ECOSYSTEM STUDIES IN A BOREAL, MACROTIDAL ESTUARY: COBSCOOK BAY, MAINE

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Peter F. Larsen, Editor

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INTRODUCTION

In 1994, an interdisciplinary, multi-institutional team of marine scientists was awarded a competitive grant from The Nature Conservancy and the Andrew W. Mellon Foundation to investigate the ecosystem dynamics of Cobscook Bay, Maine. Cobscook Bay is a hydrographically and geologically complex estuary where very high levels of biodiversity and productivity co-exist. Human impact is largely limited to living resource harvesting. Cobscook Bay is at once unique and representative. It is the ideal focus for ecosystem research directed at understanding our vital and valuable boreal estuaries and embayments.

The overall goals of this research effort were: to identify the forcing functions that initially produced, and now maintain, this unusual co-occurrence of diversity and productivity; to quantify the pathways and rates of movement of energy and materials through the system; and to define the limits or carrying capacity of the various system components. The overarching goal was to provide a sound and accessible information base to insure the continued integrity of the system. Emphasis in this two-year investigation was on primary productivity and factors regulating it

This report presents the initial contributions of the researchers included in the contract to the Bigelow Laboratory for Ocean Sciences and is an effort to make the results available as soon as possible. A comprehensive, peer-reviewed journal volume integrating the contributions of all the study participants is in progress and will be available in the near future. Please contact the appropriate authors for information on the most up-to-date citations.

Nutrient Sources and Distributions in Cobscook Bay

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Background

The same nutrients that are important for healthy growth of land plants, nitrogen and phosphorous, are also essential for the growth of marine plants. In the lighted upper portion of the sea nitrogen may be available for plant growth as nitrate and ammonium, sometimes referred to as combined inorganic nitrogen. However, during the summer months it frequently becomes exhausted while other nutrients do not, so nitrogen is often considered the limiting nutrient. By limiting we mean that adding more nitrate or ammonium will cause an increase in plant growth rate and quantity (biomass), whereas adding other nutrients will cause little response. For this reason, in marine systems, study of combined inorganic nitrogen can tell us a lot about the health and productivity of a water body.

There is often a great deal of public concern about nutrients in both fresh and saltwater, but it is important to remember that they are essential for marine life and healthy productive waters. Virtually all life in the oceans depends on a supply of nutrients to promote plant (phytoplankton and algal) growth. Herbivorous animals depend on the plants for their nutrition and become prey and food for larger animals. In the big picture, the amount of protein nitrogen that can be removed from a natural system, and this applies collectively to seaweed harvesting, shellfish digging and dragging, fishing, migratory bird feeding and a host of other activities, cannot exceed the supply of combined inorganic nitrogen to it, without depletion and ultimately detriment. Some of the most productive fisheries in the world are found in regions that have high natural rates of nutrient supply and high nutrient concentrations. The anchovy and similar fisheries of upwelling regions such as the coast of Chile are good examples, where high nutrient concentrations have direct economic value.

A frequent cause of concern when dealing with nutrients is that they may be present in excess. When this happens plant biomass increases dramatically and the process is called eutrophication. Eventually, biomass may reach to such high concentrations that night-time respiration can use up all the dissolved oxygen in the water, causing anoxia wthat results in mass mortality of plants and animals alike. Generally, the problem leading to anoxic events is one of scale: that is, there is an enormous amount of nutrient producing activity which is frequently human, and a limited, often inadequately flushed receiving water to absorb the nutrients. Anoxic events are actually quite rare and limited geographically, and even occur naturally, but they can occur as a result a variety of human activities. These include sources (and implicated areas) such as collected sewage discharge (Hudson Estuary / New York Bight), agricultural fertilizer (Chesapeake Bay) and animal feed (Long Island duck farms) that is allowed to enter coastal waters without proper safeguard.

It is important to remember that high nutrient concentrations can be natural, do not necessarily lead to eutrophication, and can have tremendous ecological and economic value. Cobscook Bay is such a case.

Nutrient Distributions

We are interested in the distribution of nutrients in Cobscook Bay because they can tell us a lot about how the Cobscook Bay ecosystem works. Our study obtained samples from many locations within the Bay twice in May, twice in July, and in October and November of 1995. Our choices of these times were to allow us to observe the start of the growing season for marine plants, its peak in the summer, and its decline in the fall. We hoped to see the nutrient distributions before plants started to use them, as they consumed them, when they were most utilized and then as use declined and ceased.

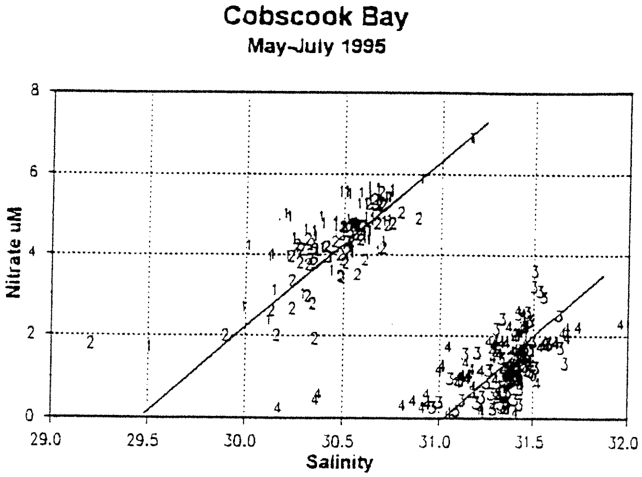
One problem with studying a region like Cobscook Bay is that a large volume of water moves in and out of the Bay on each tide on extremely strong currents. A sample taken at a particular location half an hour ago came from water that is now miles away, and a sample taken from the same location now is from water that was elsewhere when the previous sample was taken. It too will be far away half an hour from now, and all the time water is mixing and changeing as a result. In other words trying to relate nutrient concentrations to geographical locations is not very meaningful unless we could sample all locations at the same moment, which is not possible. What we often do in estuaries is relate nutrient and other distributions to salt content, or salinity, which varies from 0 at the river inflow to 32 - 33 in the sea. Mixing of fresh and seawater in the estuary provides waters with a range of salinities and related properties in between. Instead of plotting measurements against geographical location or mile point along the estuary, we plot graphs of the measurements from a sample against the salinity of the same sample.

The reason for this way of looking at things is that properties that enter with freshwater will distribute with it, with higher concentrations in fresher water in the Bay, and those that enter from the sea will have higher concentrations in saltier water. In fact, if only mixing affects the concentration of a property, then concentration should be proportional to salinity forming a straight line between the freshwater concentrations and the saltwater concentration on the graph. We may have only a general idea of where water with a particular salinity is in the Bay at any time, depending on the tide, but we can know what its properties such as nutrient concentration should be, and depending on its distribution with salinity, where the property came from. Often we find that the distribution is not proportional to salinity, which tells us that other processes have affected concentration, either removing or adding to what we would expect. With nutrients, this can tell us a lot about processes such as uptake and regeneration.

What we found, and why:

Spring and summer

The graph on the following page shows plots of nitrate against salinity in the spring (May points marked 1 and 2) and summer (July points marked 3 and 4). There are differences between the two distributions, which we expect but both show a rapid decline with decreasing salinity. What this indicates is that the source of nitrate is in waters with the highest salinity, in other words the seawater end. In the spring the concentrations are generally higher than in the summer and greater than zero because plant growth is just starting and nitrate is not used entirely or as quickly as it is in the summer. Salinities are lower than the summer because freshwater run-off is higher in the spring causing slightly more dilution of the seawater. However the general pattern in both cases is unequivocal evidence that nitrate enters Cobscook Bay from the seaward end, and the distribution is dominated by this source.



A second feature of this distribution is that in both spring and summer, nitrate would be depleted before salinity reached zero. This further reinforces the conclusion that the ocean and not the rivers provides the nitrate distribution in Cobscook Bay. It also tells us that nitrate is being utilized within the bay by plants, since if it were not, nitrate concentrations would decline much more gradually with salinity, reaching low values only when salinities approach zero.

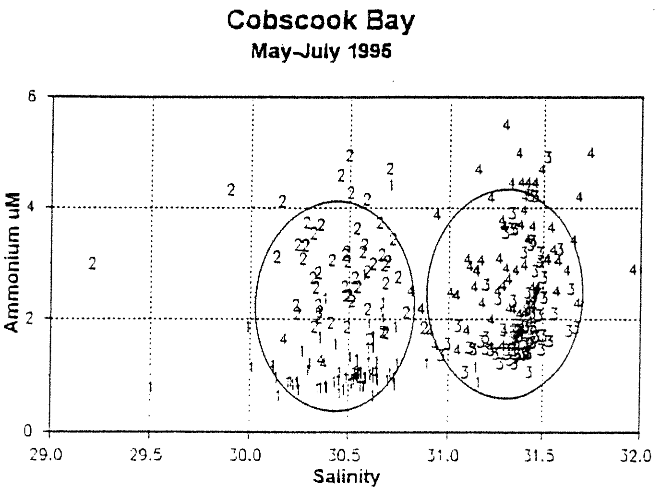
There areseveral other lines of evidence that suggest that the coastal sea is the source of nitrate. A much more complicated analysis of the nitrate and temperature / salinity data allow us to create equations that can be used to predict nitrate from temperature and salinity. Since we have hydrodynamic models that can predict the distribution of salinity and temperature (Dave Brooks), these models can also be used to describe nitrate distribution. They show high nitrate water entering the Bay from the seaward end and diminishing in concentration into bays and towards the river. (Hopefully, Dave Brooks will have an example or two on his computer and Peter Larsen should have a color overhead showing the model distribution in May).

A second line of evidence can be obtained by comparing the potential nitrogen fluxes from other candidates with the nitrate transported in and out of the Bay on the tide each day:

Nitrate tidal exchange (5uM NO_3 source in spring)	70.0	metric tons	N	per day
Nitrogen consumed by plants (400gC$m^{-2}y^{-1}$ over 6 months)	40.2	“	”	“
Nitrogen in salmon feed (1994/5 data)*	1.2	“	”	“
Total nitrogen in freshwater run-off*	0.9	“	”	“
Total nitrogen in rain and dust fallout*	0.2	“	”	“
Sewage nitrogen (10,000 people max.)	0.01	“	”	“

* Data provided by Dan Campbell

These calculations show that all the other likely candidate sources of nitrogen to Cobscook Bay combined only represent about 3% of the nitrogen that is transported by the tide each day as nitrate, and 5% of what is utilized each day in the growing season by plants. Thus, although local impacts of the other sources cannot be discounted, in the bigger picture, only tidal exchange of nitrate is comparable to plant utilization of nitrogen, and the lesser sources are insignificant.



Ammonium is excreted by animals that consume plants, and also by bacterial breakdown of nitrogen containing organic matter. It is used preferentially over nitrate by most marine plants, and is also oxidized quite rapidly by bacteria to nitrate. As a result it is important in phytoplankton nutrition, and its presence tells us about recent herbivory and recycling. In ocean waters its presence often indicates that plant production and herbivorous grazing are closely balanced, and this is observed as the ecosystem matures in the summer. The distribution of ammonium in Cobscook Bay in the spring and summer is shown in the adjacent figure.

Unlike nitrate, ammonium is distributed quite randomly with respect to salinity in both the spring and the summer. Since ammonium is produced by regenerative processes and is relatively short lived, this strongly suggests that the ammonium is being regenerated within Cobscook Bay. What is most surprising is that ammonium concentrations are almost as high in the spring as they are in the summer. High concentrations in the summer and fall would be expected because the herbivore populations have had chance to respond to the available plant food and grow to match the supply. This is not normally the case in the spring. The implication is that at least some of the herbivore population is already in place in the Bay and starts to consume plankton as soon as they grow in the spring. This scenario is consistent with large populations of filter feeding animals that are resident in the Bay, such as clams, mussels and scallops.

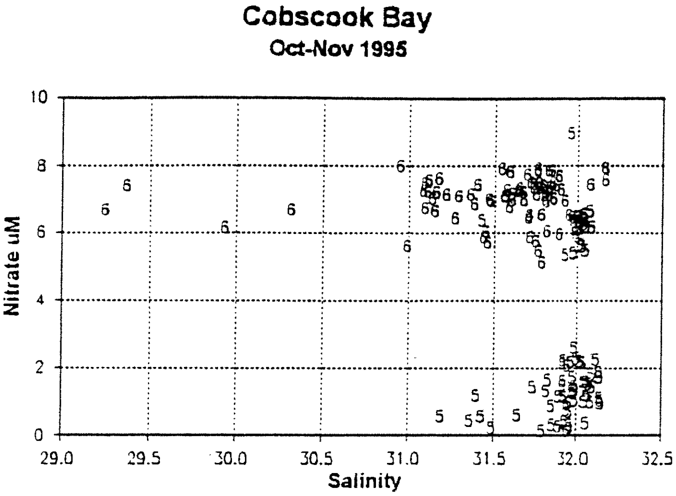
This pool of nitrogen can be put in the same perspective as the other fluxes calculated above:

Ammonium tidal exchange (2uM NH_4 in the Bay)	14.9 metric tons N per day

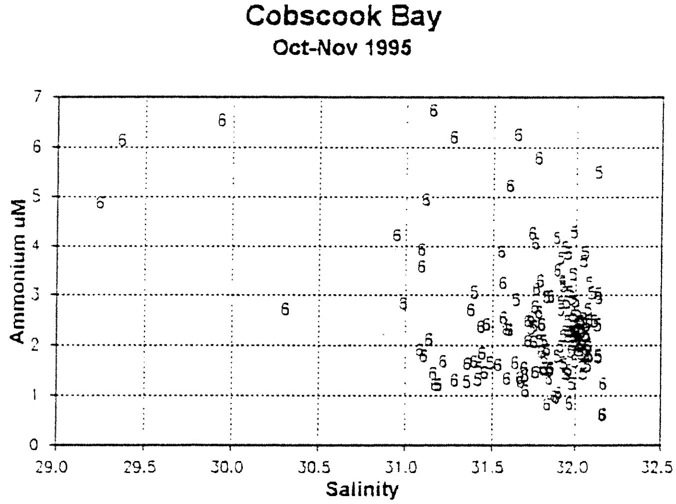
which may be lost if ebbing water is not returned on the next flood. Coincidentally this helps balance the nitrogen budget for the Bay (not the purpose of this exercise) but more importably, this flux is a factor of ten or more larger than any that man can influence.

Fall

In the fall we see nitrate utilization continuing into October (points labeled 5) and the distribution is still similar to summer conditions. However, by November nitrate uptake ceases or is very low and nitrate concentrations are both high and almost uniform over the salinity range sampled (points labelled 6). Despite the high nutrient concentrations there is insufficient light to support plankton and algal growth, and phytoplankton populations decline while fixed algae respire more than they photosynthesize, which has implicationss for regeneration.



Ammonium distributions in October are very similar to those in the summer, and for the same reasons: herbivores effectively crop the phytoplankton and regenerate ammonium within the Bay. The same distribution persists into November but primary production has been inferred to have decreased, based on the nitrate distribution, and so the source of this ammonium must be different, at least in part.



Nutrient data alone are insufficient to elucidate the source of the regeneration that continued high ammonium concentrations imply. However, by the fall there are large reservoirs of organic nitrogen in seaweeds and algal mats. These break down and are grazed, resulting in direct regeneration and a continued supply of particles for filter feeders. In fact, for a variety of reasons other than the nutrient distribution, it seems very likely that grazing on fixed algae is at least as important as filter feeding on phytoplankton in the regeneration of nitrogen as ammonium throughout the growing season and into the fall.

The ultimate source of nitrate?

A final comment on where the nitrate comes from, when much of the Gulf of Maine surface water is nutrient depleted throughout the summer, is in order. High nitrate concentrations build up in deeper waters where the products of excretion, death and decay accumulate and the nitrogen they contain is oxidized eventually to nitrate. In the absence of sufficient light this nitrate cannot be utilized until physical processes bring it to the surface where there is light, photosynthesis, plant growth and nutrient uptake. This occurs annually throughout the Gulf when winter cooling causes deep convection, water column overturn and mixing providing a nutrient supply supporting phytoplankton growth when days lengthen in the spring. Mixing is the key. Over much of the Gulf the spring warming results in warm nutrient depleted water at the surface separated by a thermocline from colder nutrient rich water below. Nutrients and high production are short lived in the surface layer.

In the Bay of Fundy two circumstances contribute to mixing of nutrients to the surface throughout the year. In moving from the Gulf into the Bay of Fundy tidal currents are compressed and accelerated by both a narrowing channel and shoaling of the bottom. At some point the increasing turbulence from increasingly faster currents acting on the bottom provides enough energy to destabilize the water column and break the thermocline. Cold nutrient rich water is mixed to the surface and it is this water that acts as a source of nutrients to Cobscook Bay. The large volume tidal exchange of the Bay throughout the year serves as the local transport mechanism.

Conclusions

Cobscook Bay is nutrient rich throughout the year, and is potentially eutrophic. This is a totally natural circumstance brought about by an abundant supply of nutrients, most importantly nitrate, from the adjacent Gulf of Maine. These nutrients promote phytoplankton and fixed algal growth and the biomass produced is heavily grazed resulting in high ammonium concentrations from excretion and regeneration. The high ammonium concentrations and its incomplete re-utilization by the phytoplankton strongly suggest that plant biomass is controlled by grazing. In other words, despite a high natural nutrient loading, natural grazing processes serve to limit the accumulation of plant material and potential eutrophication. Man made contributions are not significant to the nutrient budget of the Bay, although they may have significant local impact. Consequently, the nutrient status of Cobscook Bay has probably changed little since the end of the last ice age.

Primary Productivity of Phytoplankton and Benthic Microalgae in Cobscook Bay

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INTRODUCTION

Our research in Cobscook Bay has focused on determining the seasonal biomass and primary production of microalgae as phytoplankton and attached benthic diatoms. Biomass was measured as the concentration of the photosynthetic pigment chlorophyll *a* per unit volume of water or per unit surface area of the bottom. Primary production was modelled as the product of the concentration of chlorophyll and light intensity over the depth of the water column, or in the case of benthic diatoms, as the product of the concentration of pigment on the bottom and the average light intensity reaching the bottom. This required that we measure the optical properties of particles in the water and the transmission of light through the water. Physical measurements of temperature and salinity, and sample collections for inorganic nutrient concentrations were also made.

Our original assumptions concerning the physical regime of Cobscook Bay were that the tremendous exchange of water over the course of a tidal cycle would result in a well mixed body of water with the exception of areas of freshwater inflow (Dennys and Pennamaquan Rivers) and intertidal regions subject to solar heating. This proved to be generally true, with close agreement in surface and bottom temperature and salinity for most stations. Further, we hypothesized that intense mixing in a shallow embayment would yield extremely high levels of water column phytoplankton biomass and primary production given nutrient levels were not limiting or light penetration was not restricted due to self shading caused by dense phytoplankton biomass. The fate of this carbon production would primarily be to support the diverse assemblages of secondary producers which were known to exist in Cobscook Bay, export to adjacent waters would also be important but burial in the sediments would be extremely low.

The goal of this research was to examine the contribution of microalgae as free living phytoplankton and attached benthic diatoms to the total annual primary production of Cobscook Bay in concert with other efforts involving macroalgae and seagrasses. These four plant groups supply all of the organic material available to higher trophic level herbi-vores in the bay. Understanding the spatial and seasonal distribution of plant biomass and primary production throughout the bay is crucial to the management of other living marine resources found in Cobscook Bay.

METHODS

Six three-day field expeditions to Cobscook Bay centered around spring/neap tidal cycles were performed in 1995: two in May, two in July, one in October and one in November. Thirty-six station locations were selected, 21 peripheral stations in coves and embayments, and 15 stations comprising three sections across restrictions of the main flow axis: Lubec to Eastport, Birch to Gove Points and Leighton to Denbow Necks (Figure 1). The locations of peripheral stations were generally chosen as the center of the subtidal area of a major cove (such as East Bay or Broad Cove) or sub areas of a large portion of the bay (such as East, Mid and West South Bay) in order to sample regions where tidal flow or the influence of fresh water might be significantly different. Two stations outside the bay near the Eastport Breakwater and off Friar's Head along the Canadian and U.S boundary were also occupied during July. Nominal station locations and abbreviations can be found in Table 3. Large areas of the inner bays were not accessible to the vessel Otto Miller, Jr. (Marine Trade Center, Eastport, ME) at all states of the tide (Figure 1, hatched areas).

Several types of sampling activities were used to measure the physical, chemical biological and optical properties of the water column in Cobscook Bay: 1) underway surface mapping between stations, 2) complete suite of station measurements at peripheral stations and 3) short format CTD stations at sections across the main axis of flow. These activities also supported the hydrographic sampling required for the physical modelling (Dr. D. Brooks, Texas A&M) and nutrient analyses (Dr. C. Garside, Bigelow Laboratory).

Continuous underway sampling involved diverting seawater from the vessel's cooling system through a Turner Designs 10-005R fluorometer and thermosalinograph to measure chlorophyll fluorescence, temperature and salinity of the surface waters. Analog voltages from each instrument were monitored on a strip chart recorder with calibration samples for chlorophyll and salinity drawn from the flow at intervals. Ship position, speed, depth to bottom, digital instrument readings, bucket temperature and solar irradiance as photosynthetically active radiation (PAR) were manually logged at five minute intervals.

Peripheral stations were occupied at irregular times between tidal maxima and minima. The vessel was anchored and bottom depth determined using the fathometer. Station activities included a CTD profile of temperature and salinity to within 1m of the bottom, collection of sample water using Niskin bottles at the surface and within 1m of the bottom, profile of photosynthetically active radiation, secchi disk depth determination and benthic sediment sample wherever possible.

A short station format was employed along sections perpendicular to the main axis of tidal flow between Leighton and Denbow Necks, Birch and Gove Points and Eastport to Lubec at dead high and low water. CTD profiles, Niskin sampling and secchi disk depth were measured at closely spaced station locations in order to obtain a snapshot of physical, chemical, biological and optical conditions across these constrictions at high and low tide.

Physical Measurements - CTD profiles/Niskin sampling

A Seabird SeaCAT 19 CTD was used to profile conductivity, temperature and depth. The CTD was operated in internal recording mode with seawater free-flowing through the conductivity sensor (unpumped). The instrument was attached directly above the end of a weighted cable with a Niskin bottle above it and lowered at 0.5m per second to within 1m above the bottom. A second Niskin bottle was attached to the wire with a lead weight messenger and lowered just below the surface. After triggering the bottles to close, the equipment was retrieved in reverse order. The CTD data were processed to calculate salinity and density using standard methods provided by Seabird's SEASOFT software package for unpumped profile data and archived as ASCII files. Sample volumes of seawater were drawn from both Niskin bottles for chlorophyll concentration, particulate absorption and inorganic nutrients; salinity calibration samples were drawn only from the bottom bottle. Salinity samples were analysed using a Guildline MicroSal using standard seawater as a reference.

Biomass Measurements - Chlorophyll concentrations

Water column phytoplankton standing stocks were sampled by filtering duplicate 100ml volumes of seawater through 25mm diameter Millipore HA filters (nominal pore size 0.45μm). The filters were placed in 10ml of 85% acetone and stored on ice until they could be tranferred to a freezer ashore. Benthic diatom standing stocks were sampled by obtaining bottom sediments using a spring-loaded benthic sampler. The sampler was lowered to the bottom in the open position and triggered with a messenger to snap shut. The completely closed unit was retrieved and 1 square cm of undisturbed surficial sediments with overlying algal mat was sampled using a cookie-cutter technique. The benthic microalgae and sediments to a depth of 0.5cm were washed into a 10ml final volume of 85% acetone and handled as above.

All pigment extracts were analyzed for chlorophyll concentration by the fluorometric method of Yentsch and Menzel (1963) using a Turner Model 111 filter fluorometer. Pure chlorophyll *a* from spinach (Sigma Chemical Co.) was used as a standard. Total chlorophyll (chlorophyll *a* plus phaeophytin - a degradation product caused by grazing or physiological stress) and chlorophyll *a* concentrations for water samples were reported as mg/m^3, benthic pigment concentrations were reported as mg/m^2. The ratio of fluorescence in 85% acetone extracts before and after acidification with 1N HCl was used to calculate photosynthetically active chlorophyll *a* and phaeophytin concentrations.

Optical Measurements - Attenuation of PAR

Incident solar radiation is the source of photons which drive photosynthesis in marine systems. The availability of light between 400 and 700nm at any given depth in the sea is controlled by the concentrations of substances which act to absorb and scatter light. These substances include photosynthetic phytoplankton, non-photosynthetic particles, dissolved organic material and the water itself. The exponential loss of light with increasing depth is termed attenuation which is parameterized by the attenuation coefficient for photosynthetically active radiation, k_{PAR} in units of m^{-1}. A Biospherical Instruments QSP250 Scalar Irradiance Meter with a QSP265 Deck Reference Unit were used to measure PAR at depth intervals through the water column. All in-water measurements were normalized to the Deck Reference values to correct for variations in light levels due to clouds, etc. These values of normalized irradiance as a function of depth for each station were fit to an exponential curve to determine k_{PAR} as the slope of the curve.

A second independent measure of attenuation was determined by lowering a 25cm white disk, called a Secchi disk, until it disappeared from sight. The depth of disappearance, termed the Secchi depth, can be empirically related to k_{PAR} for a given body of water and represents a simple method for monitoring water clarity and light penetration.

Optical Measurements - Spectral Particulate Absorption

While the bulk characteristics of light availability in the ocean can be described by the attenuation of photosynthetically active radiation, more specific information concerning the nature of the substances which act to remove light can be gained from measurements of light absorption at individual wavelengths across the visible spectrum. Spectral absorption at any wavelength ($a\lambda$ in units of m^{-1}) can be partitioned as the sum of absorption due to water, particles (phytoplankton and sediment) and dissolved substances (yellow organic compounds from terrestrial runoff or algal exudates). Water absorption is constant with low values in the blue/green region of the visible spectrum increasing toward the red end. Dissolved organic matter absorption varies as a function of concentration increasing exponentially with decreasing wavelength such that absorption is high in the blue and low in the red. Sediment particles absorb light in a similar fashion as dissolved organics but can be distinquished by retention on a filter. Phytoplankton absorption varies as a function of concentration and varies spectrally according to the photosynthetic pigments the cells contain (Yentsch and Phinney, 1985). Thus, spectral particulate absorption can be diagnostic in terms of the types of particles present (biogenic vs. non-biogenic) and the types of phytoplankton present (diatoms and dinoflagellates vs. green or blue-green algae).

Spectral particulate absorption samples were obtained from the Niskin bottles by filtering 500ml of seawater through 25mm diameter Whatman GFF glass fiber filters (nominal pore size 0.7μm). Sampe filters were placed unfolded into Millipore Plastic Petri Slide holders and stored on ice until they could be transferred to a freezer ashore. In the lab, filters were analyzed in a Bausch and Lomb Spectronic 2000 dual beam spectrophotometer using a blank wetted GFF filter as reference (Yentsch and Phinney, 1989). Raw optical density values between 350 and 750nm (1.6nm resolution) were corrected for pathlength amplification in the filter (β correction) and calculated to $a_p\lambda$ with units of m^{-1}.

Productivity Model

Because Cobscook Bay was assumed to be well mixed due to tidal action, a simple model of phytoplankton production could be employed to calculate the amount of carbon fixed per unit area of sea surface from the chlorophyll concentration of the water, total daily solar irradiance reaching the sea surface and the attenuation coefficient of PAR in the water column (Ryther and Yentsch, 1957). Similarly, the concentration of benthic diatom chlorophyll per unit area, total daily irradiance and k_{PAR} could be used with an average depth to bottom over a tidal cycle to calculate carbon fixation of benthic diatoms.

The model is based on a relationship between relative photosynthesis and light intensity which can be used quantitatively when the attenuation coefficient and the assimilation number for grams C/gram Chl *a* at light saturation are known. We have improved the earlier model for this work by developing a modern dataset of radio-carbon^{14} incubated samples from the Gulf of Maine to establish the direct relationship between the carbon to chlorophyll ratio and total daily irradiance using the formulation of Platt and Jassby, (1976). For vertically homogeneous distributions of chlorophyll, the depth of the euphotic zone, Z_e (1% of surface irradiance) is determined by:

$$Z_e = -ln(0.01)/k_{PAR} \qquad (1)$$

which is the lower limit for integration unless the sonic depth is less than the euphotic zone depth in which case the sonic depth is the lower limit. Depth integrated chlorophyll (IC) is the product of the chlorophyll concentration and the depth limit for integration. The depth integrated carbon to chlorophyll ratio (C/Chl) is calculated in 1 meter bins to the depth limit and summed by:

$$C/Chl = \int P_s (1 - e^{-\alpha\, I/Ps})\, e^{(-\beta\, I/Ps)} \qquad (2)$$

where P_s is the photosynthetic rate at light saturation in grams carbon/m^2/day, α is the initial slope of the P vs I curve, β is the photoinhibition parameter at high light and I is the intensity of light in each 1 meter depth bin calculated by:

$$I = I_o\, e^{-k\, z} \qquad (3)$$

where I_o equals maximum surface irradiance in Einsteins/m^2/day (Campbell and O' Reilly, 1989), k (m^{-1}) is the measured attenuation coefficient for photosynthetically active radiation and z is the depth below the surface in meters. Constants used in Equation 2 are:

$$P_s = 89.028 \qquad \alpha = 8.672 \qquad \beta = 0.146$$

Maximum depth integrated phytoplankton primary production (PP_{max} in grams C/m^2/day) was calculated as the product of IC and C/Chl.

