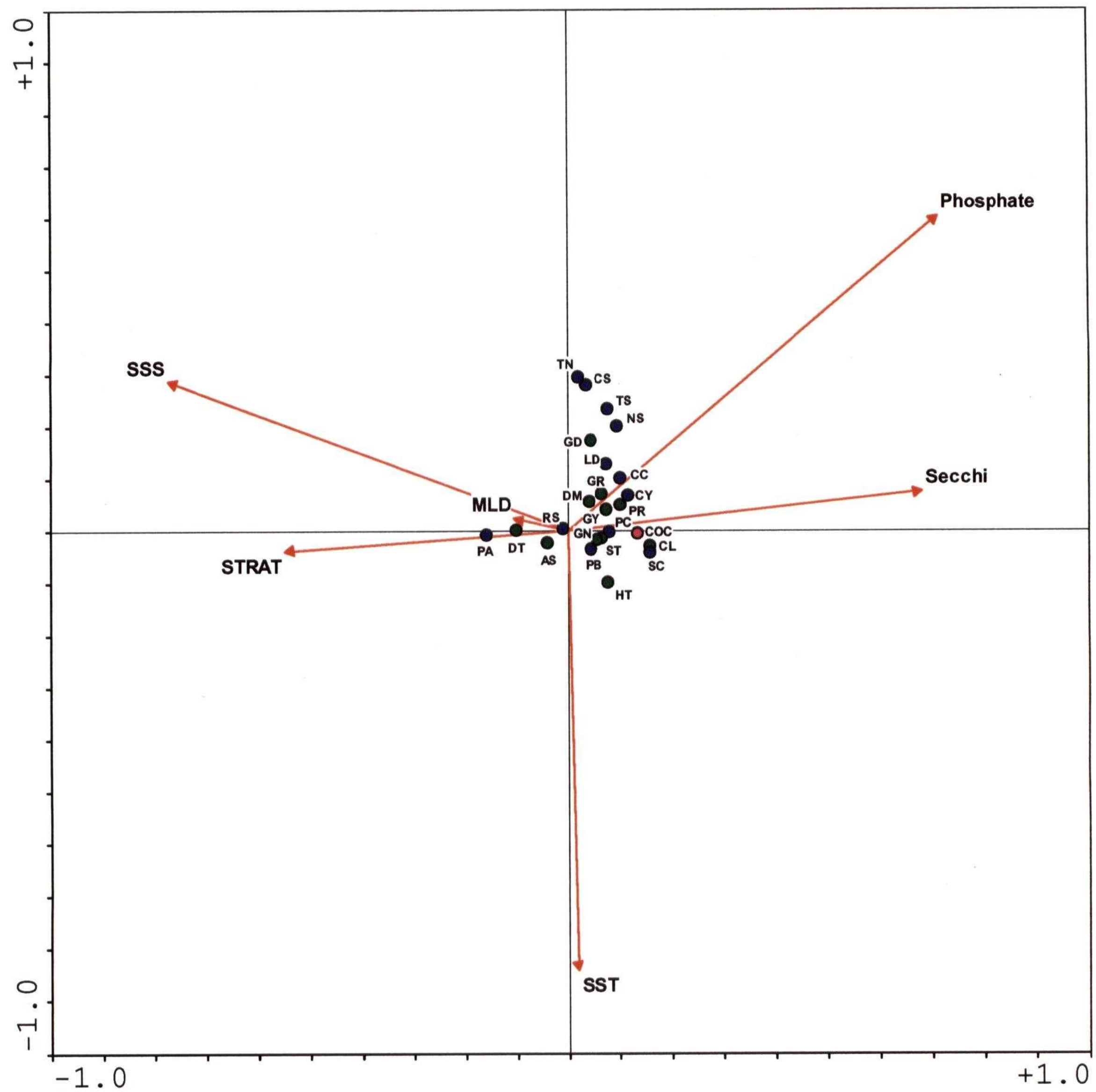

Figure H.1: CCA ordination graph showing species or groups (points) and relationships to environmental variables (arrows) on the east coast of Gwaii Haanas. Name abbreviations are: AS = *Alexandrium* spp., CC = *Coscinodiscus centralis*, CL = *Ceratium lineatum*, COC = coccolithophores, CS = *Chaetoceros* spp., CY = *Cylindrothceca closterium*, DM = *Dinohysis acuminata*, DT = *Dinophysis acuta*, GD = *Glenodinum danicum*, GN = *Gonyaulax* spp., GR = *Gyrodinium* spp., GY = *Gymnodinium* spp., HT = *Heterocapsa triquetra*, LD = *Leptocylindrus danicum*, NS = *Navicula* spp., PA = *Pseudonitzschia* "A", PB = *Pseudonitzschia* "B", PC = *Pseudonitzschia* "C", PR = *Protoperidinium* spp., RS = *Rhizosolenia setigera*, SC = *Skeletonema costatum*, ST = *Scrippsiella trochoidea*, TN = *Thalassionema nitzschiodes*, TS = *Thalassiosira* spp. Symbol key is; blue = diatoms, green = dinoflagellates, pink = coccolithophores. SST = sea surface temperature, SSS = sea surface salinity, MLD = depth of the mixed layer, STRAT = degree of stratification.