Maximum benthic diatom primary production (BPP_{max} in grams C/m^2/day) was calculated without integration using an average water depth based on a 6 meter tidal range. The state of tide for the time of sampling was calculated as the number of hours before or after high or low tide linearly interpolated to the mean depth at the rate of 1 meter/hour. Maximum solar insolation (I_o) was attenuated to the mean water depth at each station using measured k_{PAR} in Equation 3 to calculate the daily maximum light intensity on the bottom (I). C/Chl was calculated using Equation 2 and measured benthic chlorophyll concentration per square meter was used in place of IC to determine BP_{max}.

RESULTS

Field expeditions were scheduled to sample adjacent spring/neap tides in spring, summer and fall as closely as possible to the new and full moons (Table 1). The times and heights of high and low tide for these dates can be found in Table 2. Further division of the bay into four major sub-areas was used for comparison of average station data results to determine seasonal patterns and general differences. The four sub-areas included: Western - stations to the west of a line drawn from Leighton to Denbow Necks including Schooner Cove, Gooseberry Island, Dennys River, Birch Islands and Whiting Bay; North Central - stations between Leighton Neck and Birch Point north of the main axis of tidal flow including East Bay, Garnet Point and the Pennamaquan River; South Central or South Bay - stations south of the main axis of tidal flow between Denbow Neck and Seward Neck or Gove Point including west, east and mid-South Bay and Long Island; and Eastern - stations east of a line drawn from Birch to Gove Points and west of a line drawn from Lubec Neck through Treat and Razor Islands to Eastport including Johnson Bay, Broad Cove, Coopers Island, Deep Cove, Matthews Island and Bar Harbor.

<u>Temperature and Salinity</u>

Comparisons of station temperature and salinity were made by averaging the surface and bottom values from CTD profiles. This was appropriate as less than 10% of profiles varied by more than 0.5 °C or 0.3 o/oo salinity. Exceptions to this generalization were the Dennys and Pennamaquan Rivers and Whiting Bay in early May due to the presence of fresh water at the surface, several shallow stations in July when solar heating caused increased surface temperatures and stations along the Lubec-Eastport section in fall when warm, salty coastal waters entering through Lubec Narrows and/or Friars Roads dominated the lower region of the Eastern bay. In spite of this averaging, Whiting Bay (off Bell Farms) and the mid-channel station between Treat Island and Eastport at high tide (LE5-high) consistently represented the temperature and salinity end members of the bay system. From May through October, Whiting Bay was the warmest and freshest station (with Dennys River a close second), in November it was the coldest and freshest. The deep channel station off Eastport was the coldest, saltiest station during the first five samplings and the warmest and saltiest in November. Temperature data for the end member stations are compared to an average monthly curve for Eastport, Maine, (1927-1977) in Figure 2 (Diaz and Quayle, 1980).

Temperature values varied by only 1-2 °C throughout the bay in spring and autumn, 3-4 °C in summer, with maximum values of 12-15 °C probably occurring in August (when we didn't sample). The extreme inner regions of Dennys, Whiting, Penamaquan and South Bays warmed earlier in the season (by early July) than stations along the main axis of flow or in the lower bay south of Birch and Gove Points. Salinity varied by 2.5-3 o/oo throughout the bay in spring and autumn, 0.5-1.5 o/oo in summer, with a gradual increase in average values as the seasons progressed. The October sampling was characterized by lower variability in temperature and salinity probably due to wind mixing by an extremely strong northwest wind event that occurred on the second day of sampling that acted to mix the bay. Temperature varied by only 0.6 °C and salinity by 0.9 o/oo, all of the peripheral stations at the southern end of the Eastern region (Johnsohn Bay, Broad Cove and Coopers Island) had similar characteristics to the mid-channel station.

Phytoplankton and Benthic Diatom Biomass

Phytoplankton biomass measured as chlorophyll contained in particles filtered from the surface and bottom waters were also compared by averaging data at each station and within regions. Seasonal patterns show low biomass in spring, high in summer and low in fall such that the July samplings dominate the overall picture. Patterns of highest and lowest biomass for each field expedition were not as clear cut as the physical parameters, but general trends did occur. The source of waters indicated by their temperature and salinity and position in the bay at high and low tide are important to the interpretation of these patterns. For instance, waters sampled at the sections at high tide are predominantly from outside the bay, waters at the sections at low tide have been pulled from upstream and the inner bays to a lower position and represent the action of growth, mixing and grazing over a tidal cycle.

Early May was characterized by chlorophyll concentrations below 1µg/L (or mg/m^3) with no strong patterns other than high chlorophyll in the Dennys River (due to stratification by freshwater runoff) and higher than average concentrations in the Eastern region perhaps representing the end of the spring bloom outside the bay carried in by the tide. Two weeks later, average concentrations had doubled and the Western region was clearly accumulating biomass faster than the other regions. The Birch/Gove section at low tide and South Central region contained the lowest concentrations. In early July, patterns in phytoplankton biomass hinged about the Birch/Gove section and the 22-24 foot spring tides with highest concentrations between 3 and 4 µg/L. The section between Birch and Gove Points represented the highest concentrations in the bay at low tide indicating water from within the bay, and the lowest values in the bay at high tide indicating water from outside the bay. Ten days later, localized areas in the Dennys River, Whiting Bay and around Treat and Dudley Islands at the mouth of the bay at high tide contained chlorophyll concentrations between 2.5 and 3 µg/L while the Lubec/Eastport section at low tide and the Pennamaquan River, Garnet Point, Bar Harbor and Matthews Island side of the bay contained the lowest concentrations. In October and November, high biomass persisted in the extremities of each region at > 1µg/L, lowest concentrations were found along the sections at high tide and in the Eastern region as a whole in November.

Other general trends observed were: 1) the Dennys River station was the most consistent site of highest biomass, 2) the Matthews Island station was the most consistent site of lowest biomass, and 3) the South Central region produced less biomass than other regions of the bay. The percent of total chlorophyll represented by photosynthetically active pigment was 45% in May, 85% in July and 35% in Oct/Nov indicating that summer populations are in near bloom condition while spring and fall populations are under grazing and/or physiological stress.

Benthic diatom biomass was sampled at a subset of 14 subtidal stations where sediments could be obtained with a bottom grab. Chlorophyll *a* values were used as indicators of biomass as substantial concentrations of phaeophytin can accumulate in the surficial sediments due to sinking and fecal pellet deposition. Significant trends that can be drawn are: 1) benthic diatom biomass was inversely correlated with depth, ie. higher biomass at shallow stations, 2) the maximum depth of observed benthic diatom biomass on soft sediments was 12.5m, and 3) the average ratio of benthic diatom biomass (m^{-2}) was nearly 200 times integral water column phytoplankton biomass (m^{-2}). Seasonal patterns of benthic diatom biomass were highly variable but generally followed water column trends.

Light Transmission

Two methods were employed to measure the penetration of solar radiation into the waters of Cobscook Bay: 1) profiles of the intensity of photosynthetically active radiation (PAR) between 400 and 700nm, and 2) Secchi disk depth. The purpose of each method was to estimate the euphotic zone depth, or depth where 1% of surface intensity occurs. Above this depth photosynthesis exceeds respiration and plants accumulate carbon, below this depth cellular respiration exceeds photosynthesis and no net growth can occur. The attenuation coefficient, k, describes the exponential decrease of light with depth, k_{PAR} was the coefficient determined from profiles. Figure 3 shows a comparison between the two methods as euphotic zone depth in meters calculated from k_{PAR} and measured secchi depth also in meters. A good linear fit to the data suggest that either technique can be used, we have evaluated k_{PAR} values to determine seasonal patterns and for use in calculations of primary production.

Sufficient light reaches the bottom throughout the bay during spring and summer to drive net photosynthesis by phytoplankton and benthic diatoms. Waters from outside the bay found along the main axis of tidal flow at high tide were always the clearest, with k_{PAR} ranging from 0.25 to 0.35 (m^{-1}) in spring and summer increasing to as high as 0.5 in fall. Stations located at the inner extremities of the bays were the most turbid in all seasons (Dennys River, Whiting Bay, southern end of Long Island and Pennamaquan River) with k_{PAR} values ranging from 0.5 to 0.7 (m^{-1}) in spring, 0.4 to 0.6 in summer and 0.6 to 0.9 in fall. Greater than 1% of surface light reached bottom at these shallow stations, except in fall, when low sun angle had already limited photosynthesis.

Particulate Absorption

Phytoplankton cells, their associated debris (detritus), and suspended sediments combine to absorb and scatter light within the waters of Cobscook Bay. We measured spectral particulate absorption in order to determine the contribution of phytoplankton and sediments to light penetration. The shape of the spectral absorption curve for phytoplankton as a function of wavelengths of visible light (in nanometers) is composed of regions of high and low absorption according to the presence of photosynthetic pigments (Figure 4A). Absorption peaks in the blue (430nm) and red (670nm) regions are due to chlorophyll *a*. Suspended sediment and detritus absorption is characterized as exponentially increasing absorption with decreasing wavelength such that high absorption is seen below 500nm. Natural sample spectra obtained in Cobscook Bay (Figure 4B) represented the sum of biogenic and non-biogenic particle absorption and indicated that substantial concentrations of non-biogenic particles were present throughout the bay in all seasons.

In the open ocean, only phytoplankton and detritus control light transmission such that chlorophyll concentration is highly correlated to k_{PAR}. However, a poor relationship was found in Cobscook Bay (Figure 5A) where high concentrations of suspended sediment contribute to a large portion of particulate absorption. By selecting wavelengths where primary absorption by each particle type occurred, namely 400 or 350nm for non-biogenic and 670nm for phytoplankton chlorophyll, improved correlations between particle concentration and k_{PAR} were obtained (Figures 5B and C). This confirms that suspended sediment optical properties and distributions must be considered in addition to phytoplankton in order to accurately predict k_{PAR}, and hence, light penetration in the bay.

Primary Production by Phytoplankton

The results of the chlorophyll and light model calculations using measured chloro-phyll concentrations and k_{PAR} values with maximum daily solar irradiance (Campbell and O'Reilly, 1989) indicated low integrated maximum primary productivity (PP_{max}) in the water column in May and Oct/Nov (ca. 0.1 and 0.05 gC/m^2/day, respectively) with high values in July on the order of 1.0 gC/m^2/day. Regional patterns were similar to biomass distributions with the Western region increasing in late May and maintaining higher productivity through summer than other regions, and the South Central region appeared as the least productive region by a factor of two (Figure 6). However, the marked differences between the main axis of tidal flow and the extreme inner portions of the bays was not observed due to the increased depth of integration at these deeper stations where the euphotic zone depth, rather than the depth to bottom, was used as the integration limit.

The major difference for the section stations was associated with state of the tide, with inverse patterns observed at the Birch/Gove and Lubec/Eastport transects during summer (Figure 7). At high tide, PP_{max} (m^{-2}) was high along the Lubec to Eastport section, low along the Birch Point to Gove Point section and high along the Leighton Neck to Denbow Neck section. This suggests that rather than a continuous push of water along the main axis of flow, water is being drawn from a low productivity area (such as Matthews Island and Bar Harbor) to the Birch/Gove section on the incoming tide. At low tide, PP_{max} was high at the Birch/Gove section and low from Lubec to Eastport indicating that water from the Birch/Gove transect was drawn through the Eastern bay on the outgoing tide and high productivity water from the Western region was pulled to the Birch/Gove section. The Leighton/Denbow line was never sampled at low tide. High tide PP_{max} values along the transects ranged from 1.0 to 1.6 gC/m^2/day, low tide section values ranged from 0.3 to 0.7gC/m^2/day.

Annual maximum net primary production for the water column based on the standing stock of phytoplankton biomass and maximum solar irradiance values averaged 150 gC/m^2/yr. Reductions in solar radiation due to clouds would decrease this estimate by as much as a factor of two such that a more realistic estimate might be 75-100 gC/m^2/yr. The spatial distribution of net primary production in summer is shown in Figure 8 with dark regions indicating high daily rates greater than 1 gC/m^2/day in the region from the reversing falls to the Leighton/Denbow section and along the west shore of the Eastern region. Low rates of less than 0.5 gC/m^2/day were observed in all of South Bay and in the area from Shackford Head to Carryingplace Cove through Bar Harbor. Intermediate rates were observed in shallow and main flow axis regions where shallow water depths or lower chlorophyll concentrations, respectively, contributed to lower the model results.

Primary Production by Benthic Diatoms

Benthic primary productivity and biomass were highly variable, but trends could be determined from averaged data for each sampling period (Figure 9). Correction of bulk pigment values for degradation products was extremely important to obtain a valid comparison of benthic and water column components of primary production in Cobscook Bay. A large percentage of bulk pigment in the sediments was phaeophytin which must be subtracted from total chlorophyll values prior to calculation of photosynthetic production. Benthic diatom production in May increased from 0.5 to 2.0 $gC/m^2/day$ over two weeks. Early July values appeared to be low, equalling integrated water column values at 1.0 $gC/m^2/day$ while two weeks later the rates were a factor of four higher. The early July data point may be suspect, or represent a difference in the seasonal pattern of primary production for benthic diatoms where a series of blooms and subsequent population decreases occur. Benthic production values in fall were very low, less than 0.5 $gC/m^2/day$.

The resulting maximum annual net production for benthic diatoms was calculated to be 750 $gC/m^2/yr$ for clear sky conditions. Reductions in this estimate for sub-optimum irradiance conditions due to cloudy days would be less than water column reductions as the effect on the bottom is less than the effect in the well lit surface layers where the model predicts higher carbon to chlorophyll ratios. Comparisons of bay-wide production must also take into account the difference in area between benthic substrates which support attached diatoms as a function of average depth and areal water column production. Given that benthic production for comparable stations was a factor of five greater, and benthic diatoms do not occur throughout the bay, net benthic diatom production for Cobscook Bay may be only a factor of two greater than water column phytoplankton production.

DISCUSSION

Phytoplankton biomass was surprisingly low, we never measured a value higher than 4μg/L at any time. The seasonal pattern at the peripheral stations was unimodal (low in spring and autumn, maximum in July/August) with no apparent spring bloom. We were concerned that we may have missed an early spring bloom by delaying our initial sampling until early May, we do not believe this to be the case. However, it would be valuable to sample a small number of stations from February through April to confirm the absence of an early pulse of growth. A different pattern was found for the main flow axis stations which showed a drop in biomass in late July, perhaps reflecting a change in Head Harbor Passage water. Horizontal patterns appear to follow differences in residence time, with chlorophyll equal to1μg/L along the main axis of flow, 2μg/L midway into the major bays and 4μg/L in the extreme inner regions during summer. Increased residence time means that the phytoplankton have more time to grow before they are advected out of the bay system by tidal currents. Given that nutrient concentrations are high throughout the year, ie. not limiting (Garside report), and that the bay is not light limited in terms of light penetration at most stations (except in autumn when prevailing winds and shellfish dragging release large amounts of sediment into the water column), we would expect much higher levels of phytoplankton biomass, especially in spring. Grazing by copepods, larval fish, filter feeding shellfish and other invertebrates also acts to reduce the level of phytoplankton biomass observed.

The annual net primary production observed in Cobscook Bay was comparable to other estuaries where tidal flow does not play such a significant role (Ryther and Yentsch, 1958), but represented only a fraction of the levels observed in the shallow tidally mixed waters of Georges Bank and the central stratified waters of the Gulf of Maine (O'Reilly, et al., 1987). The most unexpected result was the low values for production m^{-2} day^{-1} in May when solar irradiance and nutrient concentrations were high. We suggest that another factor must have been limiting the growth of phytoplankton that was possibly unique to the conditions in Cobscook Bay. Temperature effects on photosynthetic efficiency could have been limiting growth in the spring when tidal mixing acted to prevent stratification in the bay that normally occurs in offshore waters. In early May, water temperatures had only reached $5^{o}C$ which translates to <50% of photosynthetic efficiency (Yentsch, et al., 1974.) By multiplying the curves for photosynthetic efficiency as a function of average light intensity and temperature measured at Eastport for thirty years (Figure 10), it can be shown that the modulation of temperature by tidal action in the bay can account for the seasonal pattern of primary production we observed.

Benthic diatom biomass was very high, one hundred times that of phytoplankton in the water column based on estimates per square meter, but their production numbers reflect the lower light intensities found on the bottom. It is possible that attached plants, benthic diatoms and macroalgae, account for the lion's share of primary production in Cobscook Bay as their residence time is unlimited, allowing them to accumulate and adapt to local light and nutrient conditions. Certainly, more in depth studies of the role of benthic diatoms in Cobscook Bay are indicated, we were not able to sample extensive shallow areas or the intertidal zone where benthic diatom biomass and production are sure to be significant. Additionally, we have used a production model based on carbon to chlorophyll ratios as a function of light intensity for phytoplankton, the response of benthic diatoms may be quite different due to increased chlorophyll per cell at low light or some other fundamental physiological difference. The fact that benthic diatom production exceeds water column production warrants further study.

Having some knowledge of gross primary production would be also be useful for comparisons to other highly productive regions, at least in spring and summer along the Lubec/Eastport transect on the incoming tide and in the Western bay where production occurs the earliest and reaches the highest levels. O' Reilly, et al. (1987) stated that net primary production ranges between 50 and 90% of gross or total primary production such that the total primary production for Cobscook Bay could be twice as high as we have estimated. This would still be well below estimates for Georges Bank. We could also use the maximum springtime nitrate nutrient numbers minus the summertime residual values to estimate the total yield of pigment where 1mM nitrate results in 1μg/L of chlorophyll *a* compared to our measured values of pigment. This suggests that the entire bay should have yielded 4μg/L of chlorophyll *a* which would have effectively doubled the areal estimate of net water column primary production to obtain gross primary production. It would be difficult to perform a similar exercise for benthic diatom production. It will be important to initiate studies to understand the fate of primary production in Cobscook Bay, export out of the bay and up the food chain to secondary producers will lead the list.

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FIGURE LEGENDS

Figure 1. Average station locations used in the 1995 study. Refer to Table 3 for abbreviations. Hatched areas represent shallow intertidal regions that we were unable to sample from the vessel Otto Miller, Jr. Numbers indicate the sequence that section stations were occupied.

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Figure 5. A. Relationship between chlorophyll concentration and light attenuation in the water column as k_{PAR} for all seasons in Cobscook Bay. B. Relationship between the non-biogenic (a_p400) plus biogenic (a_p670) particulate absorption and k_{PAR}. C. Same as in B with non-biogenic particulate absorption represented by a_p at 350nm. Non-biogenic material must be accounted for to explain the variance in light attenuation, shorter wave-lengths are more specific for detritus and suspended sediments.

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Table 1. Cruise Dates and Phase of the Moon

Cruise	Dates	Comment
CB1	May 2-4, 1995	3 days after full moon
CB2	May 16-18, 1995	2 days after new moon
CB3	July 11-13, 1995	new moon
CB4	July 21-23, 1995	4 days before full moon
CB5	Oct 22-24, 1995	full moon
CB6	Nov 5-7, 1995	new moon

Table 2. Times and Heights of Tides for Cobscook Bay

Julian Day	Date	Time	Height	Julian Day	Date	Time	Height	Julian Day	Date	Time	Height
122	May 2	00:03	19.5	192	July 11	03:16	-2.0	297	Oct 22	02:50	0.2
		06:28	-0.1			09:16	20.0			08:52	19.6
		12:29	18.4			15:37	-1.1			15:15	-0.4
		18:44	1.2			21:38	22.0			21:16	19.5
123	May 3	00:42	19.1	193	July 12	04:11	-2.7	298	Oct 23	03:35	-0.5
		07:07	0.2			10:12	20.5			09:36	20.5
		13:09	18.0			16:32	-1.6			16:00	-1.3
		19:24	1.6			22:33	22.3			22:00	20.1
124	May 4	01:23	18.7	194	July 13	05:05	-3.0	299	Oct 24	04:20	-1.0
		07:48	0.7			11:05	20.9			10:19	21.2
		13:51	17.6			17:26	-1.8			16:46	-1.9
		20:06	2.0			23:26	22.2			22:45	20.5
136	May 16	05:39	-3.2	202	July 21	05:44	16.8	311	Nov 5	02:58	-0.3
		11:39	21.0			12:01	2.1			09:01	20.1
		18:00	-1.7			18:09	17.9			15:26	-0.8
		23:59	22.4							21:27	19.4
137	May 17	06:32	-3.1	203	July 22	00:36	1.8	312	Nov 6	03:45	-0.3
		12:32	20.8			06:41	16.6			09:45	20.3
		18:53	-1.4			12:56	2.4			16:11	-1.0
						19:04	17.9			22:11	19.4
138	May 18	00:53	22.0	204	July 23	01:31	1.7	313	Nov 7	04:28	-0.1
		07:25	-2.7			07:36	16.6			10:27	20.3
		13:27	20.4			13:49	2.3			16:53	-0.9
		19:48	-0.9			19:56	18.1			22:52	19.2

Table 3. Average Station Locations, Abbreviations and Descriptors.

Abbreviation	Decimal Latitude	Decimal Longitude	Location
DR	44.9078	-67.1836	Dennys River
WB	44.8223	-67.1504	Whiting Bay
BI	44.8756	-67.1554	Birch Islands
GI	44.8661	-67.1145	Gooseberry Island
SC	44.8979	-67.1214	Schooner Cove
PR	44.9294	-67.1451	Pennamaquan River
WPB	44.9572	-67.1133	W Pennamaquan Bay
EB	44.9351	-67.1068	East Bay
GP	44.9167	-67.1073	Garnet Point
WSB	44.8905	-67.0758	W South Bay
MSB	44.8760	-67.0609	Mid South Bay
LI	44.8516	-67.0424	Long Island
ESB	44.8923	-67.0561	E South Bay
JB	44.8572	-67.0068	Johnson Bay
BC	44.9017	-67.0071	Broad Cove
CI	44.8894	-67.0275	Coopers Island
DC	44.9078	-67.0196	Deep Cove
MI	44.9139	-67.0292	Matthews Island
BH	44.9343	-67.0509	Bar Harbor
FH	44.8792	-66.9809	Friars Head
EBW	44.9057	-66.9727	Eastport Breakwater
LD1	44.8941	-67.1110	Leighton-Denbow Transect
LD2	44.8940	-67.1090	
LD3	44.8945	-67.1077	
LD4	44.8942	-67.1065	
BG1	44.9139	-67.0709	Birch-Gove Transect
BG2	44.9121	-67.0693	
BG3	44.9101	-67.0664	
BG4	44.9088	-67.0638	
BG5	44.9070	-67.0637	
LE1	44.8649	-66.9927	Lubec-Estes Head Transect
LE2	44.8705	-66.9932	
LE3	44.8781	-66.9974	
LE4	44.8825	-66.9991	
LE5	44.8866	-66.9982	
LE6	44.8910	-66.9968	

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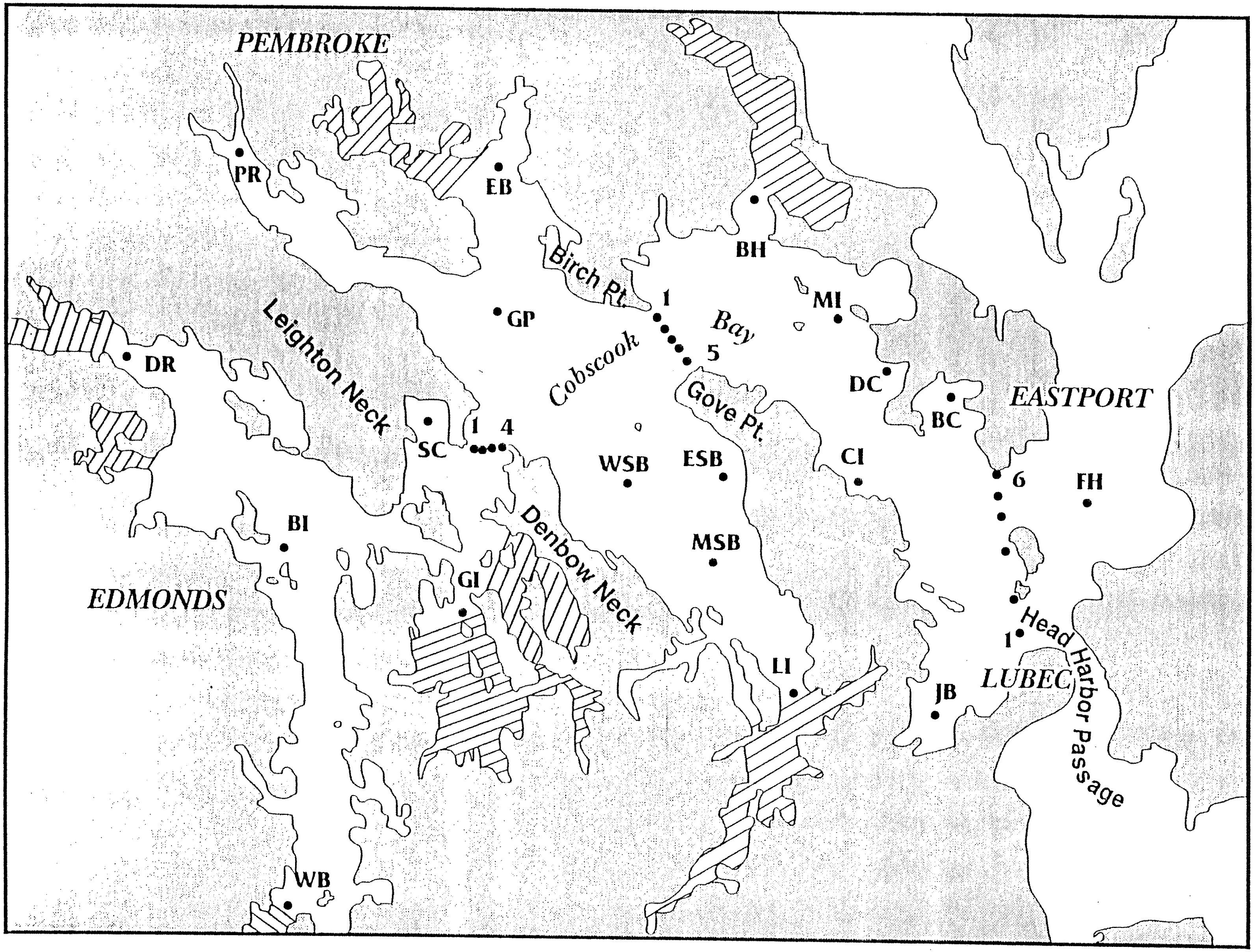
PEMBROKE
PR
EB
BH
Birch Pt.
1
Bay
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DR
Leighton Neck
Cobscook
5
DC
Gove Pt.
EASTPORT
BC
SC
1
4
WSB
ESB
CI
6
FH
BI
MSB
Denbow Neck
GI
EDMONDS
Head Harbor Passage
1
LI
JB
LUBEC
WB

Figure 1

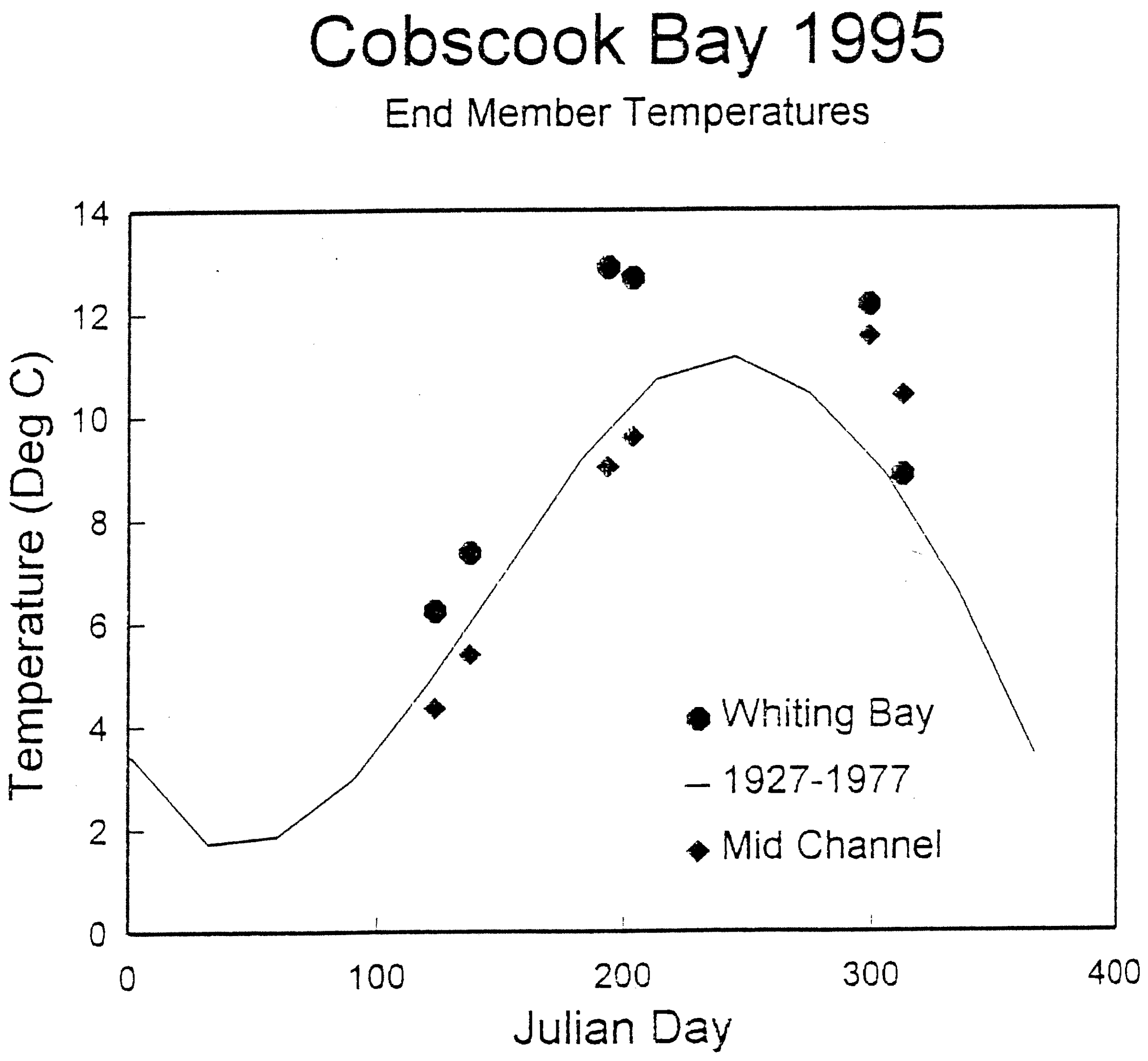

Cobscook Bay 1995
End Member Temperatures
Temperature (Deg C)
0
2
4
6
8
10
12
14
Julian Day
0
100
200
300
400
● Whiting Bay
– 1927-1977
◆ Mid Channel

Figure 2

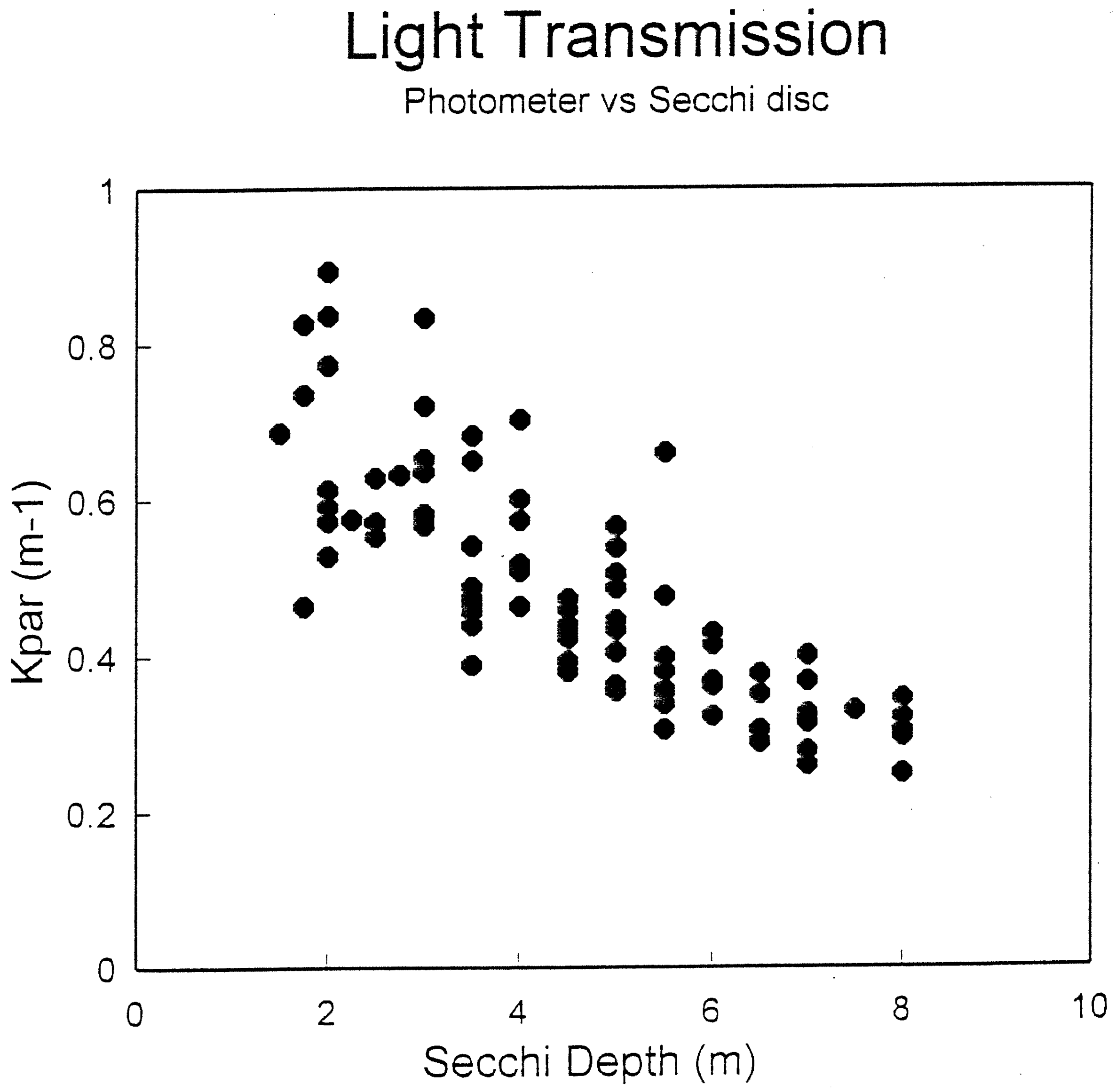

Light Transmission
Photometer vs Secchi disc
Kpar (m-1)
1
0.8
0.6
0.4
0.2
0
0
2
4
6
8
10
Secchi Depth (m)

Figure 3

Particulate Absorption

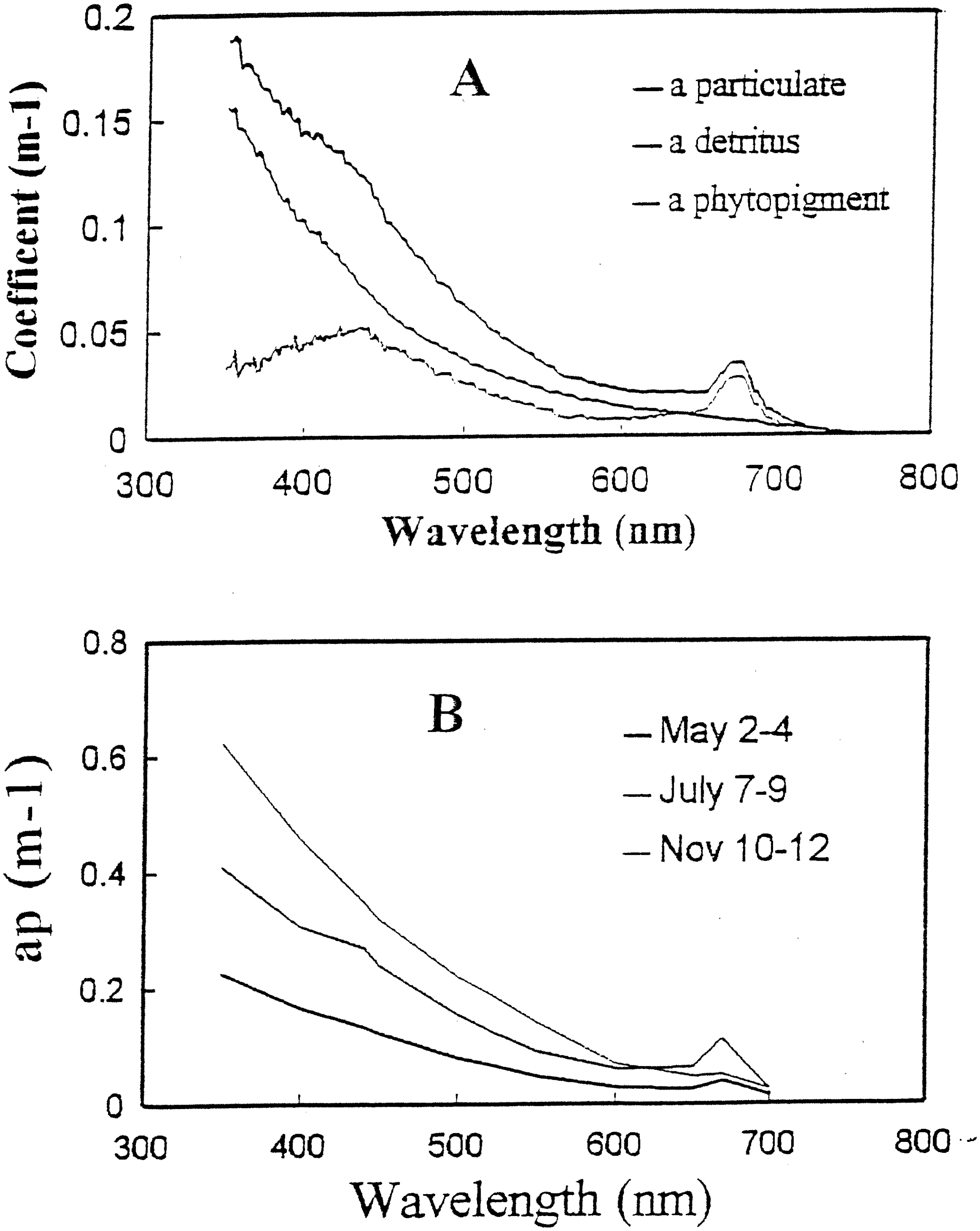


Figure 4

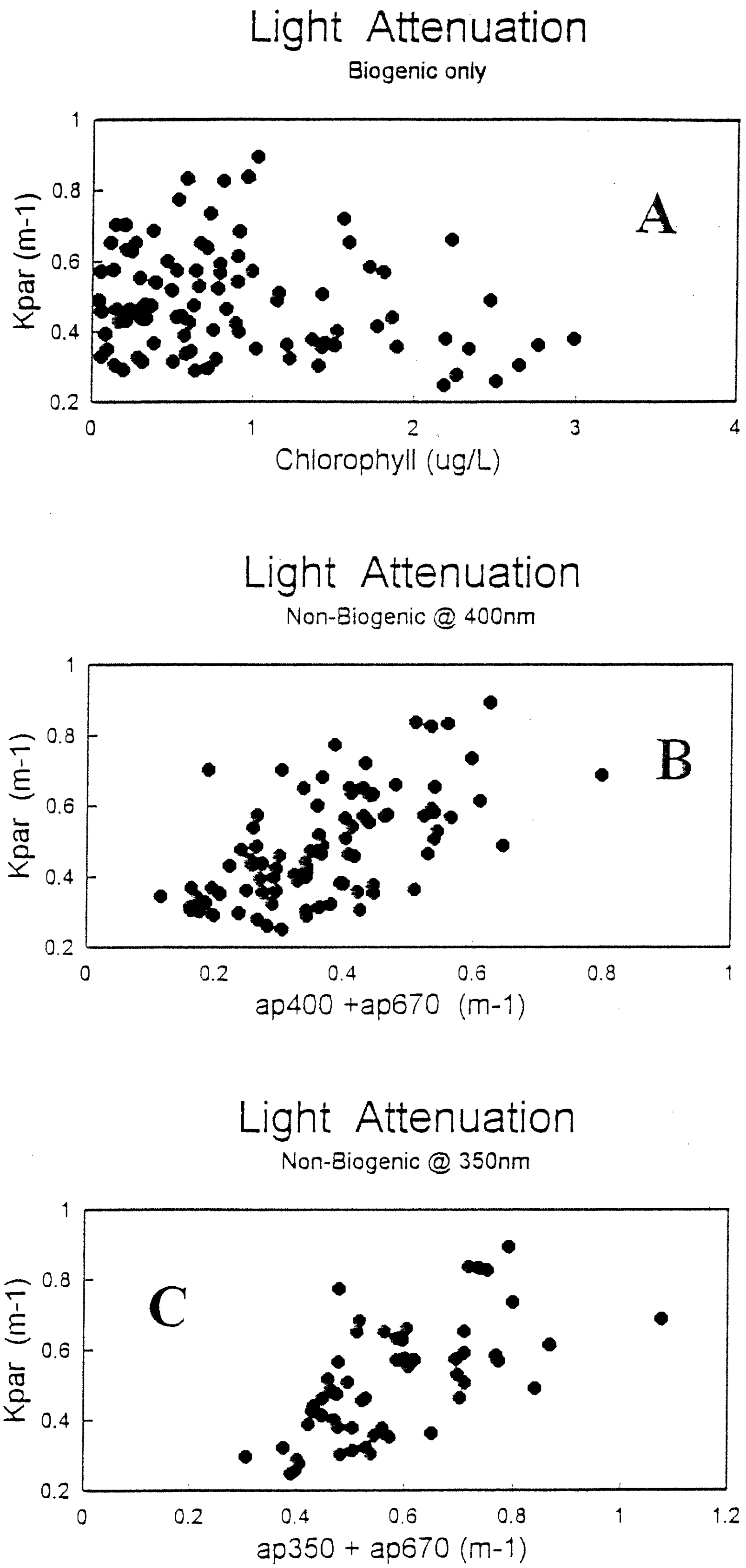

Light Attenuation
Biogenic only
Kpar (m-1)
1
0.8
0.6
0.4
0.2
0
1
2
3
4
Chlorophyll (ug/L)
A
Light Attenuation
Non-Biogenic @ 400nm
Kpar (m-1)
1
0.8
0.6
0.4
0.2
0
0.2
0.4
0.6
0.8
1
ap400 +ap670 (m-1)
B
Light Attenuation
Non-Biogenic @ 350nm
Kpar (m-1)
1
0.8
0.6
0.4
0.2
0
0.2
0.4
0.6
0.8
1
1.2
ap350 + ap670 (m-1)
C

Figure 5

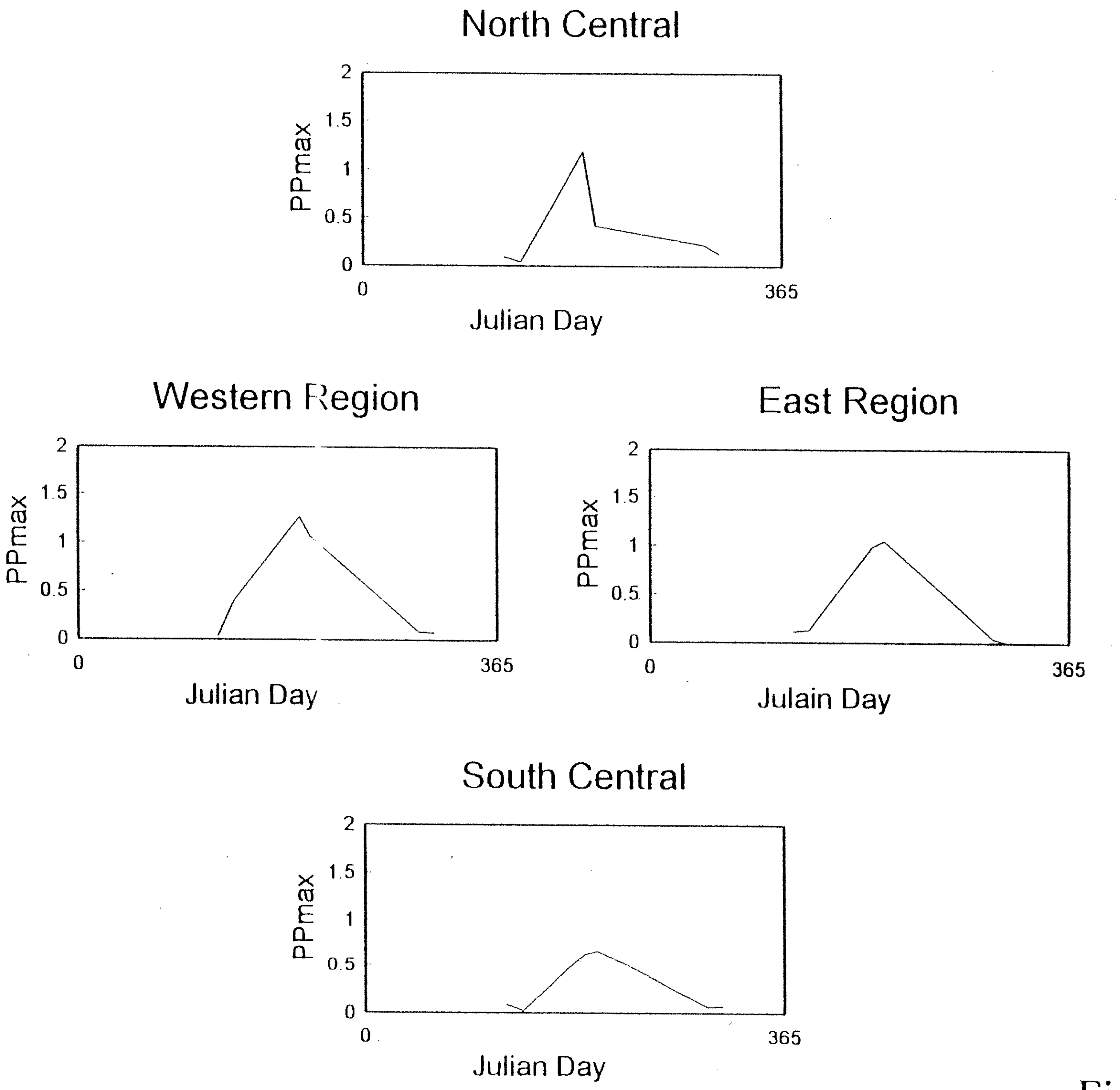

North Central
PPmax
2
1.5
1
0.5
0
0
365
Julian Day
Western Region
PPmax
2
1.5
1
0.5
0
0
365
Julian Day
East Region
PPmax
2
1.5
1
0.5
0
0
365
Julain Day
South Central
PPmax
2
1.5
1
0.5
0
0
365
Julian Day

Figure 6

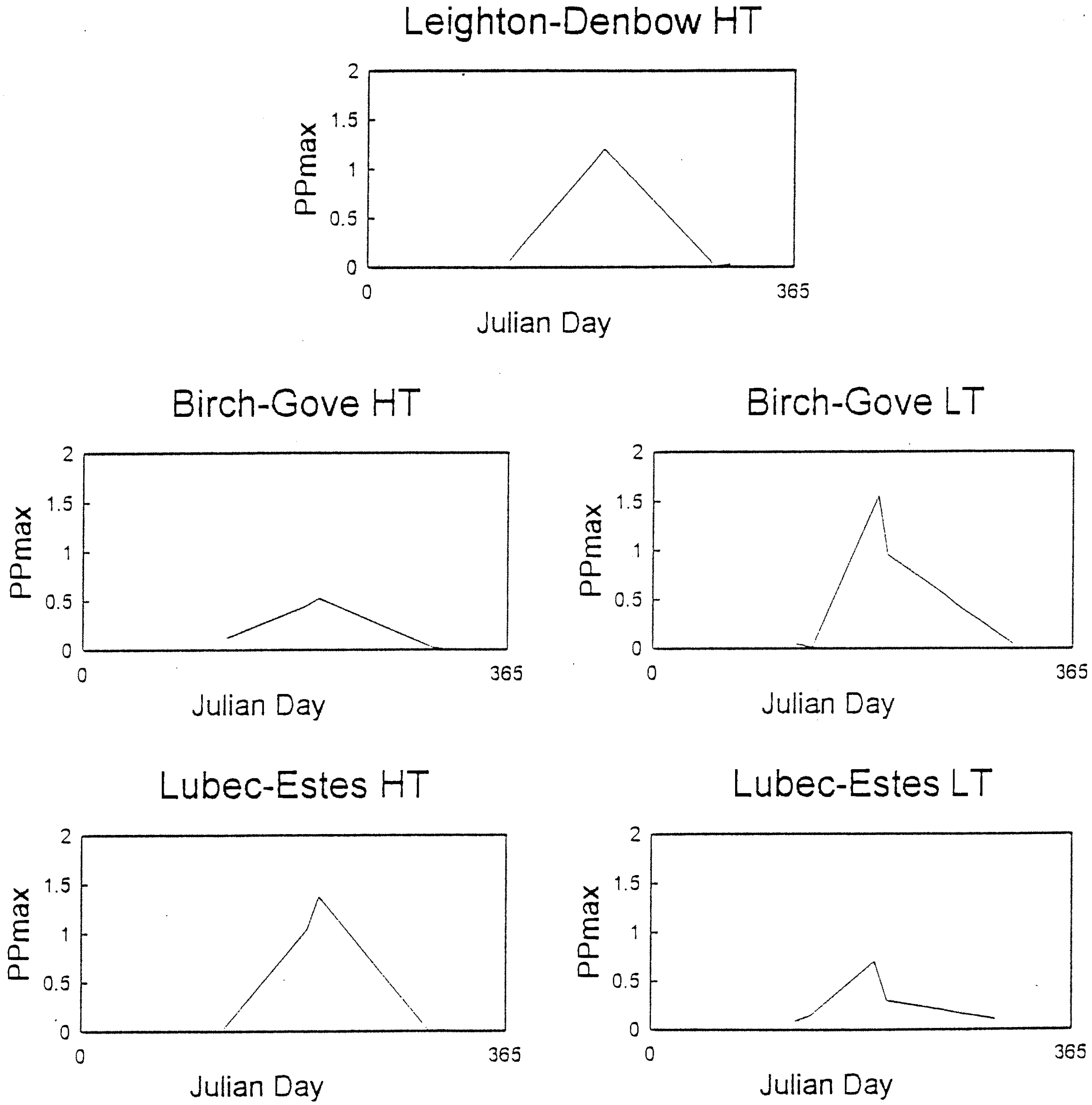

Leighton-Denbow HT
PPmax
2
1.5
1
0.5
0
0
365
Julian Day
Birch-Gove HT
PPmax
2
1.5
1
0.5
0
0
365
Julian Day
Birch-Gove LT
PPmax
2
1.5
1
0.5
0
0
365
Julian Day
Lubec-Estes HT
PPmax
2
1.5
1
0.5
0
0
365
Julian Day
Lubec-Estes LT
PPmax
2
1.5
1
0.5
0
0
365
Julian Day

Figure 7

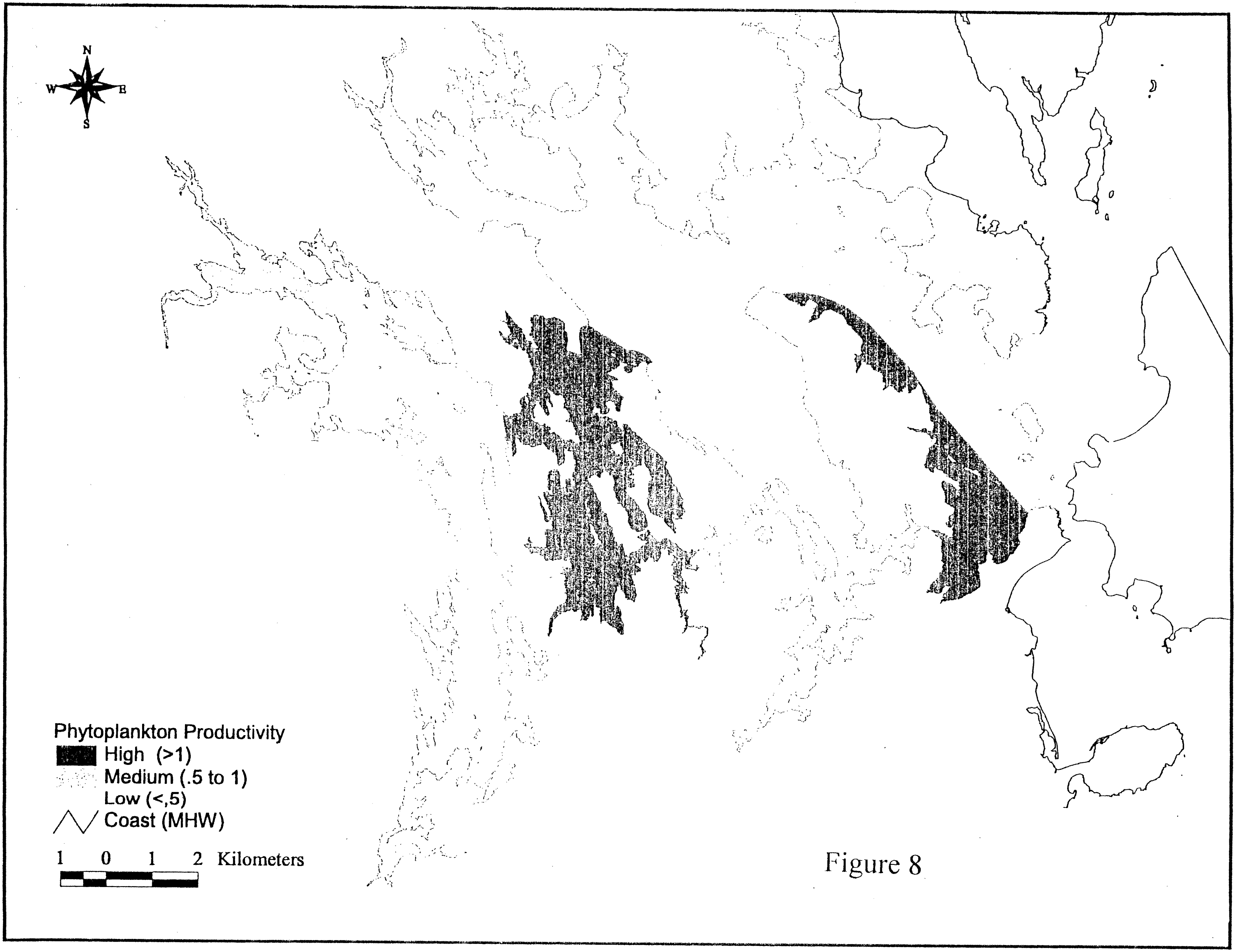

N
W
E
S
Phytoplankton Productivity
▨ High (>1)
Medium (.5 to 1)
Low (<,5)
Coast (MHW)
1 0 1 2 Kilometers