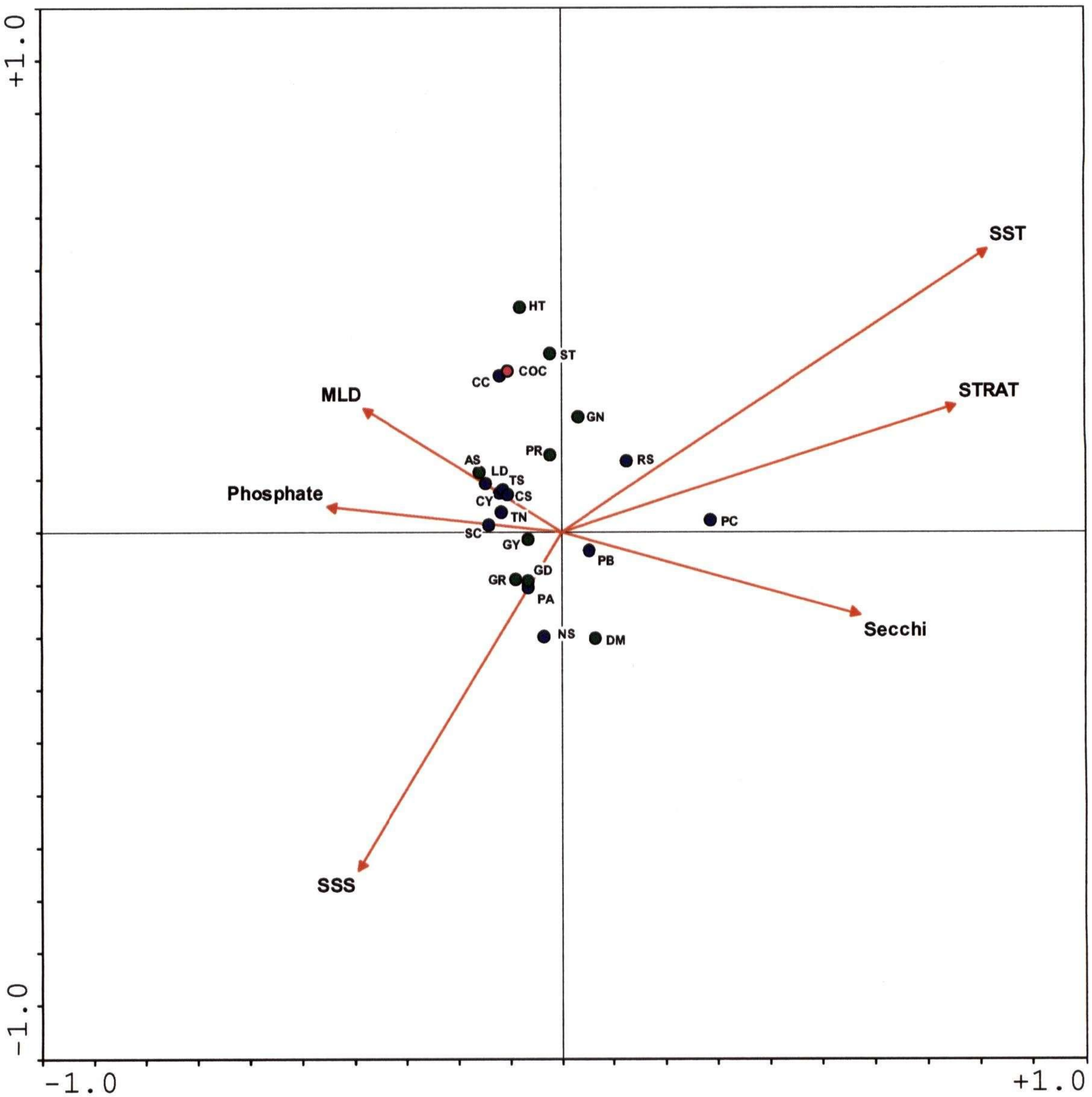

Figure H.2: CCA ordination graph showing species or groups (points) and relationships to environmental variables (arrows) on the west coast of Gwaii Haanas. Name abbreviations are: AS = *Alexandrium* spp., CC = *Coscinodiscus centralis*, CL = *Ceratium lineatum*, COC = coccolithophores, CS = *Chaetoceros* spp., CY = *Cylindrothceca closterium*, DM = *Dinohysis acuminata*, DT = *Dinophysis acuta*, GD = *Glenodinum danicum*, GN = *Gonyaulax* spp., GR = *Gyrodinium* spp., GY = *Gymnodinium* spp., HT = *Heterocapsa triquetra*, LD = *Leptocylindrus danicum*, NS = *Navicula* spp., PA = *Pseudonitzschia* "A", PB = *Pseudonitzschia* "B", PC = *Pseudonitzschia* "C", PR = *Protoperidinium* spp., RS = *Rhizosolenia setigera*, SC = *Skeletonema costatum*, ST = *Scrippsiella trochoidea*, TN = *Thalassionema nitzschiodes*, TS = *Thalassiosira* spp. Symbol key is; blue = diatoms, green = dinoflagellates, pink = coccolithophores. SST = sea surface temperature, SSS = sea surface salinity, MLD = depth of the mixed layer, STRAT = degree of stratification.

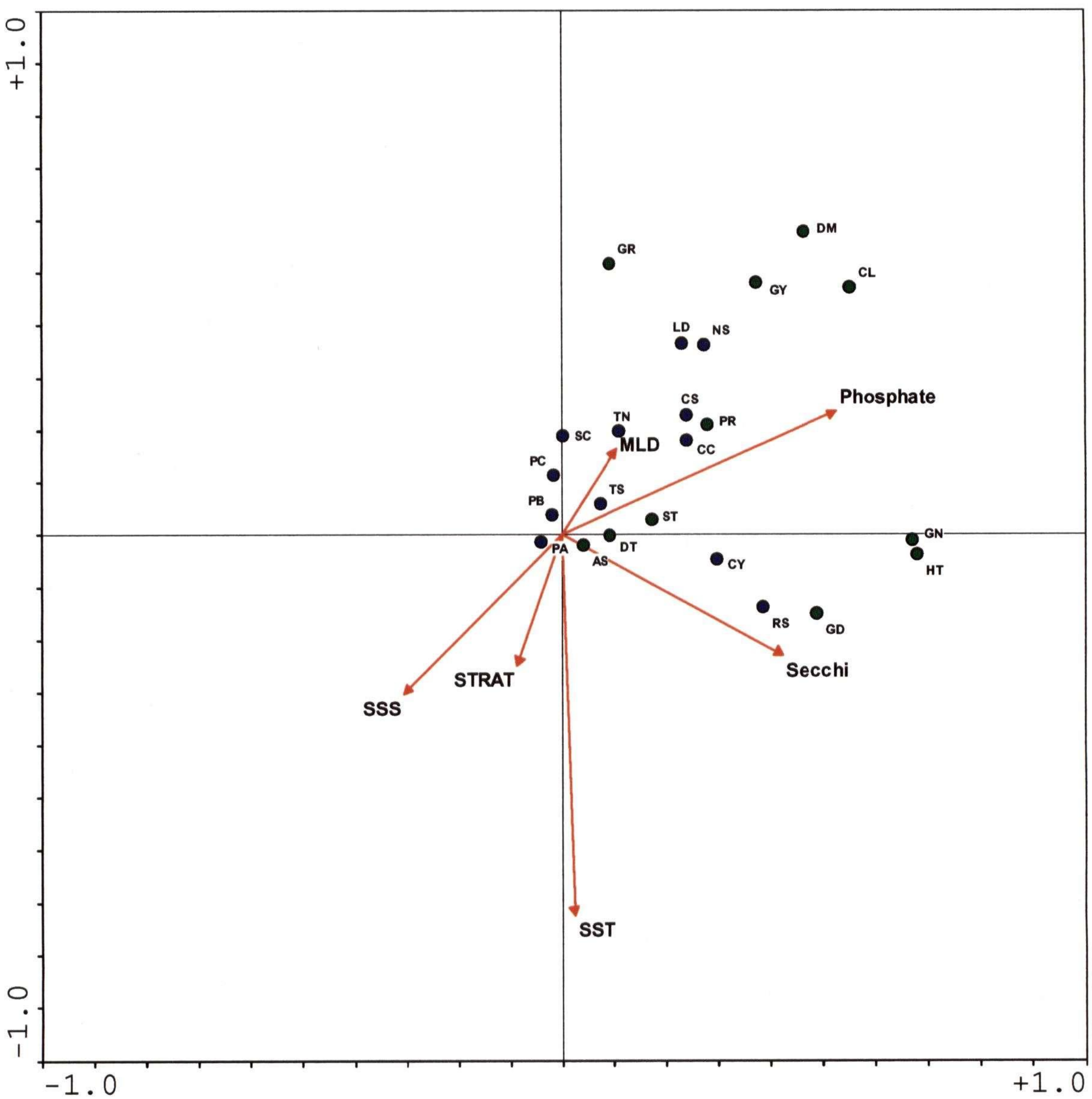

Figure H.3: CCA ordination graph showing species or groups (points) and relationships to environmental variables (arrows) in the summer of 2001. Name abbreviations are: AS = *Alexandrium* spp., CC = *Coscinodiscus centralis*, CL = *Ceratium lineatum*, COC = coccolithophores, CS = *Chaetoceros* spp., CY = *Cylindrothceca closterium*, DM = *Dinohysis acuminata*, DT = *Dinophysis acuta*, GD = *Glenodinum danicum*, GN = *Gonyaulax* spp., GR = *Gyrodinium* spp., GY = *Gymnodinium* spp., HT = *Heterocapsa triquetra*, LD = *Leptocylindrus danicum*, NS = *Navicula* spp., PA = *Pseudonitzschia* "A", PB = *Pseudonitzschia* "B", PC = *Pseudonitzschia* "C", PR = *Protoperidinium* spp., RS = *Rhizosolenia setigera*, SC = *Skeletonema costatum*, ST = *Scrippsiella trochoidea*, TN = *Thalassionema nitzschiodes*, TS = *Thalassiosira* spp. Symbol key is; blue = diatoms, green = dinoflagellates, pink = coccolithophores. SST = sea surface temperature, SSS = sea surface salinity, MLD = depth of the mixed layer, STRAT = degree of stratification.