Figure 8

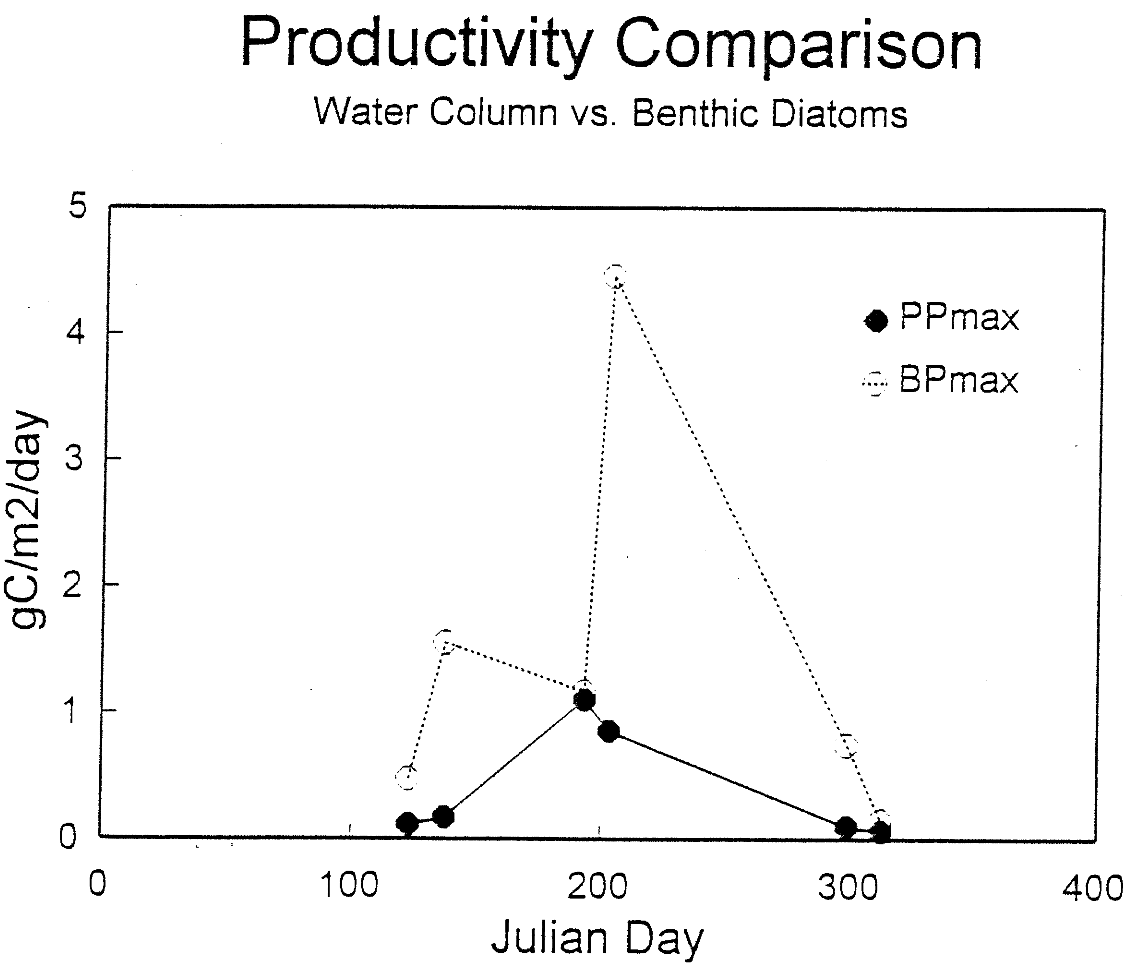
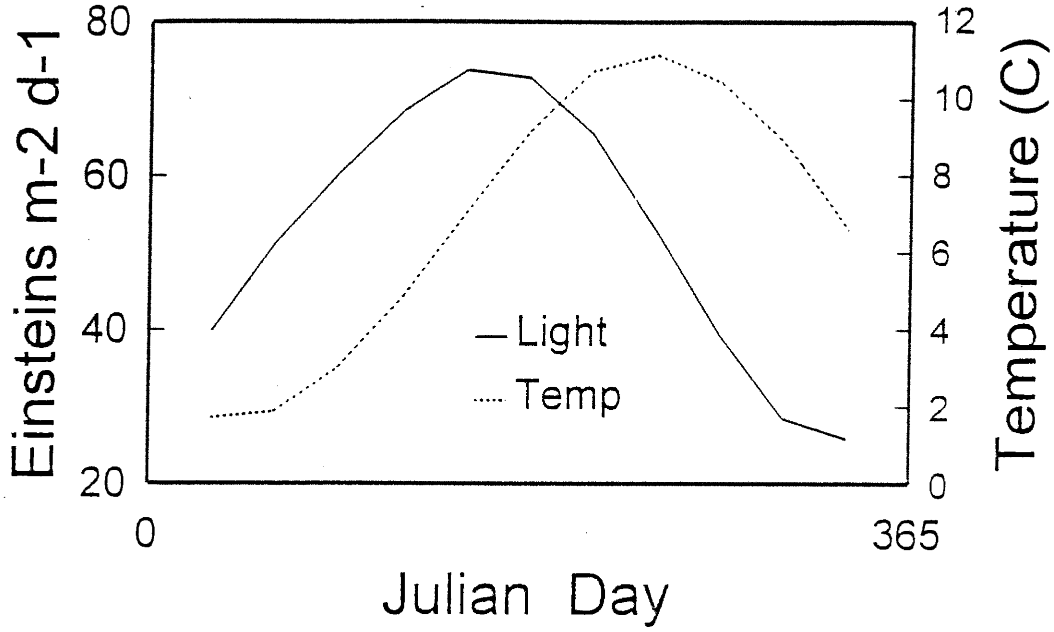

Productivity Comparison
Water Column vs. Benthic Diatoms
5
4
3
2
1
0
gC/m2/day
0
100
200
300
400
Julian Day
● PPmax
○ BPmax

Figure 9

Light and Temperature



Chlorophyll and Production

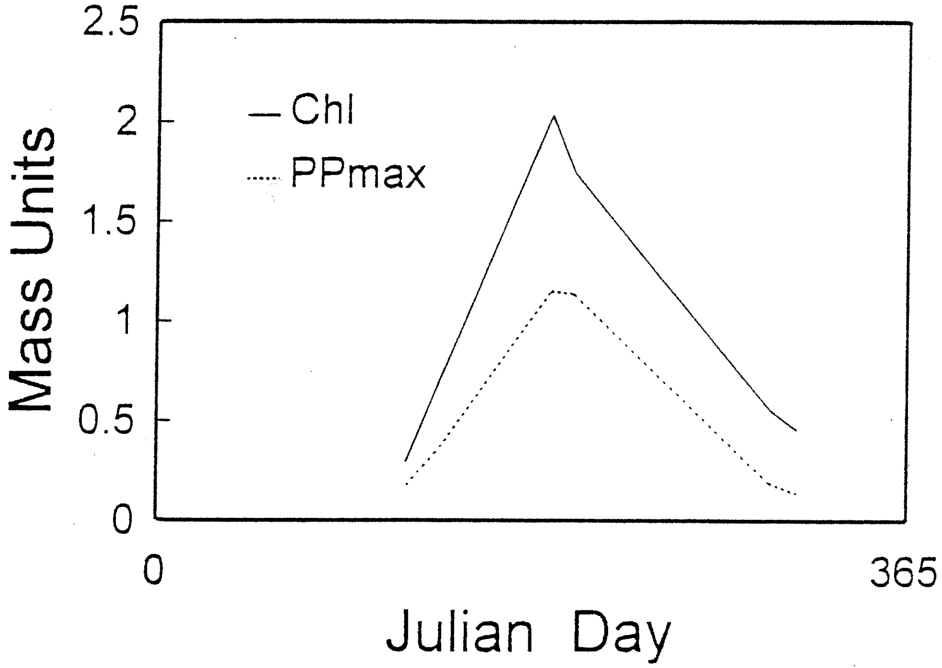


Figure 10

APPENDIX

Tables of all station data for each cruise.

Locator	Julian Day Date	Time (EST)	Tide	Station#	Latitude	Longitude	Avg temp (degrees C)	Avg Chl (mg m-3)	Avg chl a (mg m-3)	Kpar (m-1)	Secchi z (m)	Euphotic z (m)	Sonic z (m)	Light E m-2 d-1	PPmax gC m-2 d-1	Ben. Chl mg-1 m-2	Ben Chl.a mg-1 m-2	Ben. PPmax gCm-2d-1
BC	124	10:01		CB134	44.9017	67.0067	5.20	0.58	0.31	0.339	5.5	13.6	5.5	70	0.192	106.791	19.7798	0.944
BC	194	08.09		CB336	44.902	67.0062	10.37	2.80	2.70	0.415	5	11.1	4.5	75	1.171	104.686	46.07988	1.003
BC	204	09.59		CB441	44.9023	67.0065	10.47	2.26	1.64	0.277	7	16.6	7	74	1.092	313.656	85.51992	6.171
BC	313	10.20		CB631	44.9018	67.0075	10.08	0.04	0.00	0.490	3.5	9.4	7.5	32	0.000	160.522	36.9402	0.100
BC	299	08.50		CB537	44.9012	67.0077	11.54	0.79	0.36	0.562	5	8.2	5.5	36	0.113	111.828	19.21226	0.098
BC	138	09:55		CB229	44.9012	67.0078	5.68	0.91	0.46	0.397	5.5	11.6	5.7	71	0.219	128.283	42.34019	0.905
BG1	123	07:48	Low	CB109	44.915	67.07	5.21	0.06	0.00	0.366	6	12.6	6	70	0.000			
BG1	124	12:58	High	CB139	44.9133	67.07	4.96	0.18	0.04	0.297	8	15.5	12.5	70	0.031			
BG1	137	07:59	Low	CB211	44.9135	67.0702	6.22	0.05	0.00	0.415	5	11.1	6	71	0.000			
BG1	192	10.35	High	CB302	44.9122	67.0352	9.80	0.94	0.60	0.328	7	14.0	16	75	0.417			
BG1	194	06:20	Low	CB330	44.9147	67.0725	11.13	3.08	2.90	0.444	4.5	10.4	5	75	1.229			
BG1	202	13:08	Low	CB412	44.9138	67.0702	10.98	1.86	1.67	0.346	6.5	13.3	7.5	74	0.970			
BG1	203	07.38	High	CB417	44.9142	67.0715	10.83	1.01	0.67	0.328	7	14.0	8.5	74	0.464			
BG1	298	07:08	Low	CB512	44.9127	67.0708	11.82	0.70	0.29				8	37				
BG1	299	11.46	High	CB542	44.9142	67.0708	11.68	0.29	0.09	0.478	4	9.6	18	36	0.032			
BG1	312	10:50	High	CB613	44.9133	67.0715	10.22	0.15	0.00	0.686	2	6.7	17	32	0.000			
BG1	313	06.44	Low	CB622	44.9137	67.0715	9.68	0.49	0.13	0.563	3	8.2	13	32	0.041			
BG2	123	08.26	Low	CB113	44.9125	67.0683	5.38	0.47	0.26	0.328	7	14.0	14.5	70	0.175			
BG2	137	08:28	Low	CB215	44.9122	67.0688	6.10	0.36	0.10	0.415	5	11.1	10.5	71	0.052			
BG2	192	10.44	High	CB303	44.9102	67.0677	9.54	1.17	0.74	0.328	7	14.0	18	75	0.513			
BG2	194	06.30	Low	CB331	44.9132	67.0713	11.09	3.41	2.64	0.415	5	11.1	12	75	1.464			
BG2	202	13.16	Low	CB413	44.911	67.0682	11.04	0.86	0.78	0.328	7	14.0	14.5	74	0.540			
BG2	203	07.44	High	CB418	44.9125	67.0697	10.18	0.99	0.78	0.297	8	15.5	16.5	74	0.590			
BG2	298	07.31	Low	CB516	44.9123	67.0688	11.86	0.94	0.45				14.5	37				
BG2	299	12:16	High	CB546	44.9135	67.069	11.63	0.56	0.23	0.415	5	11.1	14	36	0.095			
BG2	312	11:24	High	CB617	44.9117	67.0697	10.36	0.23	0.01	0.589	2.75	7.8	20.5	32	0.002			
BG2	313	07.15	Low	CB626	44.9115	67.0705	9.82	0.63	0.24	0.618	2.5	7.4	12	32	0.068			
BG3	123	08:18	Low	CB112	44.9117	67.0667	5.44	0.21	0.06	0.312	7.5	14.8	17.5	70	0.045			
BG3	124	13:06	High	CB140	44.91	67.0667	4.94	0.73	0.43	0.297	8	15.5	28	70	0.319			
BG3	137	08:21	Low	CB214	44.911	67.0655	5.44	0.21	0.06	0.312	5	14.8	13	70	0.045			
BG3	192	10.50	High	CB304	44.9093	67.0637	9.34	1.17	0.83	0.328	7	14.0	28	75	0.582			
BG3	194	06:42	Low	CB332	44.9097	67.0645	10.90	2.73	2.73	0.415	5	11.1	27.5	75	1.514			
BG3	202	13:21	Low	CB414	44.9093	67.0653	11.18	1.60	1.42	0.346		13.3	13.8	74	0.941			
BG3	203	07:53	High	CB419	44.9098	67.069	10.36	1.42	0.90	0.297	8	15.5	24	74	0.677			
BG3	298	07:26	Low	CB515	44.9098	67.068	11.87	0.77	0.31				22.5	37				
BG3	299	12.10	High	CB545	44.9107	67.0668	0.24	0.24	0.24	0.24	5	0.24	28	0.24	0.24			
BG3	312	11:14	High	CB616	44.9098	67.0668	10.92	0.20	0.00	0.517	3.5	8.9	27	32	0.000			
BG3	313	07:08	Low	CB625	44.9088	67.0683	9.68	0.63	0.20	0.618	2.5	7.4	21.5	32	0.057			
BG4	123	08:10	Low	CB111	44.91	67.0633	5.30	0.12	0.02	0.328	7	14.0	24	70	0.016			
BG4	137	08:15	Low	CB213	44.9093	67.0642	5.90	0.17	0.01	0.415	5	11.1	21.5	71	0.006			
BG4	192	11.00	High	CB305	44.9072	67.063	9.41	0.78	0.48	0.346	6.5	13.3	33	75	0.323			
BG4	194	06:50	Low	CB333	44.908	67.0645	10.57	3.00	3.00	0.415	5	11.1	17	75	1.664			
BG4	202	13:26	Low	CB415	44.9097	67.0597	11.15	1.91	1.80	0.346	6.5	13.3	24	74	1.198			
BG4	203	08.04	High	CB420	44.9082	67.0648	10.61	1.77	0.72	0.297	8	15.5	23	74	0.549			
BG4	298	07.21	Low	CB514	44.9093	67.065	11.87	0.79	0.35				22.5	37				
BG4	299	12:04	High	CB544	44.9078	67.0657	11.65	0.17	0.01	0.478	4	9.6	22.5	36	0.005			
BG4	312	11.08	High	CB815	44.9102	67.0652	10.34	0.24	0.00	0.686	2	6.7	26	32	0.000			
BG4	313	07:00	Low	CB624	44.9067	67.0658	9.68	0.65	0.18	0.618	2.5	7.4	13.5	32	0.051			
BG5	123	08.01	Low	CB110	44.9083	67.0617	4.98	0.13	0.03	0.312	7.5	14.8	9	70	0.018			
BG5	124	13:15	High	CB141	44.9075	67.0633	5.27	0.23	0.04	0.297	8	15.5	15	70	0.030			
BG5	137	08.09	Low	CB212	44.9073	67.0632	5.77	0.14	0.01	0.415	5	11.1	7.5	71	0.003			
BG5	192	11.07	High	CB306	44.9072	67.063	10.25	0.96	0.64	0.366	6	12.6	18	75	0.403			
BG5	194	06.57	Low	CB334	44.9062	67.065	10.76	3.45	3.16	0.389	5.5	11.8	10	75	1.887			
BG5	202	13:33	Low	CB416	44.9067	67.0647	10.89	1.81	1.77	0.366	6	12.6	9	74	1.105			
BG5	203	08:09	High	CB421	44.907	67.0627	10.92	1.10	0.59	0.389	5.5	11.8	5.5	74	0.350			
BG5	298	07.15	Low	CB513	44.9067	67.064	11.81	0.78	0.35				7	37				
BG5	299	11:57	High	CB543	44.908	67.0637	11.65	0.17	0.01	0.478	4	9.6	18	36	0.005			
BG5	312	11:01	High	CB814	44.9073	67.0637	10.14	0.22	0.00	0.770	1.5	6.0	21	32	0.000			
BG5	313	06:54	Low	CB623	44.907	67.0635	9.61	0.55	0.17	0.686	2	6.7	13	32	0.044			

Locator	Julian Day Date	Time (EST) Tide	Station#	Latitude	Longitude	Avg temp (degrees C)	Avg Chl (mg m-3)	Avg chl a (mg m-3)	Kpar (m-1)	Secchi z (m)	Euphotic z (m)	Sonic z (m)	Light E m-2 d-1	PPmax gC m-2 d-1	Ben. Chl mg-1 m-2	Ben.Chl.a mg-1 m-2	Ben. PPmax gCm-2d-1
BH	299	10:30	CB541	44.9345	67.0512	11.66	1.02	0.30	0.886	2	5.2	6.5	36	0.067			
BH	138	11:46	CB233	44.9343	67.0512	5.92	0.89	0.22	0.422	4.5	10.9	6	71	0.120			
BH	192	14:56	CB312	44.9335	67.0512	12.14	1.54	1.22	0.478	4	9.6	6.7	75	0.602			
BH	124	11:57	CB138	44.9342	67.05	5.52	0.06	0.03	0.329	7.5	14.0	8.5	70	0.018			
BH	203	08.47	CB422	44.9342	67.0516	11.31	0.77	0.40	0.322	8	14.3	10	74	0.276			
BH	313	08:00	CB627	44.935	67.0505	9.16	0.29	0.00	0.555	2.5	8.3	9	32	0.000			
BI	136	11.55	CB203	44.8752	67.1553	5.66	1.51	0.86	0.360	5	12.8	6.7	71	0.522	584.998	290.9007	4.730
BI	202	10:11	CB409	44.8757	67.156	10.98	1.77	1.77	0.415	6	11.1	6.2	74	0.835	382.611	42.95809	3.138
BI	193	11:11	CB321	44.8762	67.156	10.16	2.19	1.65	0.381	4.5	12.1	7.5	75	1.111	140.776	46.19809	0.981
BI	122	12:25	CB103	44.8767	67.1533	5.20	0.20	0.05	0.698	4	6.6	6.5	70	0.017			
BI	297	11:45	CB503	44.8757	67.1558	11.71	0.52	0.15	0.439	4.5	10.5	8	37	0.062	382.611	97.51765	0.531
BI	311	09:30	CB603	44.8745	67.1557	9.96	0.73	0.27	0.731	1.75	6.3	6.5	33	0.068	456.267	119.8654	0.076
CI	299	09:10	CB538	44.8897	67.0262	11.59	0.53	0.06	0.768	2	6.0	7	36	0.015	382.611	69.21922	0.025
CI	124	10:33	CB135	44.8892	67.0283	5.27	0.61	0.43	0.344	8	13.4	8	70	0.276			
CI	204	11:11	CB443	44.8902	67.0272	10.38	2.18	1.98	0.249	8	18.5	9	74	1.651			
CI	313	09:50	CB630	44.8888	67.0275	9.95	0.13	0.00	0.576	2.25	8.0	6.5	32	0.000	75.112	98.83854	0.237
CI	194	07:46	CB335	44.8897	67.0282	10.00	2.77	2.60	0.366	6	12.6	7.5	75	1.614			
CI	138	10:23	CB230	44.8887	67.0275	5.60	1.15	0.53	0.485	5	9.5	5.2	71	0.251			
DC	299	09:30	CB539	44.9072	67.0197	11.66	0.60	0.18	0.426	4.5	10.8	6.5	36	0.075	292.387	78.94457	0.599
DC	313	09.20	CB629	44.9078	67.0197	9.75	0.24	0.01	0.631	2.5	7.3	9	32	0.003	269.552	94.61169	0.036
DC	124	10:56	CB136	44.9083	67.0192	5.65	1.45	0.85	0.368	6	12.5	6	70	0.500	75.112	11.4134	0.343
DC	138	10:49	CB231	44.9078	67.0198	5.85	0.75	0.29	0.404	5	11.4	7	71	0.159	167.910	93.76094	0.937
DR	136	10.10	CB201	44.9077	67.191	7.35	1.56	0.93	0.720	3	6.4	3.5	71	0.312	132.985	60.65581	0.443
DR	297	10:05	CB501	44.9043	67.1808	11.75	0.71	0.27	0.640	3	7.2	6	37	0.079	201.268	76.48189	0.134
DR	122	10:28	CB101	44.9033	67.18	5.77	0.67	0.34	0.649	3.5	7.1	7	70	0.123	335.372	239.527	0.708
DR	193	09:52	CB319	44.9165	67.1882	12.11	2.22	1.98	0.658	5.5	7.0	6	75	0.735	161.104	65.37475	0.189
DR	311	08.15	CB601	44.9077	67.189	9.00	0.81	0.45	0.822	1.75	5.6	4.5	33	0.101	271.790	129.9803	0.330
DR	202	08:44	CB407	44.9073	67.1888	11.87	3.03	2.56	0.478	4	9.6	7	74	1.255	212.910	98.83183	3.710
EB	123	10:15	CB116	44.9367	67.1083	5.89	0.55	0.33	0.447	5	10.3	5	70	0.167	101.753	14.48056	0.391
EB	192	11:37	CB307	44.9337	67.1062	11.49	1.89	1.89	0.357	5.5	12.9	12	75	1.196	174.358	42.52287	1.024
EB	203	11:02	CB426	44.9342	67.105	12.08	1.23	0.81	0.322	6	14.3	10	74	0.566	265.298	77.78934	3.736
EB	311	12:30	CB610	44.9347	67.108	9.73	0.64	0.40	0.569	2	8.1	13.5	33	0.124	199.477	58.63417	0.248
EB	137	07.29	CB210	44.9347	67.1062	6.84	0.23	0.06	0.478	4	9.6	5.5	71	0.031	153.694	48.94912	1.374
EB	298	09:02	CB519	44.9368	67.107	12.07	0.99	0.47	0.569	3	8.1	7.5	37	0.153	122.238	25.13277	0.027
EPB	297	14:55	CB511	44.9057	66.9727	11.62	0.80	0.38	0.415	5	11.1	37.5	37	0.163			
ESB	192	12:36	CB309	44.8928	67.0563	11.02	1.37	1.37	0.377	6.5	12.2	12	75	0.826	66.000	15.65279	0.390
ESB	123	13:07	CB120	44.89	67.0592	5.34	0.38	0.15	0.368	7	12.5	12.5	70	0.093	58.657	30.49581	0.116
ESB	137	11.12	CB221	44.8927	67.0545	6.02	0.08	0.01	0.394	4.5	11.7	10.5	71	0.005	204.514	111.7441	0.283
ESB	298	11:00	CB523	44.8928	67.0553	11.84	1.16	0.40	0.506	4	9.1	12.5	37	0.143	122.574	17.93279	0.004
ESB	312	14:00	CB621	44.8932	67.055	9.95	1.02	0.42	0.349	1.5	13.2	10.5	32	0.198	163.209	29.55888	0.585
FH	297	14:35	CB510	44.8857	66.9803	11.63	0.74	0.42	0.366	6	12.6	27.5	37	0.204			
FH	194	08:50	CB336A	44.8727	66.9815												
GI	297	12:20	CB504	44.865	67.1148	11.78	0.63	0.26	0.475	3.5	9.7	10.5	37	0.100			
GI	136	12:41	CB204	44.8672	67.1137	5.66	1.43	0.81	0.354	5	13.0	12	71	0.520			
GI	202	08.08	CB406	44.8668	67.1143	11.01	1.18	1.18	0.346	6.5	13.3	10	74	0.732			
GI	311	10:15	CB604	44.865	67.1157	10.12	0.66	0.25	0.529	2	8.7	9	33	0.084			
GI	193	12.56	CB327	44.8665	67.1138	10.90	2.98	2.71	0.377	5.5	12.2	12	75	1.674			
GP	123	10.53	CB117	44.915	67.1067	5.46	0.19	0.05	0.290	6.5	15.9	14	70	0.039	57.761	32.84208	0.175
GP	137	09.22	CB217	44.9153	67.1058	6.18	0.33	0.07	0.439	4.5	10.5	12.2	71	0.035	213.693	82.94642	0.071
GP	311	13:30	CB612	44.9163	67.1065	10.06	0.79	0.36	0.590	2	7.8	9	33	0.107	129.627	23.07755	0.023
GP	298	08.40	CB518	44.9155	67.1065	11.97	0.83	0.38	0.465	3.5	9.9	13	37	0.149	51.716	5.601478	0.001
GP	192	12:00	CB308	44.9197	67.1097	10.71	2.33	2.24	0.352	5.5	13.1	11.5	75	1.471	66.179	19.73368	0.603
GP	203	10:40	CB425	44.9185	67.1083	11.38	0.31	0.09	0.313	7	14.7	11.2	74	0.067	105.671	33.52827	1.320
JB	137	12.52	CB222	44.8532	67.0103	5.70	0.21	0.03	0.366	6	12.6	8.5	71	0.020	208.544	87.39716	5.593
JB	313	11:00	CB632	44.8545	67.0097	9.66	0.05	0.00	0.569	2.5	8.1	8	32	0.000	157.835	25.36113	0.029
JB	299	08:15	CB536	44.8572	67.0032	11.57	0.26	0.04	0.456	3.5	10.1	6.5	36	0.015	255.895	31.82902	0.277
JB	124	09:18	CB133	44.8592	67.0033	5.16	0.09	0.02	0.349	6.5	13.2	6	70	0.013	100.750	42.93123	2.205
JB	204	10:31	CB442	44.8627	67.0092	10.66	2.50	2.34	0.259	7	17.8	10	74	1.935	281.417	135.4429	7.735
JB	194	09:07	CB337	44.8563	67.0048	10.21	2.58	2.23	0.415	5	11.1	8	75	1.248	137.462	31.80439	0.185

Locator	Julian Day Date	Time (EST)	Tide	Station#	Latitude	Longitude	Avg temp (degrees C)	Avg Chl (mg m-3)	Avg chl a (mg m-3)	Kpar (m-1)	Secchi z (m)	Euphotic z (m)	Sonic z (m)	Light E m-2 d-1	PPmax gC m-2 d-1	Ben. Chl mg-1 m-2	Ben Chl a mg-1 m-2	Ben. PPmax gCm-2d-1
LD1	122	13:59	High	CB105	44.895	67.11	4.83	0.10	0.03	0.328	7	14.0	13	70	0.020			
LD1	136	13:11	High	CB205	44.894	67.1113	5.72	0.69	0.29	0.389	5.5	11.8	12	71	0.168			
LD1	193	12:14	High	CB323	44.8942	67.1113	10.67	2.77	2.43	0.415	5	11.1	9	75	1.366			
LD1	202	07:23	High	CB402	44.8937	67.1115	10.47	1.64	1.64	0.366		12.6	10	74	0.979			
LD1	297	12:50	High	CB505	44.8932	67.1107	11.78	0.05	0.00	0.389	5.5	11.8	12.5	37	0.000			
LD1	311	11:09	High	CB606	44.8943	67.1112	10.28	0.24	0.02	0.563	3	8.2	15	33	0.007			
LD2	122	14:29	High	CB108	44.8933	67.11	4.82	0.50	0.23	0.314	7	14.7	20.5	70	0.167			
LD2	136	13.30	High	CB208	44.8942	67.1055	5.37	1.06	0.54	0.389	5.5	11.8	13	71	0.319			
LD2	193	12:18	High	CB324	44.8937	67.11	10.03	1.65	1.65	0.328		14.0	19	75	1.136			
LD2	202	07:33	High	CB403	44.8943	67.1098	10.30	1.88	1.78	0.272	9	17.0	23	74	1.486			
LD2	297	13:15	High	CB508	44.8942	67.1097	11.78	0.29	0.05	0.478	4	9.6	22.5	37	0.017			
LD2	311	11:35	High	CB609	44.8942	67.1092	10.25	0.59	0.19	0.686	2	6.7	24	33	0.051			
LD3	122	14:18	High	CB107	44.8933	67.1067	4.70	0.25	0.08	0.297	8	15.5	23	70	0.058			
LD3	136	13:22	High	CB207	44.8938	67.1073	5.45	0.95	0.46	0.389	5.5	11.8	25	71	0.273			
LD3	192	12:24	High	CB325	44.895	67.1082	10.07	1.28	1.28	0.328		14.0	24	75	0.880			
LD3	202	07:40	High	CB404	44.8945	67.1078	10.41	1.93	1.73	0.312	7.5	14.8	25	74	1.272			
LD3	297	13:04	High	CB507	44.896	67.108	11.73	0.45	0.01	0.444	4.5	10.4	26.5	37	0.002			
LD3	311	11:28	High	CB608	44.8943	67.108	10.18	0.53	0.13	0.618	2.5	7.4	19	33	0.037			
LD4	122	14:10	High	CB106	44.895	67.105	4.82	0.14	0.01	0.297	8	15.5	16	70	0.009			
LD4	136	13:16	High	CB206	44.8942	67.1102	5.49	0.83	0.48	0.366	6	12.6	20	71	0.302			
LD4	193	12.50	High	CB326	44.894	67.1058	10.24	1.33	1.27	0.328	7	14.0	11	75	0.882			
LD4	202	07:49	High	CB405	44.8945	67.106	10.61	1.52	1.52	0.312	7.5	14.8	11.5	74	1.058			
LD4	297	12:56	High	CB506	44.8938	67.1057	11.72	0.08	0.00	0.478	4	9.6	12.5	37	0.000			
LD4	311	11:19	High	CB607	44.8935	67.1063	10.14	0.47	0.09	0.618		7.4	18.0	33	0.026			
LE1	123	13:54	High	CB121	44.865	66.995	4.82	0.09	0.02	0.297	8	15.5	19	70	0.013			
LE1	124	08:06	Low	CB127	44.865	66.9925	5.05	0.11	0.02	0.328	7	14.0	15	70	0.017			
LE1	138	08:57	Low	CB223	44.865	66.9923	5.52	0.26	0.06	0.389	5.5	11.8	13.5	71	0.034			
LE1	192	15:59	Low	CB313	44.8648	66.9932	10.39	1.08	1.08	0.366	6	12.6	14.5	75	0.672			
LE1	194	09:37	High	CB338	44.8653	66.992	10.00	2.25	2.03	0.366	17.5	12.6	17.5	75	1.285			
LE1	203	12:56	Low	CB429	44.8645	66.9893	10.55	1.05	0.77	0.328	7	14.0	12	74	0.532			
LE1	204	08:44	High	CB435	44.8648	66.9917	10.40	2.15	1.53	0.328	7	14.0	18.5	74	1.072			
LE1	298	11:48	High	CB524	44.8643	66.9928	11.60	0.47	0.02	0.389	5.5	11.8	20	37	0.007			
LE1	299	07.04	Low	CB530	44.8667	66.9932	11.62	0.67	0.33				14	36				
LE1	313	11.11	High	CB633	44.865	66.9922	10.04	0.06	0.00	0.517	3.5	8.9	20	32	0.000			
LE2	123	14:02	High	CB122	44.87	66.9933	4.92	0.11	0.03	0.297	8	15.5	20.5	70	0.026			
LE2	124	08:12	Low	CB128	44.87	66.9925	5.00	0.09	0.02	0.328	7	14.0	15	70	0.015			
LE2	138	09:10	Low	CB224	44.8715	66.9942	5.41	0.41	0.14	0.389	5.5	11.8	15.5	71	0.085			
LE2	192	16:06	Low	CB314	44.8717	66.9937	10.12	1.33	1.27	0.366	6	12.6	15	75	0.806			
LE2	194	09:47	High	CB339	44.8732	66.9942	10.07	2.36	2.06	0.366	6	12.6	10	75	1.308			
LE2	203	13:04	Low	CB430	44.8722	66.9948	10.52	0.88	0.42	0.328	7	14.0	15	74	0.293			
LE2	204	08:55	High	CB436	44.8718	66.994	10.55	2.91	2.34	0.312	7.5	14.8	16	74	1.718			
LE2	298	11:57	High	CB525	44.8678	66.992	11.74	0.23	0.03	0.415	5	11.1	23	37	0.015			
LE2	299	07:11	Low	CB531	44.8707	66.9937	11.66	0.75	0.37				15	36				
LE2	313	11:18	High	CB634	44.8697	66.9927	9.96	0.52	0.00	0.563	3	8.2	20	32	0.000			
LE3	123	14.13	High	CB123	44.8775	66.9983	4.82	0.11	0.03	0.297	8	15.5	24.5	70	0.022			
LE3	124	08.24	Low	CB129	44.88	66.9967	5.09	0.22	0.08	0.297	8	15.5	18	70	0.057			
LE3	138	09:21	Low	CB225				0.59	0.17	0.389	5.5	11.8	18	71	0.103			
LE3	192	16:16	Low	CB315	44.8795	66.997	10.03	1.67	1.51	0.366	6	12.6	13	75	0.960			
LE3	194	10.00	High	CB340	44.8788	66.9963	9.79	1.65	1.65	0.389	5.5	11.8	15	75	0.973			
LE3	203	13:12	Low	CB431	44.8793	66.997	10.54	0.18	0.02	0.328	7	14.0	16.5	74	0.012			
LE3	204	09.04	High	CB437	44.8772	66.9982	10.44	2.65	2.10	0.312	7.5	14.8	23	74	1.545			
LE3	298	12.06	High	CB526	44.8782	66.9965	11.71	0.14	0.01	0.389	5.5	11.8	19	37	0.004			
LE3	299	07:17	Low	CB532	44.8778	66.9975	11.66	0.68	0.33				15	36				
LE3	313	11:27	High	CB635	44.8788	66.9975	10.02	0.12	0.00	0.563	3	8.2	23	32	0.000			

Locator	Julian Day Date	Time (EST)	Tide	Station#	Latitude	Longitude	Avg temp (degrees C)	Avg Chl (mg m-3)	Avg chl a (mg m-3)	Kpar (m-1)	Secchi z (m)	Euphotic z (m)	Sonic z (m)	Light E m-2 d-1	PPmax gC m-2 d-1	Ben. Chl mg-1 m-2	Ben.Chl a mg-1 m-2	Ben. PPmax gCm-2d-1
LE4	123	14.21	High	CB124	44.8833	66.9992	4.88	0.14	0.04	0.297	8	15.5	25	70	0.029			
LE4	124	08:34	Low	CB130	44.8833	66.9992	5.15	0.17	0.06	0.297	8	15.5	16	70	0.042			
LE4	138	09:30	Low	CB226	44.8832	66.9993	5.76	0.88	0.29	0.415	5	11.1	18	71	0.159			
LE4	192	16:24	Low	CB316	44.8825	66.9965	10.41	1.57	1.17	0.366	6	12.6	14	75	0.743			
LE4	194	10:17	High	CB341	44.8827	66.999	9.85	1.21	0.81	0.415	5	11.1	17.5	75	0.459			
LE4	203	13:18	Low	CB432	44.8825	66.9992	10.80	0.28	0.04	0.312	7.5	14.8	20	74	0.027			
LE4	204	09:13	High	CB438	44.8818	66.9995	10.46	2.80	2.25	0.312	7.5	14.8	18.0	74	1.653			
LE4	298	12:16	High	CB527	44.8823	66.9992	11.69	0.12	0.01	0.388	5.5	11.8	21.5	37	0.004			
LE4	299	07:24	Low	CB533	44.8823	66.9968	11.67	0.70	0.27				15	36				
LE4	313	11.35	High	CB636	44.8823	66.9987	10.04	0.16	0.01	0.563	3	8.2	17	32	0.002			
LE5	123	14:28	High	CB125	44.8867	66.9975	4.34	0.11	0.02	0.328	7	14.0	35	70	0.011			
LE5	124	08:43	Low	CB131	44.8867	66.9983	5.37	0.35	0.17	0.301	8	15.3	31.5	70	0.129			
LE5	138	09:06	Low	CB227	44.8868	66.9982	5.54	0.91	0.49	0.389	5.5	11.8	29	71	0.290			
LE5	192	16:34	Low	CB317	44.8875	66.998	10.87	1.40	0.90	0.366	6	12.6	31	75	0.568			
LE5	194	10:27	High	CB342	44.887	66.9987	9.01	1.52	1.39	0.328	7	14.0	30.5	75	0.979			
LE5	203	13:25	Low	CB433	44.8872	66.9955	10.85	0.92	0.46	0.297	8	15.5	33	74	0.351			
LE5	204	09:25	High	CB439	44.8867	66.9968	9.90	2.13	1.72	0.297	8	15.5	37	74	1.320			
LE5	298	12.23	High	CB528	44.8862	67.0006	11.59	0.14	0.01	0.346	6.5	13.3	34	37	0.006			
LE5	299	07:30	Low	CB534	44.8883	66.9978	11.67	0.80	0.28	0.415	5	11.1	30	36	0.118			
LE5	313	11:43	High	CB637	44.8867	66.9975	10.39	0.26	0.08	0.328	7	14.0	36	32	0.040			
LE6	123	14:50	High	CB126	44.89	66.9967	4.44	0.19	0.07	0.328	7	14.0	25	70	0.049			
LE6	124	09:00	Low	CB132	44.8917	66.9967	5.25	0.59	0.37	0.297	8	15.5	22	70	0.276			
LE6	138	09.43	Low	CB228	44.8912	66.998	5.69	0.96	0.40	0.389	5.5	11.8	17	71	0.238			
LE6	192	16:41	Low	CB318	44.8908	66.998	10.64	1.19	0.72	0.366	6	12.6	20	75	0.454			
LE6	194	10:44	High	CB343	44.8915	66.9975	9.71	2.03	1.85	0.346	6.5	13.3	27	75	1.234			
LE6	203	13:30	Low	CB434	44.8912	66.9947	10.83	1.69	0.78	0.312	7.5	14.8	17	74	0.572			
LE6	204	09:44	High	CB440	44.8915	66.9947	9.58	1.59	1.21	0.297	8	15.5	15	74	0.929			
LE6	298	12.33	High	CB529	44.8907	66.9975	11.68	0.33	0.06	0.563	3	8.2	30	37	0.020			
LE6	299	07.35	Low	CB535	44.8913	66.9977	11.65	0.96	0.22	0.415	5	11.1	21	36	0.095			
LE6	313	11:51	High	CB638	44.8912	66.9975	10.32	0.36	0.12	0.478	4	9.6	29.5	32	0.043			
LI	312	13:00		CB620	44.8508	67.042	9.78	0.78	0.20	0.523	1.5	8.8	8.5	32	0.066			
LI	298	10:30		CB522	44.8505	67.0423	12.01	0.11	0.00	0.649	3	7.1	9	37	0.000			
LI	202	11:50		CB410	44.853	67.043	12.66	1.72	1.41	0.583	3	7.9	4.5	74	0.576			
LI	192	13:51		CB310	44.851	67.0425	13.16	1.59	1.19	0.849	3	7.1	5	75	0.445			
LI	123	11:46		CB118	44.8525	67.0417	5.88	0.32	0.15	0.476	5.5	9.7	6	70	0.072	110.037	30.37492	0.378
LI	137	10:23		CB219	44.852	67.0427	6.60	0.52	0.16	0.576	4	8.0	5	71	0.065			
MI	124	11:18		CB137	44.9133	67.03	5.25	0.14	0.05	0.305	6.5	15.1	6.5	70	0.080			
MI	192	09:45		CB301	44.9137	67.0285	9.86	0.64	0.37	0.288	6.5	16.0	11	75	0.285			
MI	203	09:22		CB423	44.914	67.0293	10.54	0.72	0.35	0.295	8	15.6	11	74	0.266	771.043	394.5482	15.211
MI	299	09:50		CB540	44.9138	67.0295	11.66	0.15	0.00	0.465	4	9.9	7	36	0.000	203.731	85.49977	0.316
MI	313	08:55		CB628	44.9143	67.0268	9.83	0.21	0.01	0.631	2.75	7.3	7.5	32	0.003	413.059	192.9286	0.218
MI	138	11:06		CB232	44.914	67.0292	5.83	0.21	0.03	0.434	5	10.6	6.5	71	0.016			
MSB	312	12:15		CB619	44.8747	67.0568	9.89	0.37	0.02	0.687	1.5	6.7	11	32	0.004	147.425	36.14431	0.008
MSB	203	11:33		CB427	44.8782	67.0627	11.13	1.41	1.09	0.303	8	15.2	9	74	0.794	257.238	84.16321	5.256
MSB	192	14:16		CB311	44.875	67.0607	11.69	1.43	1.34	0.506	5	9.1	7.5	75	0.630	132.179	70.53832	3.930
MSB	298	10:00		CB521	44.874	67.0552	11.84	0.26	0.02	0.849	3	7.1	9	37	0.007	93.358	21.60666	0.005
MSB	123	12.17		CB119	44.8775	67.065	5.34	0.28	0.12	0.324	7	14.2	12	70	0.084	132.649	13.23579	0.081
MSB	137	10:48		CB220	44.8765	67.0653	6.04	0.06	0.00	0.458	4.5	10.1	10.5	71	0.000	325.857	106.043	0.112
FR	298	08:00		CB517	44.9292	67.1445	12.15	1.82	1.16	0.618	2.5	7.4	6	37	0.352	111.492	20.40442	0.054
FR	137	08:53		CB216	44.928	67.143	6.77	0.46	0.15	0.598	4	7.7	6	71	0.060	137.015	32.98424	0.170
FR	193	13.33		CB328	44.9293	67.1462	12.75	1.86	1.67	0.430	3.5	10.5	8.5	75	0.896	100.119	45.37958	2.562
FR	202	12:37		CB411	44.93	67.1462	12.63	1.81	1.49	0.569	3	8.1	4.6	74	0.622	189.402		
FR	123	08:55		CB114	44.93	67.1433	6.22	0.36	0.17	0.470	4.5	9.8	5.5	70	0.081	51.380	10.68691	0.345
FR	311	13:00		CB611	44.9292	67.1453	9.41	0.90	0.47	0.614	2	7.5	9	33	0.136	165.223	31.39245	0.258
FR	203	10:13		CB424	44.9298	67.146	13.29	0.85	0.44	0.389	5.5	11.8	7	74	0.253	771.043	40.94317	2.677

Locator	Julian Day Date	Time (EST) Tide	Station#	Latitude	Longitude	Avg temp (degrees C)	Avg Chl (mg m-3)	Avg chl a (mg m-3)	Kpar (m-1)	Secchi z (m)	Euphotic z (m)	Sonic z (m)	Light E m-2 d-1	PPmax gC m-2 d-1	Ben. Chl mg-1 m-2	Ben.Chl.a mg-1 m-2	Ben. PPmax gCm-2d-1
SC	122	13.20	CB104	44.8975	67.1217	5.43	0.16	0.02	0.430	6	10.7	10.5	70	0.008	51.380	19.33316	0.076
SC	193	11:52	CB322	44.8983	67.1213	11.08	2.64	2.40	0.305	5.5	15.1	9	75	1.738	103.701	34.32886	1.738
SC	202	07:11	CB401	44.8982	67.1213	11.14	2.57	2.12	0.399	5.3	11.5	8.5	74	1.225	221.641	77.05054	1.704
SC	311	10:45	CB605	44.8977	67.1217	9.88	0.58	0.17	0.837	3	5.5	9.5	33	0.037	566.864	215.4084	0.009
SC	136	14:13	CB209	44.8977	67.1212	6.10	1.21	0.66	0.360	6	12.8	9	71	0.412	250.858	89.10312	3.811
SC	297	13:40	CB509	44.8983	67.1212	11.87	0.49	0.17	0.517	4	8.9	6	37	0.058		179.5965	8.857
WB	122	11:35	CB102	44.8233	67.15	6.23	0.14	0.01	0.698	4	6.6	6.5	70	0.002	197.798	91.58931	0.162
WB	297	11:00	CB502	44.822	67.1518	11.94	0.91	0.39	0.677	3.5	6.8	6.5	37	0.110	237.089	65.6058	0.091
WB	311	09:00	CB602	44.822	67.1505	8.85	0.96	0.50	0.837	2	5.5	5	33	0.112	116.865	30.78798	0.038
WB	202	09:29	CB408	44.8213	67.151	12.68	3.07	2.84	0.517	3.5	8.9	6.7	74	1.301	174.626	44.00585	2.135
WB	193	10:37	CB320	44.822	67.15	12.87	2.46	2.22	0.490	3.5	9.4	6	75	1.063	60.537	15.60712	0.217
WB	136	11:09	CB202	44.8233	67.1493	7.34	0.90	0.49	0.542	3.5	8.5	6.2	71	0.212	201.268	52.54687	0.204
WPB	123	09:34	CB115	44.915	67.1133	5.71	0.39	0.20	0.535	5	8.6	6.5	70	0.089	48.246	16.70369	0.183
WPB	193	14:00	CB329	44.9993	67.1132	11.77	2.76	2.71	0.363	5	12.7	10	75	1.719			
WSB	298	09:40	CB520	44.888	67.0775	11.87	0.57	0.22	0.387	3.5	11.9	12.5	37	0.102	89.664	23.56449	0.019
WSB	312	12:00	CB618	44.888	67.0812	10.17	0.23	0.00	0.465	1.75	9.9	16	32	0.000	109.142	17.84212	0.002
WSB	203	11:50	CB428	44.8923	67.0578	11.17	1.52	1.07	0.400	7	11.5	10	74	0.618	88.925	20.45278	0.679
WSB	137	09:47	CB218	44.8937	67.0865	6.07	0.31	0.03	0.434	4.5	10.6	12.5	71	0.015			

Locator	Julian Day Date	Local Time (EST) State of Tide	Station#	Latitude	Longitude	Depth meters	Total Chl (mg m-3)	Fb/Fa	CTD temp (degrees C)	CTD Sal (o/oo)	MicroSal (o/oo)	NO3 (uM)	NO2 (uM)	PO4 (uM)	SiO3 (uM)	NH4 (uM)
BC	124	10:01	CB134	44.9017	67.0067	1	0.32	1.58	5.209	30.602		4.40	0.11	0.36	7.24	1.88
BC	124	10.01	CB134	44.9017	67.0067	4	0.83	1.71	5.199	30.697	30.753	4.33	0.06	0.38	7.55	0.91
BC	138	09:55	CB229	44.9012	67.0078	1	0.91	1.66	5.714	30.578		5.57	0.04	0.69	6.99	3.03
BC	138	09:55	CB229	44.9012	67.0078	4	0.91	1.55	5.64	30.62	30.747	5.27	0.14	0.61	7.47	2.98
BC	194	08:09	CB336	44.902	67.0062	1	2.73	2.1	10.489	31.423		0.84	0.49	0.37	3.77	
BC	194	08:09	CB336	44.902	67.0062	3.5	2.87	2.21	10.249	31.513	31.562	1.21	0.37	0.29	3.47	4.92
BC	204	09:59	CB441	44.9023	67.0065	1	2.39	1.98	10.504	31.564		1.84	0.67	0.46	4.23	2.49
BC	204	09:59	CB441	44.9023	67.0065	5	2.12	1.98	10.44	31.646	31.617	2.05	0.29	0.41	3.97	3.41
BC	299	06:50	CB537	44.9012	67.0077	1	0.73	1.52	11.566	32.008		6.26	0.70	0.71	8.21	2.67
BC	299	06:50	CB537	44.9012	67.0077	4	0.85	1.58	11.517	32.004	32.189	6.14	0.50	0.59	7.97	2.10
BC	313	10:20	CB631	44.9018	67.0075	1	0.03	0.93	10.058	31.749		5.45	0.24	0.51	7.43	1.47
BC	313	10:20	CB631	44.9018	67.0075	6	0.05	0.91	10.064	31.681	31.907	7.74	0.37	0.79	10.95	1.54
BG1	123	07:48 Low	CB109	44.915	67.07	1	0.05	1	5.219	30.38		4.93	0.13	0.44	7.58	2.35
BG1	123	07.48 Low	CB109	44.915	67.07	5	0.06	1	5.201	30.39	30.749	4.76	0.08		7.94	0.78
BG1	124	12.58 High	CB139	44.9133	67.07	1	0.11	1.25	4.98	30.641		5.07	0.09	0.53	7.37	1.07
BG1	124	12.58 High	CB139	44.9133	67.07	10	0.24	1.33	4.966	30.644	30.836	4.90	0.07	0.45	7.50	0.92
BG1	137	07:59 Low	CB211	44.9135	67.0702	1	0.01	1.05	6.214	30.314		2.96	0.04	0.30	4.45	
BG1	137	07:59 Low	CB211	44.9135	67.0702	5	0.09	1.03	6.221	30.316	30.471	3.75	0.03	0.46	5.55	3.53
BG1	192	10:35 High	CB302	44.9122	67.0352	1	0.91	1.76	9.927	31.364						
BG1	192	10.35 High	CB302	44.9122	67.0352	15	0.96	1.79	9.669	31.433	31.549	2.44	0.23	0.44	4.14	1.78
BG1	194	06:20 Low	CB330	44.9147	67.0725	1	2.91	2.17	11.133	31.35		0.39	0.01	0.23	2.97	1.61
BG1	194	06.20 Low	CB330	44.9147	67.0725	4	3.24	2.09	11.124	31.373	31.528	0.94	0.04	0.20	3.19	1.96
BG1	202	13:08 Low	CB412	44.9138	67.0702	1	1.81	1.98	11.005	31.011		1.26	0.14	0.39	4.20	2.47
BG1	202	13.08 Low	CB412	44.9138	67.0702	5.5	1.9	2.18	10.957	31.276	31.387	1.46	0.30	0.39	4.33	2.60
BG1	203	07:38 High	CB417	44.9142	67.0715	1	1.34	1.94	10.829	31.287		1.87	0.44	0.52	4.64	5.49
BG1	203	07:38 High	CB417	44.9142	67.0715	5	0.67	1.67	10.824	31.549	31.478	1.81	0.17	0.39	4.38	3.24
BG1	298	07.08 Low	CB512	44.9127	67.0708	1	0.72	1.53	11.815	31.983		2.60	0.27	0.49	4.93	3.43
BG1	298	07:08 Low	CB512	44.9127	67.0708	6	0.67	1.47	11.819	31.999	32.141	2.28	0.33	0.48	4.54	2.88
BG1	299	11:46 High	CB542	44.9142	67.0708	1	0.3	1.29	11.675	31.995		6.43	0.52	0.62	8.52	2.35
BG1	299	11.46 High	CB542	44.9142	67.0708	15	0.27	1.43	11.677	31.999	32.155	6.10	0.44	0.68	7.81	1.69
BG1	312	10:50 High	CB613	44.9133	67.0715	1	0.11	1	10.202	31.706		7.49	0.58	0.70	11.79	2.09
BG1	312	10:50 High	CB613	44.9133	67.0715	15	0.18	1.03	10.244	31.739	31.895	7.13	0.52	0.69	10.64	2.39
BG1	313	06:44 Low	CB622	44.9137	67.0715	1	0.54	1.3	9.605	31.69		6.44	0.51	0.63	10.07	1.40
BG1	313	06:44 Low	CB622	44.9137	67.0715	10	0.44	1.36	9.748	31.657	31.871	7.20	0.44	0.61	10.49	1.35
BG2	123	08:26 Low	CB113	44.9125	67.0683	1	0.43	1.64	5.445	30.238		4.40	0.06	0.32	7.69	0.85
BG2	123	08 26 Low	CB113	44.9125	67.0683	12	0.51	1.68	5.306	30.342	30.666	4.58	0.09	0.36	7.41	0.76
BG2	137	08.28 Low	CB215	44.9122	67.0688	1	0.36	1.3	6.125	30.344		4.02	0.19	0.51	5.72	2.25
BG2	137	08 28 Low	CB215	44.9122	67.0688	9	0.36	1.34	6.083	30.411	30.526	3.95	0.07	0.49	5.83	3.05
BG2	192	10:44 High	CB303	44.9102	67.0677	1	1.21	1.74	9.596	31.411		2.51	0.17	0.41	4.33	2.21
BG2	192	10.44 High	CB303	44.9102	67.0677	17	1.12	1.79	9.482	31.464	31.635	2.57	0.23	0.45	4.19	1.69
BG2	194	06:30 Low	CB331	44.9132	67.0713	1	3.27	1.78	11.088	31.329		0.60	0.03	0.21	2.95	1.55
BG2	194	06:30 Low	CB331	44.9132	67.0713	4.5	3.54	2.08	11.085	31.332	31.5	0.31	0.08	0.15	1.68	1.77
BG2	202	13 16 Low	CB413	44.911	67.0682	1	0.94	2	11.111	31.163		1.18	0.15	0.37	4.26	3.05
BG2	202	13 16 Low	CB413	44.911	67.0682	13	0.78	2.19	10.971	31.259	31.352	1.33	0.21	0.36	4.36	3.07
BG2	203	07:44 High	CB418	44.9125	67.0697	1	0.99	2.1	10.175	31.407		2.60	0.27	0.49	4.93	3.43
BG2	203	07:44 High	CB418	44.9125	67.0697	15	0.99	1.8	10.184	31.432	31.556					
BG2	298	07 31 Low	CB516	44.9123	67.0688	1	0.97	1.55	11.866	31.924		1.13	0.29	0.43	4.43	3.18
BG2	298	07:31 Low	CB516	44.9123	67.0688	10	0.91	1.61	11.854	31.953	32.152	0.69	0.49	0.45	4.39	2.19
BG2	299	12:16 High	CB546	44.9135	67.069	1	0.63	1.57	11.63	32.071		6.13	0.66	0.70	7.01	2.50
BG2	299	12:16 High	CB546	44.9135	67.069	12	0.49	1.4	11.629	32.064	32.225	6.63	0.64	0.79	8.54	1.59
BG2	312	11:24 High	CB617	44.9117	67.0697	1	0.26	1.05	10.33	31.884		5.96	0.31	0.58	8.57	3.50
BG2	312	11:24 High	CB617	44.9117	67.0697	18	0.2	1.02	10.382	31.918	32.092	6.95	0.52	0.66	9.17	3.27
BG2	313	07.15 Low	CB626	44.9115	67.0705	1	0.63	1.47	9.958	31.283		7.09	0.47	0.70	11.70	1.30
BG2	313	07:15 Low	CB626	44.9115	67.0705	10	0.62	1.46	9.688	31.356	31.51	7.13	0.29	0.74	10.54	1.83
BG3	123	08:18 Low	CB112	44.9117	67.0667	1	0.27	1.4	5.467	30.245		4.17	0.15	0.44	7.71	0.75
BG3	123	08 18 Low	CB112	44.9117	67.0667	15	0.14	1.33	5.419	30.241	30.434	4.39	0.16	0.45	7.60	0.89
BG3	124	13:06 High	CB140	44.91	67.0667	1	0.61	1.67	4.952	30.625		4.59	0.09	0.50	6.86	0.97
BG3	124	13:06 High	CB140	44.91	67.0667	24	0.85	1.75	4.919	30.641	30.823	4.86	0.10	0.46	7.72	0.94