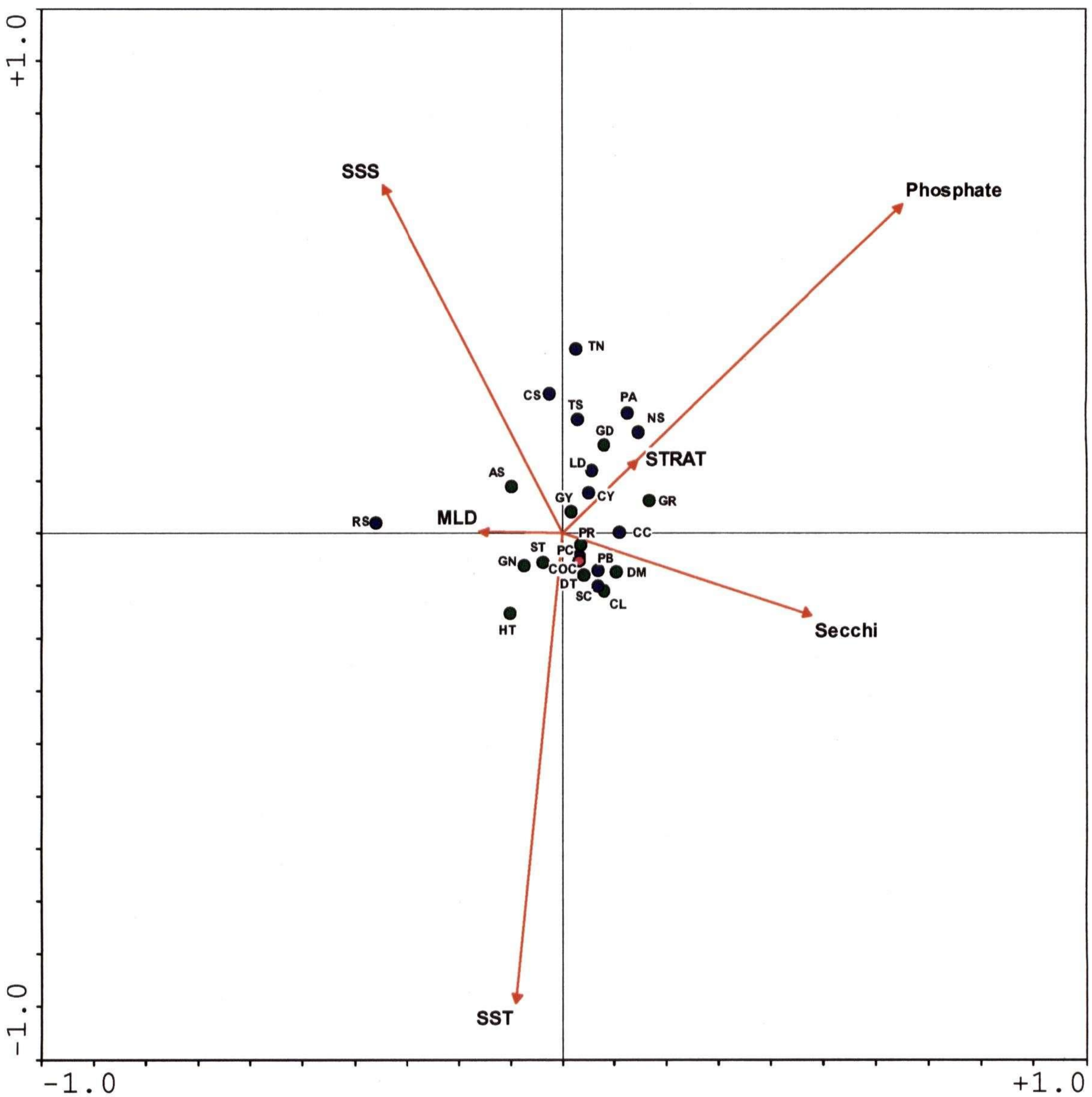

Figure H.4: CCA ordination graph showing species or groups (points) and relationships to environmental variables (arrows) in the summer of 2002. Name abbreviations are: AS = *Alexandrium* spp., CC = *Coscinodiscus centralis*, CL = *Ceratium lineatum*, COC = coccolithophores, CS = *Chaetoceros* spp., CY = *Cylindrothceca closterium*, DM = *Dinohysis acuminata*, DT = *Dinophysis acuta*, GD = *Glenodinum danicum*, GN = *Gonyaulax* spp., GR = *Gyrodinium* spp., GY = *Gymnodinium* spp., HT = *Heterocapsa triquetra*, LD = *Leptocylindrus danicum*, NS = *Navicula* spp., PA = *Pseudonitzschia* "A", PB = *Pseudonitzschia* "B", PC = *Pseudonitzschia* "C", PR = *Protoperidinium* spp., RS = *Rhizosolenia setigera*, SC = *Skeletonema costatum*, ST = *Scrippsiella trochoidea*, TN = *Thalassionema nitzschiodes*, TS = *Thalassiosira* spp. Symbol key is; blue = diatoms, green = dinoflagellates, pink = coccolithophores. SST = sea surface temperature, SSS = sea surface salinity, MLD = depth of the mixed layer, STRAT = degree of stratification.