Locator	Julian Day Date	Local Time (EST)	State of Tide	Station#	Latitude	Longitude	Depth meters	Total Chl (mg m-3)	Fb/Fa	CTD temp (degrees C)	CTD Sal (o/oo)	MicroSal (o/oo)	NO3 (uM)	NO2 (uM)	PO4 (uM)	SIO3 (uM)	NH4 (uM)
BG3	137	08:21	Low	CB214	44.911	67.0655	1	0.28	1.13	6.005	30.28		4.12	0.03	0.52	5.84	3.72
BG3	137	08:21	Low	CB214	44.911	67.0655	11	0.38	1.21	5.957	30.313	30.523	4.38	0.06	0.55	6.23	2.73
BG3	192	10:50	High	CB304	44.9093	67.0637	1	1.22	1.85	9.481	31.447		2.23	0.09	0.40	4.04	1.59
BG3	192	10:50	High	CB304	44.9093	67.0637	27	1.12	1.85	9.204	31.5	31.716	3.20	0.18	0.44	4.27	1.71
BG3	194	06:42	Low	CB332	44.9097	67.0645	1	4.25	2.21	10.894	31.337		0.88	0.01	0.24	3.04	1.82
BG3	194	06:42	Low	CB332	44.9097	67.0645	25.5	1.21	2.25	10.911	31.336	31.494	0.67	0.05	0.19	2.73	3.62
BG3	202	13:21	Low	CB414	44.9093	67.0653	1	2.04	1.88	11.192	31.142		0.95	0.17	0.40	4.45	2.86
BG3	202	13:21	Low	CB414	44.9093	67.0653	12	1.164	2.26	11.16	31.173	31.314	0.74	0.32	0.48	6.05	2.28
BG3	203	07:53	High	CB419	44.9098	67.069	1	1.91	1.84	10.309	31.387		2.06	0.29	0.37	4.28	3.96
BG3	203	07:53	High	CB419	44.9098	67.069	22	0.93	1.68	10.407	31.956	31.585	2.28	0.33	0.48	4.54	2.88
BG3	298	07:26	Low	CB515	44.9098	67.068	1	0.79	1.54	11.868	31.911		1.61	0.30	0.47	4.63	3.76
BG3	298	07:26	Low	CB515	44.9098	67.068	20	0.75	1.42	11.871	31.909	32.071	1.45	0.04	0.46	4.59	2.86
BG3	299	12:10	High	CB545	44.9107	67.0668	1	0.22	1.23	11.625	32.074		6.15	0.50	0.63	7.25	1.78
BG3	299	12:10	High	CB545	44.9107	67.0668	25	0.25	1.2	11.629	31.419	32.228	6.36	0.51	0.64	7.58	1.31
BG3	312	11:14	High	CB616	44.9098	67.0688	1	0.2	1.01	10.212	31.722		7.33	0.44	0.71	9.74	2.55
BG3	312	11:14	High	CB616	44.9098	67.0688	24	0.2	1.01	11.63	32.067	32.098	7.44	0.25	0.68	9.54	1.96
BG3	313	07:08	Low	CB625	44.9088	67.0683	1	0.66	1.4	9.647	31.134		7.02	0.63	0.78	14.18	2.11
BG3	313	07:08	Low	CB625	44.9088	67.0683	18	0.6	1.36	9.715	31.215	31.358	7.12	0.51	0.81	11.65	1.69
BG4	123	08:10	Low	CB111	44.91	67.0633	1	0.09	1.25	5.344	30.208		3.97	0.09	0.36	7.17	0.89
BG4	123	08:10	Low	CB111	44.91	67.0633	20	0.14	1.23	5.249	30.298	30.603	4.62	0.08	0.45	7.45	1.20
BG4	137	08:15	Low	CB213	44.9093	67.0642	1	0.23	1.09	6.022	30.261		4.23	0.06	0.56	6.02	3.08
BG4	137	08:15	Low	CB213	44.9093	67.0642	20	0.1	1.07	5.777	30.497	30.658	4.57	0.05	0.55	6.14	2.42
BG4	192	11:00	High	CB305	44.9072	67.063	1	0.83	1.68	10.187	1.192		1.58	0.11	0.37	3.81	1.68
BG4	192	11:00	High	CB305	44.9072	67.063	32	0.73	1.81	8.659	31.503	31.549	3.58	0.16	0.46	4.42	2.38
BG4	194	06:50	Low	CB333	44.908	67.0645	1	2.19	2.18	10.611	31.36		0.86	0.11	0.33	3.17	1.79
BG4	194	06:50	Low	CB333	44.908	67.0645	16	3.81	2.66	10.534	31.386	31.533	1.02	0.05	0.29	3.28	3.19
BG4	202	13:26	Low	CB415	44.9097	67.0597	1	2.58	1.98	11.249	31.117		1.02	0.11	0.35	4.35	
BG4	202	13:26	Low	CB415	44.9097	67.0597	22	1.23	2.29	11.041	31.212	31.369	1.14	0.26	0.49	4.45	4.17
BG4	203	08:04	High	CB420	44.9082	67.0648	1	2.46	1.83	10.939	31.238		2.13	0.20	0.53	4.95	2.72
BG4	203	08:04	High	CB420	44.9082	67.0648	21	1.08	1.14	10.274	31.402	31.545	1.32	0.34	0.42	4.53	4.29
BG4	298	07:21	Low	CB514	44.9093	67.065	1	0.79	1.51	11.865	31.912		2.13	0.20	0.53	4.95	2.72
BG4	298	07:21	Low	CB514	44.9093	67.065	20	0.78	1.55	11.869	31.913	32.072	2.24	0.45	0.42	4.66	3.22
BG4	299	12:04	High	CB544	44.9078	67.0657	1	0.17	1.12	11.647	32.035		6.49	0.62	0.68	7.61	2.06
BG4	299	12:04	High	CB544	44.9078	67.0657	20	0.16	1.06	11.649	32.034	32.193	6.36	0.54	0.68	7.85	2.04
BG4	312	11:08	High	CB615	44.9102	67.0652	1	0.24	1.01	10.266	31.768		6.53	0.43	0.59	8.81	2.67
BG4	312	11:08	High	CB615	44.9102	67.0652	24			10.404	31.947	32.257	6.50	0.30	0.60	8.44	1.43
BG4	313	07:00	Low	CB624	44.9067	67.0658	1	0.67	1.3	9.873	31.089		7.50	0.56	0.72	12.20	3.92
BG4	313	07:00	Low	CB624	44.9067	67.0658	15	0.63	1.37	9.896	31.156	31.75	7.21	0.36	0.69	11.69	1.44
BG5	123	08:01	Low	CB110	44.9083	67.0617	1	0.13	1.27	4.899	30.517		4.88	0.08	0.44	7.80	0.85
BG5	123	08:01	Low	CB110	44.9083	67.0617	5	0.13	1.22	4.869	30.544	30.737	4.77	0.08	0.41	7.87	0.95
BG5	124	13:15	High	CB141	44.9075	67.0633	1	0.23	1.21	5.357	30.521		4.15	0.11	0.42	6.79	1.04
BG5	124	13:15	High	CB141	44.9075	67.0633	10	0.22	1.22	5.176	30.624	30.77	4.35	0.04	0.42	7.00	1.50
BG5	137	08:09	Low	CB212	44.9073	67.0632	1	0.13	1.04	5.787	30.535		4.34	0.03	0.42	5.69	3.63
BG5	137	08:09	Low	CB212	44.9073	67.0632	6	0.14	1.05	5.743	30.593	30.828	4.68	-0.02	0.53	6.29	2.18
BG5	192	11:07	High	CB306	44.9072	67.063	1	0.78	1.79	10.695	31.24		0.86	0.08	0.34	3.57	1.39
BG5	192	11:07	High	CB306	44.9072	67.063	17	1.14	1.82	9.798	31.433	31.443	2.19	0.01	0.43	4.04	1.64
BG5	194	06:57	Low	CB334	44.9062	67.065	1	3.54	2.03	10.791	31.355		0.93	0.50	0.31	3.48	1.36
BG5	194	06:57	Low	CB334	44.9062	67.065	8	3.36	2.17	10.726	31.423	31.521	0.69	0.21	0.22	2.64	1.07
BG5	202	13:33	Low	CB416	44.9067	67.0647	1	2.22	2.06	11.132	31.105		1.03	0.31	0.35	4.09	2.84
BG5	202	13:33	Low	CB416	44.9067	67.0647	8	1.39	2.3	10.641	31.48	31.453	1.42	0.18	0.40	4.42	3.04
BG5	203	08:09	High	CB421	44.907	67.0627	1	1.18	1.76	10.939	31.273		1.61	0.30	0.47	4.63	3.76
BG5	203	08:09	High	CB421	44.907	67.0627	4.5	1.02	1.52	10.902	31.413	31.419	2.24	0.45	0.42	4.66	3.22
BG5	298	07:15	Low	CB513	44.9067	67.064	1	0.81	1.54	11.818	31.941		2.06	0.29	0.37	4.28	3.96
BG5	298	07:15	Low	CB513	44.9067	67.064	5	0.74	1.53	11.797	31.987	32.134	1.32	0.34	0.42	4.53	4.29
BG5	299	11:57	High	CB543	44.908	67.0637	1	0.17	1.1	11.656	32.027		6.23	0.52	0.70	7.93	2.49
BG5	299	11:57	High	CB543	44.908	67.0637	16	0.17	1.09	11.644	32.029	32.191	6.54	0.49	0.61	7.62	1.84
BG5	312	11:01	High	CB614	44.9073	67.0637	1	0.21	1.02	10.059	31.563		7.27	0.60	0.75	10.84	2.55
BG5	312	11:01	High	CB614	44.9073	67.0637	18	0.22	1.02	10.22	31.704	31.85	5.86	0.42	0.63	8.58	2.48

Locator	Julian Day Date	Local Time (EST) State of Tide	Station#	Latitude	Longitude	Depth meters	Total Chl (mg m-3)	Fb/Fa	CTD temp (degrees C)	CTD Sal (o/oo)	MicroSal (o/oo)	NO3 (uM)	NO2 (uM)	PO4 (uM)	SIO3 (uM)	NH4 (uM)
BG5	313	06:54 Low	CB623	44.907	67.0635	1	0.52	1.35	9.617	31.082		7.25	0.55	0.73	11.66	1.90
BG5	313	06:54 Low	CB623	44.907	67.0635	10	0.57	1.39	9.585	31.102	31.223	7.22	0.47	0.70	11.73	1.79
BH	124	11:57	CB138	44.9342	67.05	1	0.07	1.23	5.518	30.429		3.93	0.02	0.34	6.68	0.89
BH	124	11:57	CB138	44.9342	67.05	6	0.05	1.83	5.519	30.433	30.844	3.58	0.08	0.37	6.51	1.55
BH	138	11:46	CB233	44.9343	67.0512	1	1.08	1.57	5.915	30.484		4.48	0.17	0.55	5.91	2.41
BH	138	11:46	CB233	44.9343	67.0512	4	0.69	1.04	5.921	30.492	30.745	4.70	0.25	0.47	6.23	3.03
BH	192	14:56	CB312	44.9335	67.0512	1	1.41	1.91	12.119	31.316		0.35	0.08	0.26	3.41	1.29
BH	192	14:56	CB312	44.9335	67.0512	5	1.66	2	12.16	31.354	31.538	0.63	0.06	0.31	3.38	1.89
BH	203	08:47	CB422	44.9342	67.0516	1	0.94	1.67	11.32	31.293		0.58	0.38	0.42	3.68	2.91
BH	203	08:47	CB422	44.9342	67.0516	7	0.59	1.57	11.307	31.309	31.419	0.69	0.49	0.45	4.39	2.19
BH	299	10:30	CB541	44.9345	67.0512	1	0.93	1.33	11.661	31.98		6.07	0.75	0.71	7.78	2.28
BH	299	10:30	CB541	44.9345	67.0512	5	1.1	1.38	11.658	31.974	32.16	5.41	0.46	0.59	7.60	1.24
BH	313	08:00	CB627	44.935	67.0505	1	0.27	1	9.175	31.111		7.57	0.38	0.79	12.34	4.94
BH	313	08:00	CB627	44.935	67.0505	7	0.3	1	9.141	31.088	31.213	6.74	0.36	0.73	11.11	3.58
BI	122	12:25	CB103	44.8767	67.1533	1	0.15	1.26	5.21	30.195	30.461	5.01	0.04	0.48	7.89	0.87
BI	122	12:25	CB103	44.8767	67.1533	7	0.25	1.33	5.192	30.22	30.492	4.93	0.02	0.46	7.55	0.83
BI	136	11:55	CB203	44.8752	67.1553	1	1.49	1.61	5.657	30.496		3.13	0.13	0.26	3.80	5.96
BI	136	11:55	CB203	44.8752	67.1553	6	1.53	1.75	5.658	30.504	30.703	3.79	-0.08	0.38	4.59	4.26
BI	193	11:11	CB321	44.8762	67.156	1	3.05	1.84	10.16	31.127		1.55	0.28	0.38	3.75	1.47
BI	193	11:11	CB321	44.8762	67.156	6	1.32	2.19	10.152	31.439	31.534	1.63	0.14	0.36	3.83	2.11
BI	202	10:11	CB409	44.8757	67.156	1	1.16	2.48	11.136	31.094		0.98	0.12	0.21	4.08	1.80
BI	202	10:11	CB409	44.8757	67.156	4	2.37	2	10.832	31.316	31.384	2.20	0.14	0.41	3.86	1.90
BI	297	11:45	CB503	44.8757	67.1558	1	0.46	1.31	11.701	32.015		2.20	0.14		3.86	1.90
BI	297	11:45	CB503	44.8757	67.1558	6	0.58	1.39	11.72	32.074	32.241	0.98	0.12		4.08	1.80
BI	311	09:30	CB603	44.8745	67.1557	1	0.71	1.47	9.96	31.639		7.31	0.64	0.73	11.17	6.24
BI	311	09:30	CB603	44.8745	67.1557	5	0.74	1.43	9.955	31.632	31.78	7.25	0.43	0.69	10.93	1.65
CI	124	10:33	CB135	44.8892	67.0283	1	0.47	1.81	5.298	30.546		4.44	0.06	0.50	7.79	1.09
CI	124	10:33	CB135	44.8892	67.0283	5	0.75	1.89	5.235	30.601	30.743	4.54	0.12	0.43	7.55	1.48
CI	138	10:23	CB230	44.8887	67.0275	1	1.16	1.54	5.607	30.665		5.01	0.36	0.58	6.73	3.15
CI	138	10:23	CB230	44.8887	67.0275	4	1.13	1.58	5.587	30.699	30.967	4.16	0.19	0.35	5.32	4.71
CI	194	07:46	CB335	44.8897	67.0282	1	3.74	2.04	10.014	31.427				0.55	3.14	
CI	194	07:46	CB335	44.8897	67.0282	6.5	1.79	2.22	9.993	31.452	31.589	1.68	0.17	0.27	3.37	4.21
CI	204	11:11	CB443	44.8902	67.0272	1	2.42	2.04	10.357	31.471		1.32	0.29		3.77	2.58
CI	204	11:11	CB443	44.8902	67.0272	7	1.93	2.15	10.394	31.52	31.597	0.84	0.21		3.87	3.06
CI	299	09:10	CB538	44.8897	67.0262	1	0.3	1.19	11.586	32.042		6.18	0.61	0.61	7.60	1.44
CI	299	09:10	CB538	44.8897	67.0262	5	0.76	1.08	11.586	32.027	32.218	6.40	0.59	0.65	8.02	2.48
CI	313	09:50	CB630	44.8888	67.0275	1	0.1	0.81	9.951	31.692		6.52	0.22	0.64	8.78	1.10
CI	313	09:50	CB630	44.8888	67.0275	5	0.15	0.98	9.95	31.665	31.864	6.97	0.31	0.67	8.71	1.28
DC	124	10:56	CB136	44.9083	67.0192	1	0.19	1.43	5.676	30.385		4.16	0.12	0.47	7.17	0.80
DC	124	10:56	CB136	44.9083	67.0192	5	2.71	1.98	5.631	30.516	30.601	3.91	0.01	0.45	6.75	0.89
DC	138	10.49	CB231	44.9078	67.0198	1	0.71	1.47	5.872	30.477		4.00	0.25	0.48	5.32	3.14
DC	138	10.49	CB231	44.9078	67.0198	5	0.78	1.45	5.827	30.528	30.687	4.47	0.11	0.52	6.12	2.73
DC	299	09:30	CB539	44.9072	67.0197	1	0.52	1.33	11.663	31.954		8.98	0.62	0.73	7.95	3.85
DC	299	09:30	CB539	44.9072	67.0197	5	0.67	1.41	11.659	31.924	32.219	5.34	0.69	0.62	7.43	1.65
DC	313	09:20	CB629	44.9078	67.0197	1	0.21	1.04	9.726	31.395		7.44	0.35	0.79	11.37	1.67
DC	313	09:20	CB629	44.9078	67.0197	7	0.26	1.07	9.774	31.454	31.93	5.70	0.26	0.56	8.07	1.46
DR	122	10:28	CB101	44.9033	67.18	1	0.69	1.6	5.836	27.959	22.624	3.13	0.23	0.42	16.06	1.86
DR	122	10:28	CB101	44.9033	67.18	5	0.64	1.61	5.709	28.581	28.611	3.89	0.11	0.42	9.64	1.06
DR	136	10:10	CB201	44.9077	67.191	1	1.67	1.77	7.488	28.204		2.15	0.35	0.29	6.37	6.38
DR	136	10:10	CB201	44.9077	67.191	2.5	1.45	1.66	7.21	28.663	27.656	1.98	0.04	0.26	5.73	2.63
DR	193	09:52	CB319	44.9165	67.1882	1	1.84	2.1	12.133	30.997		0.38	0.05	0.28	3.12	1.57
DR	193	09:52	CB319	44.9165	67.1882	4	2.6	2.04	12.092	31.05	31.213	0.95	0.00	0.24	3.09	1.88
DR	202	08:44	CB407	44.9073	67.1888	1	2.87	2	12.201	30.371		0.57	0.12	0.41	4.77	1.21
DR	202	08:44	CB407	44.9073	67.1888	5	3.18	2.03	11.544	30.933	30.879	0.57	0.10	0.33	3.60	1.54
DR	297	10:05	CB501	44.9043	67.1808	1	0.74	1.45	11.745	31.358	30.911	0.43	0.15		4.64	1.28
DR	297	10:05	CB501	44.9043	67.1608	4	0.67	1.47	11.758	31.424	31.398	0.57	0.10		3.60	1.54
DR	311	08:15	CB601	44.9077	67.189	1	0.93	1.86	8.861	29.366	27.589	7.39	0.60	0.56	22.69	6.12
DR	311	08.15	CB601	44.9077	67.189	4	0.69	1.46	9.135	30.31	30.161	6.68	0.56	0.70	17.07	2.71

Locator	Julian Day Date	Local Time (EST) State of Tide	Station#	Latitude	Longitude	Depth meters	Total Chl (mg m-3)	Fb/Fa	CTD temp (degrees C)	CTD Sal (o/oo)	MicroSal (o/oo)	NO3 (uM)	NO2 (uM)	PO4 (uM)	SiO3 (uM)	NH4 (uM)
EB	123	10:15	CB116	44.9367	67.1083	1	0.39	1.6	6.031	30.117		2.36	0.11	0.35	7.29	1.09
EB	123	10:15	CB116	44.9367	67.1083	4	0.71	1.86	5.756	30.289	30.346	3.02	0.08	0.39	7.53	1.09
EB	137	07:29	CB210	44.9347	67.1062	1	0.3	1.57	6.861	30.156		2.00	-0.03	0.24	4.33	4.11
EB	137	07:29	CB210	44.9347	67.1062	5	0.15	1.11	6.824	30.353	30.289	1.92	0.00	0.22	4.01	3.69
EB	192	11:37	CB307	44.9337	67.1062	1	1.25	2.33	11.73	31.418		0.33	0.00	0.28	3.36	1.40
EB	192	11:37	CB307	44.9337	67.1062	10	2.53	2.17	11.246	31.3	31.422	0.53	0.05	0.31	3.47	1.45
EB	203	11:02	CB426	44.9342	67.105	1	1.32	1.88	12.963	31.048		0.14	0.19	0.38	3.89	1.44
EB	203	11:02	CB426	44.9342	67.105	8	1.14	1.7	11.2	31.316	31.47			0.44	3.63	1.50
EB	298	09:02	CB519	44.9368	67.107	1	1.13	1.56	12.087	31.776		0.14	0.25		6.01	2.10
EB	298	09:02	CB519	44.9368	67.107	5	0.85	1.58	12.052	31.602	31.962	1.31	0.32	0.44	4.81	2.08
EB	311	12:30	CB610	44.9347	67.108	1	0.65	1.48	9.713	31.461		7.00	0.73	0.73	12.08	
EB	311	12:30	CB610	44.9347	67.108	8	0.62	2.04	9.755	31.468	31.656	6.95	0.61	0.71	11.42	2.42
EPB	297	14:55	CB511	44.9057	66.9727	1	0.83	1.59	11.647	32.077		1.81	0.17	0.39	4.38	3.24
EPB	297	14:55	CB511	44.9057	66.9727	35	0.76	1.55	11.589	32.123	32.294	1.87	0.44	0.52	4.64	5.49
ESB	123	13:07	CB120	44.89	67.0592	1	0.26	1.5	5.388	30.352		4.46	0.13	0.42	7.75	1.66
ESB	123	13:07	CB120	44.89	67.0592	10	0.5	1.45	5.287	30.454	30.663	4.51	0.14	0.47	7.47	0.68
ESB	137	11:12	CB221	44.8927	67.0545	1	0.1	1.16	6.135	30.341		4.03	0.12	0.48	6.16	2.82
ESB	137	11:12	CB221	44.8927	67.0545	8	0.06	1.08	5.912	30.452	30.605	4.31	0.11	0.52	6.14	4.59
ESB	192	12:36	CB309	44.8928	67.0563	1	1.7	2.11	11.523	31.189		0.38	0.07	0.29	3.81	1.48
ESB	192	12:36	CB309	44.8928	67.0563	11	1.03	2.3	10.509	31.462	31.484	1.15	0.09	0.33	3.77	1.70
ESB	298	11:00	CB523	44.8928	67.0553	1	1.57	1.5	11.851	31.957		0.22	0.16	0.36	4.40	1.50
ESB	298	11:00	CB523	44.8928	67.0553	10	0.75	1.32	11.837	31.964	32.117	2.18	0.24	0.47	5.34	2.28
ESB	312	14:00	CB621	44.8932	67.055	1	0.95	1.49	9.824	31.374		6.85	0.75	0.66	11.25	2.70
ESB	312	14:00	CB621	44.8932	67.055	9	1.08	1.51	10.071	31.594	31.75	7.17	0.46	0.70		5.23
FH	194	08:50	CB336A	44.8727	66.9815	1			10.165	31.453		1.45	0.04	0.46	4.59	2.86
FH	194	08:50	CB336A	44.8727	66.9815	9			10.124	31.48		1.13	0.29	0.43	4.43	3.18
FH	297	14:35	CB510	44.8857	66.9803	1	0.81	1.73	11.666	32.085		1.42	0.18	0.40	4.42	3.04
FH	297	14:35	CB510	44.8857	66.9803	25	0.67	1.64	11.588	32.131	32.29	1.03	0.31		4.09	2.94
GI	136	12:41	CB204	44.8672	67.1137	1	1.46	1.63	5.706	30.479		3.48	0.05	0.31	4.80	2.57
GI	136	12:41	CB204	44.8672	67.1137	10	1.4	1.73	5.622	30.527	30.704	2.90	0.05	0.29	3.71	3.14
GI	193	12:56	CB327	44.8665	67.1138	1	3.29	2.1	11.175	31.269		0.59	0.04		2.84	1.22
GI	193	12:56	CB327	44.8665	67.1138	11	2.66	2.09	10.628	31.405	31.516	1.13	0.06	0.29	3.13	1.42
GI	202	08:08	CB406	44.8668	67.1143	1	1.48	2.2	11.255	31.134		1.32	0.29	0.43	3.77	2.58
GI	202	08:08	CB406	44.8668	67.1143	8	0.87	2.44	10.773	31.375	31.422	1.11	0.19	0.39	4.14	4.46
GI	297	12:20	CB504	44.865	67.1148	1	0.56	1.56	11.831	31.908		1.17	0.26		4.44	
GI	297	12:20	CB504	44.865	67.1148	8	0.7	1.44	11.735	32.048	32.133	0.36	0.00	0.39	4.53	3.86
GI	311	10:15	CB604	44.865	67.1157	1	0.62	1.44	10.093	31.744		7.89	0.47	0.83	10.42	4.05
GI	311	10:15	CB604	44.865	67.1157	8	0.69	1.49	10.146	31.752	31.92	7.47	0.50	0.72	10.70	3.12
GP	123	10:53	CB117	44.915	67.1067	1	0.18	1.46	5.684	30.132		4.00	0.11	0.48	7.99	0.95
GP	123	10:53	CB117	44.915	67.1067	12	0.19	1.2	5.228	30.359	30.447	4.08	0.11	0.48	7.80	0.78
GP	137	09:22	CB217	44.9153	67.1058	1	0.29	1.26	6.284	30.236		3.36	0.06	0.59	5.87	3.33
GP	137	09:22	CB217	44.9153	67.1058	10	0.36	1.23	6.084	30.323	30.456	3.89	0.09	0.48	6.01	1.87
GP	192	12:00	CB308	44.9197	67.1097	1	3.49	2.14	11.006	31.113		0.44	0.16	0.23	3.27	1.50
GP	192	12:00	CB308	44.9197	67.1097	10	1.16	2.17	10.409	31.362	31.39	1.14	0.13	0.27	3.75	1.37
GP	203	10:40	CB425	44.9185	67.1083	1	0.3	1.42	11.923	30.908		0.25	0.26	0.36	4.28	1.78
GP	203	10:40	CB425	44.9185	67.1083	9	0.32	1.3	10.835	31.363		1.31	0.32	0.44	4.81	2.08
GP	298	08:40	CB518	44.9155	67.1065	1	0.93	1.57	12.028	31.811		1.63	0.15	0.47	4.55	2.97
GP	298	08:40	CB518	44.9155	67.1065	10	0.73	1.54	11.809	31.904	32.045	0.15	0.28		4.35	1.88
GP	311	13.30	CB612	44.9163	67.1065	1	0.84	1.54	9.854	31.594		6.97	0.56	0.70	11.71	2.30
GP	311	13.30	CB612	44.9163	67.1065	12	0.74	1.55	10.268	31.78	31.966	7.40	0.55	0.71	10.39	1.87
JB	124	09:18	CB133	44.8592	67.0033	1	0.14	1.6	5.304	30.734		3.70	0.08	0.49	7.23	1.11
JB	124	09:18	CB133	44.8592	67.0033	5	0.03	1	5.025	30.73	30.843	4.87	-0.06	0.47	8.69	0.83
JB	137	12:52	CB222	44.8532	67.0103	1	0.2	1.19	5.797	30.79		5.04	0.14	0.56	6.74	2.12
JB	137	12:52	CB222	44.8532	67.0103	6	0.22	1.19	5.605	30.88	30.919	4.90	0.09	0.49	6.53	1.84
JB	194	09:07	CB337	44.8563	67.0048	1	1.61	2	10.28	31.392		0.56	0.09	0.39	3.90	3.18
JB	194	09:07	CB337	44.8563	67.0048	6	3.54	2.08	10.168	31.498	31.624	1.06	0.28	0.23	3.36	2.74
JB	204	10:31	CB442	44.8627	67.0092	1	2.37	2.08	10.819	31.44		1.75	0.28		4.35	3.66
JB	204	10:31	CB442	44.8627	67.0092	8	2.62	2.17	10.492	31.534	31.63	1.72	0.32	0.41	4.23	3.64

Locator	Julian Day Date	Local Time (EST) State of Tide	Station#	Latitude	Longitude	Depth meters	Total Chl (mg m-3)	Fb/Fa	CTD temp (degrees C)	CTD Sal (o/oo)	MicroSal (o/oo)	NO3 (uM)	NO2 (uM)	PO4 (uM)	SiO3 (uM)	NH4 (uM)
JB	299	08:15	CB536	44.8572	67.0032	1	0.22	1.15	11.587	32.04		5.48	0.67	0.67	8.30	2.52
JB	299	08:15	CB536	44.8572	67.0032	5	0.29	1.21	11.551	32.023	32.215	5.60	0.70	0.73	8.36	2.00
JB	313	11:00	CB632	44.8545	67.0097	1	0.04	0.95	9.674	31.736		5.73	0.24	0.61	8.31	2.06
JB	313	11:00	CB632	44.8545	67.0097	6	0.05	1	9.645	31.725	31.943	7.45	0.42	0.81	10.57	4.26
LD1	122	13:59 High	CB105	44.895	67.11	1	0.09	1.36	4.869	30.506		5.56	0.21	0.51	7.85	1.33
LD1	122	13:59 High	CB105	44.895	67.11	10	0.11	1.33	4.797	30.623	30.774	5.58	0.16	0.48	8.10	1.06
LD1	136	13:11 High	CB205	44.894	67.1113	1	0.66	1.44	5.725	30.485		3.43	0.02	0.32	4.33	3.20
LD1	136	13:11 High	CB205	44.894	67.1113	9	0.71	1.56	5.716	30.491	30.688	3.85	0.05	0.40	5.04	1.87
LD1	193	12:14 High	CB323	44.8942	67.1113	1	2.35	2.02	10.751	31.328		1.03	0.01	0.34	3.79	1.44
LD1	193	12:14 High	CB323	44.8942	67.1113	7	3.18	2.09	10.587	31.4	31.514	1.04	0.02	0.34	3.61	1.54
LD1	202	07:23 High	CB402	44.8937	67.1115	1	2.46	2.2	10.483	31.317		1.81	0.18	0.35	4.07	4.44
LD1	202	07:23 High	CB402	44.8937	67.1115	8	0.81	2.77	10.464	31.39	31.48	1.93	0.24	0.50	4.37	4.20
LD1	297	12:50 High	CB505	44.8932	67.1107	1	0.04	1.06	11.784	31.925		0.42	0.08		4.63	2.18
LD1	297	12:50 High	CB505	44.8932	67.1107	10	0.05	1	11.782	31.956	32.1	0.30	0.26		6.15	2.49
LD1	311	11:09 High	CB606	44.8943	67.1112	1	0.21	1.09	10.296	31.839		7.46	0.63	0.66	10.10	1.55
LD1	311	11:09 High	CB606	44.8943	67.1112	13	0.27	1.13	10.267	31.814	31.976	7.14	0.54	0.67	10.10	2.96
LD2	122	14:29 High	CB108	44.8933	67.11	1	0.69	1.77	4.949	30.477		5.56	0.05	0.48	8.18	0.73
LD2	122	14:29 High	CB108	44.8933	67.11	18	0.3	1.36	4.688	30.623	30.825	5.67	0.30	0.49	8.54	0.64
LD2	136	13:30 High	CB208	44.8942	67.1055	1	1.12	1.69	5.377	30.686		5.54	0.03	0.55	6.54	1.76
LD2	136	13:30 High	CB208	44.8942	67.1055	10	0.99	1.54	5.367	30.693	30.887	5.24	-0.01	0.49	6.57	3.03
LD2	193	12:18 High	CB324	44.8937	67.11	1	1.48	2.36	10.337	31.288		2.15	0.10	0.42	3.81	3.54
LD2	193	12:18 High	CB324	44.8937	67.11	17	1.81	2.25	9.732	31.636	31.588	1.69	0.12	0.33	4.05	2.54
LD2	202	07:33 High	CB403	44.8943	67.1098	1	1.86	2.18	10.338	31.344		1.80	0.35	0.48	6.73	2.87
LD2	202	07:33 High	CB403	44.8943	67.1098	21	2.1	2.09	10.261	31.357	31.455	2.19	0.13	0.48	4.72	4.99
LD2	297	13:15 High	CB508	44.8942	67.1097	1	0.24	1.2	11.788	31.939		0.74	0.32	0.48	6.05	2.28
LD2	297	13:15 High	CB508	44.8942	67.1097	20	0.33	1.18	11.769	31.948	32.114	0.95	0.17	0.40	4.45	2.86
LD2	311	11:35 High	CB609	44.8942	67.1092	1	0.86	1.32	10.195	31.8		6.04	0.35	0.54	8.86	1.75
LD2	311	11:35 High	CB609	44.8942	67.1092	22	0.52	1.47	10.311	31.841	31.993	7.02	0.54	0.71	10.66	2.97
LD3	122	14:18 High	CB107	44.8933	67.1067	1	0.25	1.37	4.733	30.585	30.806	5.53	0.14	0.47	8.19	0.95
LD3	122	14:18 High	CB107	44.8933	67.1067	20			4.674	30.594						
LD3	136	13:22 High	CB207	44.8938	67.1073	1	1.09	1.59	5.493	30.605		3.86	0.03	0.40	5.43	1.65
LD3	136	13:22 High	CB207	44.8938	67.1073	20	0.81	1.58	5.402	30.67	30.91	4.77	-0.04	0.42	5.85	1.78
LD3	192	12:24 High	CB325	44.895	67.1082	1	1.21	2.35	10.088	31.403		0.95	0.03	0.19	2.83	1.47
LD3	192	12:24 High	CB325	44.895	67.1082	20	1.34	2.31	10.046	31.407	31.575	1.46	0.12	0.24	3.42	1.41
LD3	202	07:40 High	CB404	44.8945	67.1078	1	1.79	2.16	10.557	31.252		1.84	0.67	0.46	4.23	2.49
LD3	202	07:40 High	CB404	44.8945	67.1078	23	2.06	2	10.265	31.411	31.415	2.05	0.29	0.41	3.97	3.41
LD3	297	13:04 High	CB507	44.896	67.108	1	0.76	1	11.716	31.969		1.33	0.21	0.36	4.36	3.07
LD3	297	13:04 High	CB507	44.896	67.108	25	0.13	1.03	11.736	31.396	32.101	1.18	0.15	0.37	4.26	3.05
LD3	311	11:28 High	CB608	44.8943	67.108	1	0.49	1.26	10.169	31.786		6.99	0.45	0.65	10.52	2.42
LD3	311	11:28 High	CB608	44.8943	67.108	18	0.56	1.33	10.193	31.793	32.03	7.18	0.49	0.69	10.38	1.52
LD4	122	14:10 High	CB108	44.895	67.105	1	0.14	1.1	4.801	30.525		5.50	0.17	0.48	8.69	0.95
LD4	122	14:10 High	CB106	44.895	67.105	10	0.14	1.11	4.739	30.606	30.701	5.28	0.16	0.47	8.17	1.01
LD4	136	13:16 High	CB208	44.8942	67.1102	1	0.9	1.81	5.555	30.568		3.49	0.05	0.32	4.87	3.20
LD4	136	13:16 High	CB206	44.8942	67.1102	17	0.75	1.6	5.416	30.652	30.834	5.37	-0.02	0.52	6.53	3.72
LD4	193	12:50 High	CB326	44.894	67.1058	1	1.88	2.1	10.251	31.252		1.15	0.18	0.21	3.13	2.35
LD4	193	12:50 High	CB328	44.894	67.1058	10	0.78	2.19	10.228	31.38	31.538	0.92	0.10	0.14	2.12	1.40
LD4	202	07:49 High	CB405	44.8945	67.106	1	0.81	2.57	10.636	31.278		1.75	0.28	0.46	4.35	3.66
LD4	202	07:49 High	CB405	44.8945	67.106	9.5	2.22	1.98	10.591	31.264	31.415	1.72	0.32	0.41	4.23	3.64
LD4	297	12:56 High	CB506	44.8938	67.1057	1	0.07	1	11.717	31.987		1.46	0.30	0.39	4.33	2.60
LD4	297	12:56 High	CB506	44.8938	67.1057	10	0.09	0.95	11.729	31.979	32.146	1.26	0.14	0.39	4.20	2.47
LD4	311	11:19 High	CB607	44.8935	67.1063	1	0.42	1.22	10.136	31.761		7.35	0.60	0.70	10.29	5.78
LD4	311	11:19 High	CB607	44.8935	67.1063	15	0.52	1.24	10.148	31.773	31.95	5.13	0.38	0.45	7.42	3.28
LE1	123	13.54 High	CB121	44.865	66.995	1	0.05	1.2	4.952	30.573		5.27	0.23	0.54	7.95	2.79
LE1	123	13.54 High	CB121	44.865	66.995	16	0.12	1.3	4.686	30.674	30.856	5.65	0.10	0.49	7.56	1.75
LE1	124	08:06 Low	CB127	44.865	66.9925	1	0.12	1.37	5.169	30.674		4.08	0.13	0.43	8.36	2.29
LE1	124	08:06 Low	CB127	44.865	66.9925	12	0.09	1.19	4.923	30.707	30.867	4.83	0.15	0.48	7.51	4.40
LE1	138	08:57 Low	CB223	44.865	66.9923	1	0.16	1.13	5.577	30.683		5.32	0.18	0.55	7.52	2.64
LE1	138	08:57 Low	CB223	44.865	66.9923	10	0.36	1.41	5.47	30.75	30.867	4.78	0.10	0.51	5.95	2.75

Locator	Julian Day Date	Local Time (EST)	State of Tide	Station#	Latitude	Longitude	Depth meters	Total Chl (mg m-3)	Fb/Fa	CTD temp (degrees C)	CTD Sal (o/oo)	MicroSal (o/oo)	NO3 (uM)	NO2 (uM)	PO4 (uM)	SiO3 (uM)	NH4 (uM)
LE1	192	15:59	Low	CB313	44.8648	66.9932	1	0.9	2.67	11.172	31.103		0.90	0.04	0.33	3.87	1.49
LE1	192	1559	Low	CB313	44.8648	66.9932	12	1.25	2.24	9.6	31.477	31.489	2.35	0.15	0.37	3.96	2.07
LE1	194	09:37	High	CB338	44.8653	66.992	1	2.17	2.16	10.11	31.414		1.23	0.10	0.25	3.30	2.47
LE1	194	09:37	High	CB338	44.8653	66.992	17	2.33	2	9.894	31.577	31.604	1.79	0.08	0.30	3.76	3.25
LE1	203	12:56	Low	CB429	44.8645	66.9893	1	0.94	1.84	10.883	31.041		1.71	0.31	0.50	4.79	2.41
LE1	203	12:56	Low	CB429	44.8645	66.9893	10	1.16	1.91	10.216	31.671	31.705	2.18	0.24	0.47	5.34	2.28
LE1	204	08:44	High	CB435	44.8648	66.9917	1	2.552	1.93	10.553	31.371		1.60	0.22	0.58	3.79	3.69
LE1	204	08:44	High	CB435	44.8648	66.9917	17	1.75	1.78	10.248	31.46	31.589	2.25	0.16	0.33	4.15	2.49
LE1	298	11:48	High	CB524	44.8643	66.9928	1	0.81	1	11.605	32.123		1.71	0.31	0.50	4.79	2.41
LE1	298	11:48	High	CB524	44.8643	66.9928	18	0.12	1.08	11.603	32.127	32.282	1.73	0.25	0.36	4.30	3.03
LE1	299	07:04	Low	CB530	44.8667	66.9932	1	0.66	1.69	11.599	32.041		1.60	0.22		3.79	3.69
LE1	299	07:04	Low	CB530	44.8667	66.9932	12	0.68	1.49	11.633	31.976	32.228	1.70	0.21	0.31	3.69	1.97
LE1	313	11:11	High	CB633	44.865	66.9922	1	0.05	0.82	10.06	31.745		7.85	0.46	0.76	10.21	2.76
LE1	313	11:11	High	CB633	44.865	66.9922	18	0.07	1	10.027	31.17	31.907	7.63	0.37	0.77	10.10	1.20
LE2	123	14:02	High	CB122	44.87	66.9933	1	0.13	1.38	4.929	30.674		5.60	0.22	0.51	8.19	1.99
LE2	123	14:02	High	CB122	44.87	66.9933	16	0.08	1.42	4.904	30.71	30.889	5.44	0.19	0.52	8.43	1.02
LE2	124	08:12	Low	CB128	44.87	66.9925	1	0.1	1.44	5.02	30.605		4.94	0.54	0.51	7.70	1.23
LE2	124	08:12	Low	CB128	44.87	66.9925	11	0.08	1.13	4.973	30.641	30.927	4.89	0.26	0.50	7.79	1.25
LE2	138	09:10	Low	CB224	44.8715	66.9942	1	0.43	1.46	5.412	30.778		5.97	0.09	0.57	7.13	2.97
LE2	138	09:10	Low	CB224	44.8715	66.9942	12	0.39	1.38	5.408	30.786	30.988	6.06	0.07	0.59	7.06	3.53
LE2	192	16:06	Low	CB314	44.8717	66.9937	1	1.08	2.18	10.143	31.407		1.43	0.04	0.38	3.90	1.89
LE2	192	16:06	Low	CB314	44.8717	66.9937	14	1.57	2.12	10.095	31.411	31.597	1.65	0.05	0.36	4.20	2.16
LE2	194	09:47	High	CB339	44.8732	66.9942	1	1.93	2.1	10.095	31.316		1.44	0.10	0.34	3.86	3.62
LE2	194	09:47	High	CB339	44.8732	66.9942	7	2.78	2	10.035	31.66	31.589	1.32	0.14	0.23	3.06	1.86
LE2	203	13:04	Low	CB430	44.8722	66.9948	1	0.3	1.29	10.585	31.403		1.46	0.23	0.26	3.16	2.23
LE2	203	13:04	Low	CB430	44.8722	66.9948	13	1.45	1.88	10.461	31.57	31.55	1.73	0.25	0.36	4.30	3.03
LE2	204	08:55	High	CB436	44.8718	66.994	1	3.16	1.91	10.542	31.421		2.13	0.17	0.44	4.57	2.35
LE2	204	08:55	High	CB436	44.8718	66.994	14	2.66	2.02	10.55	31.429	31.58	1.70	0.21	0.31	3.69	1.97
LE2	298	11:57	High	CB525	44.8678	66.992	1	0.24	1.1	11.748	32.052		1.46	0.23		3.16	2.23
LE2	298	11:57	High	CB525	44.8678	66.992	18	0.22	1.26	11.725	32.056	32.217	1.18	0.24		2.96	2.40
LE2	299	07:11	Low	CB531	44.8707	66.9937	1	0.85	1.62	11.659	32.027		2.13	0.17	0.44	4.57	2.35
LE2	299	07:11	Low	CB531	44.8707	66.9937	12	0.65	1.55	11.656	32.016	32.203					
LE2	313	11:18	High	CB634	44.8697	66.9927	1	0.94	1	9.96	31.814		7.84	0.57	0.80	10.31	1.92
LE2	313	11:18	High	CB634	44.8697	66.9927	18	0.1	0.96	9.953	31.796	31.943	6.92	0.53	0.70	8.96	1.55
LE3	123	14:13	High	CB123	44.8775	66.9983	1	0.12	1.23	4.903	30.664		5.30	0.23	0.51	7.97	2.12
LE3	123	14:13	High	CB123	44.8775	66.9983	20	0.09	1.43	4.727	30.741	31.109	5.57	0.17	0.49	8.30	1.85
LE3	124	08:24	Low	CB129	44.88	66.9967	1	0.22	1.47	5.095	30.549		4.70	0.32	0.53	7.63	1.04
LE3	124	08:24	Low	CB129	44.88	66.9967	15	0.22	1.36	5.088	30.559	30.801	4.79	0.17	0.51	7.49	0.81
LE3	138	09:21	Low	CB225			1	0.7	1.33				5.24	0.15	0.52	6.96	3.98
LE3	138	09:21	Low	CB225			15	0.48	1.38			30.89	5.73	0.17	0.59	6.98	3.03
LE3	192	16:16	Low	CB315	44.8795	66.997	1	2.08	1.85	10.028	31.401		2.01	0.02	0.34	4.23	1.86
LE3	192	16:16	Low	CB315	44.8795	66.997	10	1.25	2.33	10.033	31.494	31.566	1.84	0.02	0.35	4.21	1.47
LE3	194	10:00	High	CB340	44.8788	66.9963	1	1.37	2.54	9.809	31.443		1.47	0.11	0.22	2.85	3.40
LE3	194	10:00	High	CB340	44.8788	66.9963	13	1.93	2.1	9.77	31.481	31.614	1.65	0.12	0.30	3.50	3.03
LE3	203	13:12	Low	CB431	44.8793	66.997	1	0.14	1.1	10.557	31.378		1.60	0.01	0.42	3.48	1.80
LE3	203	13:12	Low	CB431	44.8793	66.997	15	0.21	1.13	10.519	31.45	31.533	1.18	0.24	0.65	2.96	2.40
LE3	204	09:04	High	CB437	44.8772	66.9982	1	2.6	1.97	10.44	31.437		2.51	0.35	0.50	4.86	2.56
LE3	204	09:04	High	CB437	44.8772	66.9982	21	2.69	1.94	10.435	31.449	31.589	2.15	0.26	0.38	4.18	2.23
LE3	298	12:06	High	CB526	44.8782	66.9965	1	0.15	1.08	11.715	32.052		1.60	0.01		3.48	1.80
LE3	298	12:06	High	CB526	44.8782	66.9965	15	0.13	1.08	11.71	32.054	32.219	1.18	0.11		3.32	1.89
LE3	299	07:17	Low	CB532	44.8778	66.9975	1	0.62	1.51	11.657	32.01		5.78	0.73	0.72	8.28	2.23
LE3	299	07:17	Low	CB532	44.8778	66.9975	12	0.73	1.66	11.655	32.007	32.187	5.63	0.50	0.64	8.83	2.25
LE3	313	11:27	High	CB635	44.8788	66.9975	1	0.1	1	10.002	31.877		7.68	0.33	0.73	9.70	0.95
LE3	313	11:27	High	CB635	44.8788	66.9975	19	0.14	0.97	10.046	31.894	32.033	7.27	0.31	0.68	9.36	1.06
LE4	123	14:21	High	CB124	44.8833	66.9992	1	0.12	1.13	4.985	30.627		5.46	0.18	0.51	7.99	1.69
LE4	123	14:21	High	CB124	44.8833	66.9992	20	0.16	1.52	4.777	30.729	30.928	5.45	0.16	0.51	8.37	0.96
LE4	124	08:34	Low	CB130	44.8833	66.9992	1	0.22	1.4	5.165	30.526		4.74	0.29	0.50	7.55	0.92
LE4	124	08:34	Low	CB130	44.8833	66.9992	12	0.11	1.41	5.144	30.532	30.942	4.75	0.01	0.48	7.55	1.02

Locator	Julian Day Date	Local Time (EST)	State of Tide	Station#	Latitude	Longitude	Depth meters	Total Chl (mg m-3)	Fb/Fa	CTD temp (degrees C)	CTD Sal (o/oo)	MicroSal (o/oo)	NO3 (uM)	NO2 (uM)	PO4 (uM)	SiO3 (uM)	NH4 (uM)
LE4	138	09:30	Low	CB226	44.8832	66.9993	1	0.79	1.34	5.818	30.493		4.67	0.17	0.50	6.02	4.95
LE4	138	09:30	Low	CB226	44.8832	66.9993	15	0.97	1.44	5.694	30.589	30.815	4.72	0.11	0.52	6.14	2.85
LE4	192	16:24	Low	CB316	44.8825	66.9985	1	1.8	1.94	10.42	31.374		1.29	0.09	0.32	3.78	1.90
LE4	192	16:24	Low	CB316	44.8825	66.9985	12	1.34	1.85	10.4	31.401	31.607	1.39	-0.02	0.35	3.70	1.58
LE4	194	10:17	High	CB341	44.8827	66.999	1	1.48	1.83	9.95	31.424		1.40	0.02	0.24	2.76	4.22
LE4	194	10:17	High	CB341	44.8827	66.999	15.5	0.94	2	9.952	31.428	31.606	1.50	0.16	0.19	2.67	3.33
LE4	203	13:18	Low	CB432	44.8825	66.9992	1	0.24	1.16	10.798	31.332		1.17	0.10	0.53	3.38	2.18
LE4	203	13:18	Low	CB432	44.8825	66.9992	18	0.32	1.16	10.809	31.378	31.533	1.18	0.11	0.49	3.32	1.89
LE4	204	09:13	High	CB438	44.8818	66.9995	1	3.09	1.97	10.538	31.414		1.11	0.19		4.14	4.46
LE4	204	09:13	High	CB438	44.8818	66.9995	9	2.51	1.96	10.385	31.485	31.596	1.04	0.22		3.76	4.68
LE4	298	12:16	High	CB527	44.8823	66.9992	1	0.1	1.07	11.695	32.061		1.17	0.10		3.38	2.18
LE4	298	12:16	High	CB527	44.8823	66.9992	18	0.13	1.11	11.681	32.068	32.265	1.54	0.10	0.46	4.29	2.71
LE4	299	07:24	Low	CB533	44.8823	66.9988	1	0.69	1.5	11.669	31.99		5.90	0.60	0.68	7.88	2.19
LE4	299	07:24	Low	CB533	44.8823	66.9988	12	0.71	1.44	11.671	31.985	32.158	5.98	0.58	0.64	8.14	2.22
LE4	313	11:35	High	CB636	44.8823	66.9987	1	0.16	1.06	10.036	31.86		7.41	0.27	0.76	9.50	0.87
LE4	313	11:35	High	CB636	44.8823	66.9987	15	0.16	1.04	10.051	31.83	32.014	7.84	0.38	0.82	10.00	1.34
LE5	123	14:28	High	CB125	44.8867	66.9975	1	0.09	1.18	4.53	30.897		5.87	0.18	0.46	8.08	1.21
LE5	123	14:28	High	CB125	44.8867	66.9975	30	0.13	1.17	4.14	31.158	31.369	6.89	0.12	0.60	8.78	0.87
LE5	124	08:43	Low	CB131	44.8867	66.9983	1	0.34	1.6	5.226	30.454		4.83	0.05	0.57	8.42	1.05
LE5	124	08:43	Low	CB131	44.8867	66.9983	30	0.35	1.61	5.509	30.575	30.924	4.71	0.01	0.49	7.40	0.80
LE5	138	09:06	Low	CB227	44.8868	66.9982	1	0.85	1.7	5.569	30.677		5.23	0.09	0.64	8.46	2.97
LE5	138	09:06	Low	CB227	44.8868	66.9982	25	0.97	1.6	5.506	30.718	30.844	4.72	0.14	0.53	8.28	3.43
LE5	192	16:34	Low	CB317	44.8875	66.998	1	1.34	1.85	10.934	31.328		0.97	0.04	0.31	3.56	1.67
LE5	192	16:34	Low	CB317	44.8875	66.998	29	1.45	1.69	10.803	31.333	31.529	1.21	0.04	0.36	3.64	2.32
LE5	194	10:27	High	CB342	44.887	66.9987	1	1.78	2.05	8.985	31.531		3.10	0.10	0.29	3.51	1.62
LE5	194	10:27	High	CB342	44.887	66.9987	30	1.25	2.15	9.036	31.553	31.675	2.95	0.09	0.31	3.30	2.09
LE5	203	13:25	Low	CB433	44.8872	66.9955	1	0.62	1.53	10.793	31.287		0.93	0.16	0.44	3.47	1.80
LE5	203	13:25	Low	CB433	44.8872	66.9955	31	1.21	1.67	10.915	31.308	31.453	1.54	0.10	0.46	4.29	2.71
LE5	204	09:25	High	CB439	44.8867	66.9968	1	2.31	1.98	10.254	31.45		1.81	0.18		4.07	4.44
LE5	204	09:25	High	CB439	44.8867	66.9968	35	1.95	1.96	9.542	31.672	31.716	1.93	0.24	0.50	4.37	4.20
LE5	298	12:23	High	CB528	44.8862	67.0006	1	0.14	1.09	11.589	32.129		0.93	0.16		3.47	1.80
LE5	298	12:23	High	CB528	44.8862	67.0006	30	0.13	1.12	11.59	32.128	32.282	1.09	0.09		3.31	1.76
LE5	299	07:30	Low	CB534	44.8883	66.9978	1	0.79	1.54	11.669	31.978		6.19	0.91	0.68	8.07	2.93
LE5	299	07:30	Low	CB534	44.8883	66.9978	28	0.81	1.29	11.67	31.974	32.149	6.35	0.63	0.69	7.92	1.93
LE5	313	11:43	High	CB637	44.8867	66.9975	1	0.24	1.44	10.388	32.157		7.90	0.26	0.76	9.01	1.24
LE5	313	11:43	High	CB637	44.8867	66.9975	33	0.27	1.32	10.387	32.149	32.296	7.94	0.33	0.77	9.10	0.60
LE6	123	14:50	High	CB126	44.89	66.9967	1	0.27	1.49	4.729	30.744		5.62	0.16	0.54	8.18	1.20
LE6	123	14:50	High	CB126	44.89	66.9967	20	0.11	1.41	4.158	31.146	31.362	6.91	0.16	0.60	8.64	1.14
LE6	124	09:00	Low	CB132	44.8917	66.9967	1	0.87	1.9	5.278	30.453		4.76	0.11	0.49	7.43	0.91
LE6	124	09:00	Low	CB132	44.8917	66.9967	15	0.31	1.59	5.226	30.49	30.706	4.65	0.15	0.51	7.28	0.96
LE6	138	09:43	Low	CB228	44.8912	66.998	1	1.06	1.52	5.703	30.574		4.49	0.06	0.54	5.93	3.34
LE6	138	09:43	Low	CB228	44.8912	66.998	15	0.86	1.49	5.684	30.585	30.711	4.36	0.10	0.49	5.87	4.15
LE6	192	16:41	Low	CB318	44.8908	66.998	1	1.25	1.82	10.715	31.352		0.89	0.06	0.27	3.58	1.59
LE6	192	16:41	Low	CB318	44.8908	66.998	18	1.12	1.63	10.557	31.366	31.514	1.08	0.02	0.33	3.69	1.71
LE6	194	10:44	High	CB343	44.8915	66.9975	1	2.06	1.96	9.978	31.36			0.09	0.32	3.61	1.90
LE6	194	10:44	High	CB343	44.8915	66.9975	27	1.99	2.23	9.435	31.627	31.633	2.50	0.09	0.29	3.72	1.80
LE6	203	13:30	Low	CB434	44.8912	66.9947	1	1.68	1.37	10.839	31.34		0.99	0.11	0.63	3.14	1.63
LE6	203	13:30	Low	CB434	44.8912	66.9947	15	1.88	1.74	10.825	31.36	31.486	1.09	0.09	0.42	3.31	1.76
LE6	204	09:44	High	CB440	44.8915	66.9947	1	1.96	1.87	9.955	31.613		1.80	0.35	0.48	6.73	2.87
LE6	204	09:44	High	CB440	44.8915	66.9947	13	1.21	1.96	9.232	31.732	31.873	2.19	0.13	0.48	4.72	4.99
LE6	298	12:33	High	CB529	44.8907	66.9975	1	0.42	1.31	11.745	32.04		0.99	0.11		3.14	1.63
LE6	298	12:33	High	CB529	44.8907	66.9975	25	0.23	1.13	11.624	32.105	32.265	2.25	0.16	0.33	4.15	2.49
LE6	299	07:35	Low	CB535	44.8913	66.9977	1	1.01	1.05	11.641	32.008		6.25	0.57	0.72	8.22	2.40
LE6	299	07:35	Low	CB535	44.8913	66.9977	18	0.9	1.51	11.663	31.996	32.162	6.31	0.63	0.73	8.07	2.57
LE6	313	11:51	High	CB638	44.8912	66.9975	1	0.34	1.25	10.243	31.965		6.45	0.26	0.61	8.35	0.83
LE6	313	11:51	High	CB638	44.8912	66.9975	28	0.38	1.56	10.39	32.155	32.292	7.55	0.35	0.63	8.49	0.61
LI	123	11:46		CB118	44.8525	67.0417	1	0.26	1.45	6.001	30.101		1.92	0.12	0.35	6.19	1.39
LI	123	11:46		CB118	44.8525	67.0417	4	0.38	1.67	5.757	30.344	30.519	2.58	0.04	0.37	6.49	1.36

Locator	Julian Day Date	Local Time (EST) State of Tide	Station#	Latitude	Longitude	Depth meters	Total Chl (mg m-3)	Fb/Fa	CTD temp (degrees C)	CTD Sal (o/oo)	MicroSal (o/oo)	NO3 (uM)	NO2 (uM)	PO4 (uM)	SiO3 (uM)	NH4 (uM)
LI	137	10:23	CB219	44.852	67.0427	1	0.32	1.31	8.656	30.236		2.65	0.04	0.38	5.23	2.09
LI	137	10:23	CB219	44.852	67.0427	4	0.71	1.43	8.536	30.339	30.452	2.78	0.04	0.44	5.15	2.09
LI	192	13:51	CB310	44.851	67.0425	1	1.52	1.79	13.138	31.279		0.22	0.08	0.23	2.87	1.81
LI	192	13:51	CB310	44.851	67.0425	4	1.66	2	13.172	31.3	31.518	0.58	0.13	0.28	3.09	1.38
LI	202	11:50	CB410	44.853	67.043	1	2.04	1.9	12.659	30.939		0.36	0.00	0.39	4.53	3.86
LI	202	11:50	CB410	44.853	67.043	2.5	1.39	2.07	12.657	30.995	31.087	1.17	0.26	0.25	4.44	
LI	298	10:30	CB522	44.8505	67.0423	1	0.11	1.04	12.009	31.836		0.29	0.20		4.28	1.52
LI	298	10:30	CB522	44.8505	67.0423	4	0.11	1	12.018	31.834	31.996	0.86	0.31		4.57	1.51
LI	312	13:00	CB620	44.8508	67.042	1	0.71	1.28	9.797	30.987		5.61	0.46	0.51	10.88	2.83
LI	312	13:00	CB620	44.8508	67.042	6	0.85	1.34	9.771	31.268	31.413	6.42	0.50	0.60	11.33	6.19
MI	124	11:18	CB137	44.9133	67.03	1	0.14	1.41	5.255	30.532		4.16	0.06	0.40	7.13	1.08
MI	124	11:18	CB137	44.9133	67.03	5	0.14	1.45	5.254	30.542	30.731	4.04	0.09	0.41	6.67	1.29
MI	138	11:06	CB232	44.914	67.0292	1	0.18	1.13	5.85	30.513		4.34	0.12	0.49	5.76	2.33
MI	138	11:06	CB232	44.914	67.0292	4	0.24	1.21	5.805	30.544	30.718	4.60	0.23	0.52	6.39	2.57
MI	192	09:45	CB301	44.9137	67.0285	1	0.85	1.9	9.911	31.323		2.40	0.17	0.43	4.04	3.90
MI	192	09:45	CB301	44.9137	67.0285	10	0.43	1.48	9.806	31.409	31.529	4.80	0.17	0.42	4.09	5.07
MI	203	09:22	CB423	44.914	67.0293	1	0.58	1.48	10.622	31.394		1.63	0.15	0.47	4.55	2.97
MI	203	09:22	CB423	44.914	67.0293	9	0.85	1.7	10.457	31.445	31.527	1.42	0.25	0.43	3.64	2.34
MI	299	09:50	CB540	44.9138	67.0295	1	0.11	0.98	11.658	32		6.47	0.67	0.74	8.10	2.30
MI	299	09:50	CB540	44.9138	67.0295	5	0.18	1.04	11.657	31.972	32.162	6.36	0.53	0.64	8.61	1.88
MI	313	08:55	CB628	44.9143	67.0288	1	0.2	1.04	9.77	31.534		7.91	0.42	0.83	11.02	1.61
MI	313	08:55	CB628	44.9143	67.0288	6	0.21	1.1	9.883	31.583	31.827	7.80	0.38	0.81	10.69	1.34
MSB	123	12:17	CB119	44.8775	67.065	1	0.14	1.39	5.612	30.261		4.16	0.09	0.41	7.56	1.43
MSB	123	12:17	CB119	44.8775	67.065	10	0.42	1.65	5.063	30.563	30.771	4.74	0.05	0.49	8.50	1.04
MSB	137	10:48	CB220	44.8765	67.0653	1	0.05	1.11	6.04	30.349		4.13	0.09	0.52	7.06	2.13
MSB	137	10:48	CB220	44.8765	67.0653	8	0.07	1.07	8.038	30.408	30.54	4.19	0.08	0.48	5.88	1.94
MSB	192	14:16	CB311	44.875	67.0607	1	1.25	2	12.253	31.324		0.26	0.09	0.27	3.10	1.59
MSB	192	14:16	CB311	44.875	67.0607	6	1.61	2.25	11.12	31.394	31.47	0.45	0.17	0.27	2.97	1.37
MSB	203	11:33	CB427	44.8782	67.0627	1	1.37	1.92	11.241	31.277		0.29	0.20	0.20	4.28	1.52
MSB	203	11:33	CB427	44.8782	67.0627	7	1.44	1.95	11.02	31.428	31.415	0.92	0.18	0.39	4.51	1.62
MSB	298	10:00	CB521	44.874	67.0552	1	0.26	1.15	11.838	31.937		0.14	0.19		3.89	1.44
MSB	298	10:00	CB521	44.874	67.0552	7	0.28	1.06	11.838	31.936	32.112	0.92	0.18	0.39	4.51	1.62
MSB	312	12:15	CB619	44.8747	67.0568	1	0.34	1.06	9.879	31.431		5.86	0.47	0.54	9.80	2.36
MSB	312	12:15	CB619	44.8747	67.0568	9	0.4	1.05	9.909	31.442	31.593	6.01	0.37	0.57	10.24	1.84
PR	123	08:55	CB114	44.93	67.1433	1	0.21	1.42	6.528	29.504		1.70	0.12	0.22	11.09	0.78
PR	123	08:55	CB114	44.93	67.1433	4	0.51	1.69	5.914	29.98	30.011	1.94	0.20	0.32	7.29	0.71
PR	137	08:53	CB218	44.928	67.143	1	0.44	1.45	6.831	29.894		1.99	0.11	0.39	7.37	4.32
PR	137	08:53	CB218	44.928	67.143	5	0.47	1.35	6.71	30.128	30.086	2.60	-0.05	0.43	5.08	3.11
PR	193	13:33	CB328	44.9293	67.1462	1	1.84	2.16	13.608	31.087		0.20	-0.03	0.10	2.65	1.06
PR	193	13:33	CB328	44.9293	67.1462	6	1.88	2	11.896	31.345	31.491	0.24	0.06	0.13	2.45	1.32
PR	202	12:37	CB411	44.93	67.1462	1	1.93	1.95	12.663	30.809		0.30	0.26	0.26	6.15	2.49
PR	202	12:37	CB411	44.93	67.1462	2.5	1.68	2.03	12.588	30.864	31.079	0.42	0.08	0.29	4.63	2.18
PR	203	10:13	CB424	44.9298	67.146	1	0.81	1.7	14.568	31.396		0.14	0.25	0.23	6.01	2.10
PR	203	10:13	CB424	44.9298	67.146	5	0.89	1.53	12.006	31.221	31.191	0.15	0.28	0.21	4.35	1.98
PR	298	08:00	CB517	44.9292	67.1445	1	2.19	1.81	12.16	31.635		0.58	0.38		3.68	2.91
PR	298	08:00	CB517	44.9292	67.1445	4	1.44	1.73	12.133	31.722	31.812	1.42	0.25		3.64	2.34
PR	311	13:00	CB611	44.9292	67.1453	1	0.91	1.62	9.34	30.945		8.00	0.92	0.73	13.84	4.22
PR	311	13:00	CB611	44.9292	67.1453	7	0.89	1.63	9.478	31.147	31.363	6.65	0.70	0.71	12.63	6.73
SC	122	13:20	CB104	44.8975	67.1217	1	0.08	1	5.464	30.011		4.22	0.39	0.50	8.12	1.14
SC	122	13:20	CB104	44.8975	67.1217	8	0.24	1.23	5.392	30.119	30.379	3.94	0.45	0.52	7.59	1.18
SC	136	14:13	CB209	44.8977	67.1212	1	1.13	1.65	6.144	30.275		3.79	0.00	0.43	5.89	3.32
SC	136	14:13	CB209	44.8977	67.1212	6	1.29	1.66	6.05	30.345	30.482	3.78	0.04	0.45	5.66	2.03
SC	193	11:52	CB322	44.8983	67.1213	1	2.37	2.08	11.243	31.167		0.65	0.15	0.29	3.33	1.61
SC	193	11:52	CB322	44.8983	67.1213	7	2.91	2.1	10.908	31.449	31.489	1.26	0.21	0.31	3.60	1.85
SC	202	07:11	CB401	44.8982	67.1213	1	2.6	1.93	11.193	31.094		0.84	0.21	0.37	3.87	3.06
SC	202	07:11	CB401	44.8982	67.1213	6.5	2.53	2.05	11.079	31.149	31.317	1.04	0.22	0.40	3.76	4.68
SC	297	13:40	CB509	44.8983	67.1212	1	0.44	1.48	11.95	31.881		1.14	0.26	0.49	4.45	4.17
SC	297	13:40	CB509	44.8983	67.1212	4	0.54	1.33	11.796	31.988	32.086	1.02	0.11		4.35	

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SC	311	10:45	CB605	44.8977	67.1217	1	0.52	1.35	9 876	31.55		7.08	0.39	0 70	11.14	3.88
SC	311	10:45	CB605	44.8977	67.1217	8	0 63	1.34	9.886	31.556	31.725	7.11	0.54	0 72	11.33	3.24
WB	122	11:35	CB102	44.8233	67.15	1	0.12	1.04	6.51	27.857	27.305	3.50	0.24	0 33	16.95	1.50
WB	122	11:35	CB102	44.8233	67.15	5	0.16	1.06	5.941	28.901	29.192	3.74	0.04	0.32	8.68	0.98
WB	136	11:09	CB202	44.8233	67.1493	1	0.94	1.75	7.553	28.429		2.04	0.10	0.14	4 95	3.80
WB	136	11:09	CB202	44.8233	67.1493	5	0.86	1.56	7.118	29.204	29.069	1.78	0.07	0.23	3.97	2.99
WB	193	10:37	CB320	44.822	67.15	1	2.33	2	13.171	30.965		0.26	0.12	0.25	2.95	1.36
WB	193	10:37	CB320	44.822	67.15	4	2.58	2.17	12.578	31.221	31.366	0.50	-0.02	0.25	2.78	1.45
WB	202	09:29	CB408	44.8213	67.151	1	3.05	2.06	12.739	30.168		0.23	0.08	0.18	5.12	1.64
WB	202	09:29	CB408	44.8213	67.151	4.5	3.09	2.16	12 626	30.358	30.388	0.43	0.15	0.30	4.64	1.28
WB	297	11:00	CB502	44.822	67.1518	1	0.87	1.55	11.948	31.187	31.298	0.57	0.12		4.77	1.21
WB	297	11:00	CB502	44.822	67.1518	4	0.94	1.49	11.935	31.486	31.54	0.23	0.08		5.12	1.64
WB	311	09:00	CB602	44.822	67.1505	1	0.89	1.57	8.75	29.245	28.876	6.68	0.55	0.60	17.28	4.88
WB	311	09:00	CB602	44.822	67.1505	5	1.03	1.68	8 956	29.928	29.83	6.14	0.45	0.59	14.85	6.53
WPB	123	09:34	CB115	44.915	67.1133	1	0.3	1.49	5.811	29.987		2.68	0.28	0.42	7.65	1.85
WPB	123	09:34	CB115	44.915	67.1133	4	0.48	1.77	5.604	30.145	30.274	3.11	0.27	0.32	8.79	0.64
WPB	193	14:00	CB329	44.9993	67.1132	1	2.64	2.23	12.219	31.188		0.35	0.03	0.13	2.49	2.62
WPB	193	14:00	CB329	44.9993	67.1132	10	2.87	2.13	11.322	31.34	31.46	0.39	0.01	0.12	2.67	1.22
WSB	137	09:47	CB218	44.8937	67.0865	1	0.28	1.08	6.12	30.228		3.95	0.20	0.49	5.78	2.24
WSB	137	09:47	CB218	44.8937	67.0865	10	0.34	1.14	6.017	30.33	30.498	4.24	0.12	0.50	5.92	2.56
WSB	203	11:50	CB428	44.8923	67.0578	1	1.42	1.93	11.444	31.215		0.22	0.16	0.36	4.40	1.50
WSB	203	11:50	CB428	44.8923	67.0578	8	1.61	1.76	10.888	31.402	31.43	0.86	0.31	0.34	4.57	1.51
WSB	298	09:40	CB520	44.888	67.0775	1	0.58	1.54	11.879	31.884		0.25	0.26	0.36	4.28	1.78
WSB	298	09:40	CB520	44.888	67.0775	10	0.56	1.4	11.866	31.898	32.053				3.63	1.50
WSB	312	12:00	CB618	44.888	67.0812	1	0.22	1.04	10.032	31.579		6.75	0.54	0.66	10.28	2.31
WSB	312	12:00	CB618	44.688	67.0812	13	0.24	1	10.314	31.819	31.963	7.37	0.35	0.70	10.61	0.82

Use of Remote Sensing to Map and Measure Marine Intertidal Habitats in Support of Ecosystem Modeling Efforts - Cobscook Bay, Maine

by

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INTRODUCTION

In 1994, an interdisciplinary, multi-institutional team of marine scientists was awarded a competitive grant from The Nature Conservancy and the Andrew W. Mellon Foundation to investigate the ecosystem dynamics of Cobscook Bay, Maine. Cobscook Bay is a hydrographically and geologically complex estuary where very high levels of biodiversity and productivity co-exist. Human impact is largely limited to living resource harvesting. Cobscook Bay is at once unique and representative. It is the ideal focus for ecosystem research directed at understanding our vital and valuable boreal estuaries and embayments.

The overall goals of this research effort were: to identify the forcing functions that initially produced, and now maintain, this unusual co-occurrence of diversity and productivity; to quantify the pathways and rates of movement of energy and materials through the system; and to define the limits or carrying capacity of the various system components. The overarching goal was to provide a sound and accessible information base to insure the continued integrity of the system. Emphasis in this two-year investigation was on primary productivity and factors regulating it.

In Cobscook Bay, as in most macrotidal estuaries, the intertidal/nearshore region is a very significant component of the system. The resident ulvoid and fucoid beds, kelp forests and eelgrass meadows contribute substantially to the primary productivity budget of the bay. The productivity contribution is temporally distinct from the spring phytoplankton bloom and, hence, is important in smoothing the carbon input curve. In many macrotidal embayments, including Cobscook Bay (Phinney and Yentsch, this volume), the productivity of the benthic diatoms of mud and sand flats exceeds that of the phytoplankton. The intertidal region provides habitat for ecologically, commercially and recreationally important invertebrates, fishes, marine mammals and birds. It is a feeding ground for several species of fish, being especially important to certain age classes (Tyler, 1971). The intertidal is a major interface between the terrestrial and marine environment. Human activity is concentrated at the shore and the intertidal is a conduit of materials from the land to the sea. The intertidal and its resident flora and fauna are uniquely vulnerable to oil spills.

Meaningful ecosystem modeling begins with knowledge of: 1) the identity of the principal system components; and 2) their distribution in space and time. Such knowledge is not always easily attainable. In fact, in the coastal zone, with multiple sources of primary production, complex geology and steep environmental gradients, gaining sufficiently rigorous information on the contributions of ecosystem components can be time-consuming and costly. Only a decade or two ago, attempting to characterize a region on the scale of Cobscook Bay at a resolution adequate to contribute to an ecosystem model would have consumed most of the program budget. Realizing that we would have to accept compromises, we endeavored to devise a method to produce area measurements of significant habitat types that was optimally comprehensive, synoptic, objective, repeatable and affordable.

In this report we describe our efforts to use, singly and in combination, two types of remotely derived images of very different spatial resolution. These are aerial photographs and Landsat Thematic Mapper (TM) data.

THE SETTING

Cobscook Bay, located in extreme eastern Maine, is characterized by a narrow opening to the sea and a very convoluted shoreline (Fig. 1). High tide surface area is approximately 104 km^2 with 325 linear kilometers of shoreline. The bay has an average depth of 8 m and at the deepest point is 30 m. Sunlight can reach the bottom everywhere in the bay. Freshwater input from the modest 1,000 km^2 watershed is small. Turbidity is low. Salinities are generally marine (>30 o/oo) throughout the bay except at the heads of the very inner arms. The climate is continental with moderation from the proximate Gulf of Maine.

One of the outstanding features of Cobscook Bay is the large tidal range. The mean tide at Eastport is 5.7 meters. The geometry of the bay enhances the tidal wave toward the inner bay and causes a phase delay of over one hour. Extreme spring tides are 7.6 meters at Eastport. This large tidal range is the result of the near resonance of the semidiurnal tide of the North Atlantic Ocean with the Gulf of Maine/Bay of Fundy basin (Garrett, 1972). The dominant astronomical constituent controlling the tidal range in this region is the phase of the moon (Trites and Garrett, 1983). This means that the most extreme low tides occur in the early morning and late afternoon.

The interaction of the large tidal range with the structural geology of Cobscook Bay results in a very large intertidal zone. Indeed, approximately one-third of the area of bay is exposed to the atmosphere at low tide and another significant portion remains covered by only very shallow water. In many places the intertidal zone is a kilometer or more in width. These characteristics suggest that the important ecological habitats of Cobscook Bay could reasonably be mapped and measured using remote sensing techniques.

More information on the Cobscook Bay region is contained in the recent bibliography of Larsen and Webb (1996).

METHODS

Image Acquisition

A true color aerial photography survey of Cobscook Bay was flown during the morning spring tide of August 22, 1993. Film type was Aerochrome MS 2448. Photography took place between 0808 and 0911 hours. Low tide, 1.8 feet below MLW, occurred at 0901 at Eastport. The resulting scale of the photographs was 1:12000.

Two Landsat Thematic Mapper (TM) images were obtained for the purpose of mapping the habitats of Cobscook Bay. Images in this region are captured at 0942 local sun time. The first image was acquired on June 25, 1991. On that date in Eastport, a neap high tide occurred at 0936 indicating that water levels in the bay were at or approaching high tide when the image was acquired. The second image was acquired on October 20, 1993. A mean low tide occurred at Eastport at 0812 that day. The tide in the inner bay would have been precisely low at the time of image acquisition.

Image Processing

The density of data represented in the aerial photographs precluded the processing of the entire set. Two subsets, representing a total of 38 photograghs, were selected for processing. These photographs were digitally scanned as raster data (data organized in a grid by columns and rows). They were then georegistered (matched to roads and other landmarks of known location) and rectified (rotating and/or scaling the images to match real world coordinates). All 38 images were then mosaicked, i.e. the overlapping data of less quality were eliminated so that the individual images fit together to produce a single image of each of the two study areas. Ideally, the habitat classification process would work with these large (630MB) mosiacked images; but unfortunately, computer limitations dictated that we work with single or partial scenes. Using a grid system, the mosiacked images were divided into smaller files of approximately 32 megabytes to allow for easier image identification and manipulation. The resulting images had a very high spatial resolution, pixel size less than a square meter, but low spectral resolution, i.e. the three visible light bands.

By contrast, the synoptic Landsat TM data had a much lower spatial resolution, pixels of thirty meters on a side, but a higher spectral resolution. The seven spectral bands of Landsat TM are: three visible, one near-infrared, two mid-infrared, and one thermal (Table 1).

Table 1. Landsat Thematic Mapper Sensitivity of Electromagnetic Radiation Bands (Erickson and Campbell, 1997).

Band	Description	Spectral Location	Application
1	Blue	Visible	coastal water, differentiating soil & vegetation, forest mapping, cultural features
2	Green	Visible	healthy vegetation, cultural features
3	Red	Visible	plant species, soil & geological boundaries, cultural features
4	Near IR	Infrared	vegetation biomass, crop identification, soil/crop & land/water contrasts
5	Middle IR	Infrared	plant water, plant health, discriminate between ice, snow, & clouds
6	Thermal IR	Infrared	vegetation stress, heat, insecticide applications, thermal pollution, geothermal activity
7	Middle IR	Infrared	geological formations, soil boundaries, soil moisture content

Using ERDAS Imagine image analysis software, the images were masked to exclude land areas. This was done to focus the analyses on the areas of interest, i.e. the intertidal and shallow subtidal environments. The images were classified using the ISODATA algorithm, which clusters pixels according to minimum spectral distance. This unsupervised training sorts the image pixel by pixel, groups the pixels together by similar spectral characteristics, and then sorts the pixels into recognizable categories. A spectral set is then calculated using the statistical parameters (e.g., mean and covariance matrix) of the pixels that are in the training sample. This signature set is used to assign each pixel to a class. Pixels that do not fall within a cluster are assigned to the cluster that is closest to its spectral value. The images were variously classified using ten, 15 and 20 classes and the classifications that gave the most sensible environmental resolution were chosen for further processing. A color palette was created which gave the best all-around visual definition and was applied to all the images.

Once the unsupervised classified images were created, statistical reports and spectral signature graphs for each of the classes were generated. The graphs from the statistics report charted brightness values reflected by a substance against each of the bands in the images. By comparing these graphs to reference data and field observations (see below), conclusions were drawn about the environmental characteristics. Based on these conclusions, selected images were edited to remove repetitious or clinal classes.

Reference Data

In addition to the field data, nautical charts and topographic maps, two significant sets of reference data were available to us for use in planning and image intepretation. The first is the previously described complete set of true color aerial photographs taken at low tide on August 22, 1993 at a scale of 1:12,000.

Also used was a set of maps, the Coastal Maine Geological Environments (CMGE), available in paper and digital formats (Maine Geological Survey, 1976). These 109 maps, produced in the early 1970's by aerial photo interpretation, detail the locations and shapes of 55 defined geological environments found on the coast of Maine. Although widely used for a variety of purposes, specifics on the methodology of their production or accuracy are not documented. Details of the catagories used were published with paper maps and further described in a 1983 publication of the Maine State Planning Office.

Field Data

Two subregions of the bay known to contain a broad range of habitat types and reasonable road access were chosen for the collection of field data. These sites were surveyed during the spring tides of September 1997. The areas were: 1) in the eastern bay, the shore between Broad Cove and the head of Halfmoon Cove (Bar Harbor); and 2) in the western bay, Dennys Bay from Mahar Point around to Hallowell Island (Fig. 1). Based on review of aerial photographs and classified satellite images, emphasis was placed on Broad Cove, Carryingplace Cove, the entrance to Halfmoon Cove, around Carlow Island, near Quoddy Village and the Pleasant Point

Indian Reservation, inside Dram Island, Young's Cove, the Hardscabble River, around Hinckley Point and near Hallowell Island.

The principal method of documenting field observations was the annotation of the 1993 aerial photography. Photographs were overlaid with acetate transparencies and environmental features of sufficient size and character to be distinguished by the satellite were outlined and described using an indelible pen. In some cases, the same procedure was followed using a printout of the preliminary classification of the images. Additionally, 35 mm slides were taken at all sites visited in an effort to capture both the habitats and the surrounding features that could aid in identifying the polygons defined in the classified images.

RESULTS

Aerial Photography

The Dennys Bay subimage was selected for experimentation to determine the most suitable computer classification techniques. Two examples of early classification attempts of the Hardscrabble River portion of Dennys Bay are enclosed. The unclassified digital image is presented in Fig. 2 for comparson. For classification purposes a mask is applied to land areas to exclude them from the classification. In the first classification, ten classes are defined which give an enhanced definition to the visible habitats in the aerial photos (Fig. 3). Running the classification again using 15 unsupervised classes produces an image with even sharper habitat definition (Fig. 4).

When the classified aerial image of the Denny's River area is compared to the reference data, it is clear that the unsupervised classification pulls out meaningful information that could not be reasonably documented or quantified by visual examination of the field data or aerial photographs. Even using a small number of classes, the 0.60 pixel size creates a very complex mosiac which reflects the small scale habitat diversity extant in much of Cobscook Bay.

Whereas photograph classifications define the intertidal habitats with a great deal of precision, problems occur across photographic boundaries. The photographs are taken along transects with a slight time lag between each photo and a larger time lag between adjacent transects. Each photo is then a discrete image and in each one the sun angle, which influences brightness and reflected light, is unique. The result is that the same habitat may be classified differently in adjacent digitized photos. This phenomenon is clearly visible as a linear discontinuity at the seams in the mosiac (Fig. 5). Corrections can be applied to the data set by applying radiometric filters or by color matching the data between photos. The former process is technologically advanced and some techniques must be applied during data collection. Such a process was not required for the original purposes of the photographic survey. Color matching of such a detailed data set is a very time-consuming process. The information gain for the project, i.e. detailed information on a limited area, would not justify the costs and would exceed the resources available. Hence, we reluctantly decided to redirect our efforts.

Satellite Imagery

The classified 1991 high tide Landsat Thematic Mapper image is presented in Figure 6. This image is most noteworthy in its depiction of the water surface. In particular, it seems to indicate two counterrotating eddies in South Bay and East Bay presumably caused by the incoming tidal wave encounting the restriction of the narrows between Denbow and Leighton Points.

Major attention was given to the 1993 low tide Landsat image which was well suited for defining and measuring intertidal habitats. Using the unsupervised procedure, the image was classified using 10, 15 and 20 unsupervised classes. The 20-class image gave an intuitively satisfying initial product that was sufficiently detailed without being mottled (Fig. 7). Comparing the high tide and low tide images demonstrates the large intertidal area and the apparent suitability of Landsat imagery for investigations of macrotidal systems (Fig. 8).

Examination of the reference and field data allowed us to identify the make-up of the classes and, in some cases, to combine classes. Classes 1, 2, 3 and 4 proved to be deep water classes. These classes were recoded to class 1 and named Deep Water. Class 5 represented areas of turbid water. Reference to nautical charts showed that parts of Class 5 consisted of turbidity plumes over relatively deep water. These pixel were recoded to the Deep Water class. The larger part of Class 5 appeared to represent shallow water containing tidally resuspended bottom sediments. This phenomenon continued into progressively shallower water represented by Classes 6 and 7. Actual depths were not quantified, but it is estimated that the depth gradient encompassed by these three unsupervised shallow water classes range from less than two meters to a few centimeters. Classes 5 and 6 were combined and named Shallow Water. Interestingly, the numerous salmon aquaculture pens in Cobscook Bay also were assigned to this class by the computer. Class 7 was always the most shoreward class and, in the field, shorebirds

Table 2. Numbers of pixels and areas resulting from a 20-class unsupervised classification of the 1993 Landsat image.

# of Pixels	Class #	Acres	Hectares
14757	Class 1	3281.88	1328.13
29355	Class 2	6528.41	2641.95
20961	Class 3	4661.62	1886.49
7009	Class 4	1558.77	630.81
2342	Class 5	520.85	210.78
3481	Class 6	774.16	313.29
2993	Class 7	665.63	269.37
2366	Class 8	526.19	212.94
3024	Class 9	672.52	272.16
4843	Class 10	1077.06	435.87
5300	Class 11	1178.69	477.00
3869	Class 12	860.45	348.21
6120	Class 13	1361.06	550.80
3174	Class 14	705.88	285.66
7007	Class 15	1558.32	630.63
12796	Class 16	2845.77	1151.64
4059	Class 17	902.70	365.31
9868	Class 18	2194.59	888.12
6517	Class 19	1449.35	586.53
7493	Class 20	1666.41	674.37

were frequently observed wading and feeding in it. It represents the most shallow lense of water over the flats and was named Very Shallow Water.

The initial Class 10 represented areas of dense green algae, predominantly of the genus *Enteromorpha*. Classes 9 and 11 contained a mixture of green and brown algae of low to moderate density. The separation into classes is probably related to the relative proportions of the two algal types and the exposed sediments. Classes 9 and 11 were combined and named Algal Flat. Class 12 is similar to the Algal Flat class in the percentage coverage of algae and sediments, but the algae is almost exclusively green. This class was named Moderate Green Algae.

The next three classes represented a gradation of sediment types. Class 13 consisted of pure mud and, hence, was named Mud.

Class 14 appeared to be a mixture of coarser and/or drier sediments. This Mixed Sediment class was most often found in association with the Mud class. Class 15 was largely cobbles with up to a 50% coverage of brown algae. This class was named Cobble/Brown Algae.

The unsupervised classification lumped the areas with the densest coverage of brown algae, predominantly *Ascophyllum*, into Class 16 which was named Brown Algae. Brown algae was also present in moderate concentrations in Class 17. This class appears to occur on ledges higher in the intertidal zone and was named Ledge/Brown Algae.

Class 18 pixels were located where marshes were indicated in the reference data. It was clear, however, that some upland pixels were also included. Likewise, Class 19 appeared to be largely upland, but some marsh areas were also included. They were called Marsh/Upland and Upland/Marsh, respectively. Using the untested assumption that the errors in Classes 18 and 19 cancel one another out, the area of Class 18, Marsh/Upland was used as an estimate of Cobscook Bay marsh habitat. Class 20, definitely upland habitat, was recoded to a value of 0 and became part of the masked out area. Table 3 shows the distribution of the classes following the recode.

The Landsat sensors did not penetrate adequately below the surface of even very shallow water, hence, the resulting images do not provide any information on the distributions of kelps or submerged aquatic vegetation.

Table 3. 1993 distribution of classes following the recode.

# of pixels	Class Name	Acreage	Hectares
71337	Deep water	15864.99	6420.21
8303	Shallow water/Pens	1846.55	747.26
2354	Channel/Shallow water	523.52	211.86
4839	Green algae	1076.17	435.50
6549	Algal flat	1456.46	589.40
3832	Moderate Green algae	852.22	344.87
6091	Mud	1354.61	548.18
3005	Mixed sediment	668.30	270.45
2749	Cobble/Brown algae	611.36	247.41
6622	Brown algae	1472.70	595.70
3784	Ledge/Brown algae	841.54	340.55
3885	Marsh/Upland	864.00	349.64
3322	Upland/Marsh	738.80	298.97

The recoded classes were operationally defined as follows:

Deep Water- Water of sufficient depth to mask any signals from the bottom or tidally resuspended sediments.

Shallow Water/Pens - Shallow water containing perceptible levels of tidally resuspended sediments. Estimated depth range is two meters to several centimeters.

Very Shallow Water - Lense of water over mud. Knee deep to a shorebird.

Dense Green Algae - 80-100% coverage of green algae.

Algal Flat - Mixture of green and brown algae; 25% coverage of each.

Moderate Green Algae - 50-60% coverage of green algae.

Mud - Pure, clean, glistening mud. Classification near the green algae classes may indicate the presence of chlorophyll of benthic diatoms.

Mixed Sediment - Mixture of sediments from mud to gravel. In the extreme represented by gravel waves interspersed with mud. Often has sparse green and brown algae.

Moderate Brown Algae - 50% coverage of brown algae.

Dense Brown Algae - 90-100% coverage by browns in most locations. One area placed in this class only had 60-70% cover.

Ledge/Brown Algae - Brown algae on upper intertidal ledges; perhaps differentiated from the above two classes by the presence on blue-greens and/or exposed ledge above high tide line. Coverage by browns approximately 50%.

Marsh/Upland - Marginal upper intertidal class. Difficult to separate marsh and upland vegetation because of spectral similarities and fine scale uncertainties in geopositioning. This class is most likely dominated by marsh vegetation.

Upland/Marsh - Marginal upper intertidal class. Difficult to separate marsh and upland vegetation because of spectral similarities and fine scale uncertainties in geopositioning. This class is most likely dominated by terrestrial vegetation.

Discussion

The fine detail produced by the digitization and computer classification of the aerial photographs creates a very complex mosiac even with a small number of classes. The unsupervised classifications pulled out information that was not evident in the raw data and made distinctions which were not obvious to the naked eye. The subjective correlation between a single processed image and the reference and field data was quite high. Initially, such results seemed ideally suited for evaluation of the heterogenous environments encountered in Cobscook Bay. Problems arise, however, when classifications are extended across adjacent photographs and, especially, adjacent transects. The slight differences in radiological conditions result in the same classification being applied differently between the mosaicked photographs producing marked discontinuities in the final output. This limitation can be overcome with sufficient resources. The sheer volume of detailed data produced by digitizing aerial photographs, which is ideal for localized studies, is a limitation when applying this technique to large scale surveys. Two additional limitations of using photographic surveys for large scale, broad-based ecological investigations is that standard photography only records light in the visible portion of the spectrum and it is relatively expensive to do repeated aerial surveys.

Satellite imagery has several advantages over photographic surveys. First, the sensors in the satellite measure several bands of electromagnetic radiation and, hence, "see" much more than is seen by the naked eye or a photograph. This is important in differentiating plant taxa or in evaluating their health or vigor. Second, satellites sample an area in frequent intervals over a period of years so time series data are relatively easy and inexpensive to obtain. Finally, satellite images are on a scale to include all of Cobscook Bay and, hence, are truly synoptic. With proper field data, a single classifcation can be applied to the entire bay. A disadvantage to using Landsat satellite images is that the resolution is coarse. The Landsat Thematic Mapper perceives the environment in 30 meter pixels and, therefore, does not provide the fine detail of aerial photographic survey discussed above. On the other hand, data needs to be scaled to the questions being asked. Our purpose is to map and measure the habitats of the major producer groups in Cobscook Bay.

Using 30 meter pixels to survey thousands of hectares is probably a suitable scale for this purpose. Additionally, the larger pixel size results in smaller data files which can then be more rigorously analyzed on standard computers.

The classes derived by comparing the field observations and reference data with unsupervised classification are probably uneven in their faithfulness. The Mud, Green Algae and Brown Algae classes are very consistent. These classes contain one dominant element and, in many cases, occur in large, homogeneous polygons. This results in an unambiguous signal to the satellite's sensors that can be tightly defined. The satellite seemed especially sharp when discerning the greens. For example, when an isolated Green Algae pixel was located in the image that appeared to be misclassified, examination of aerial photos and/or the color slides made of the groundtruthing areas invariably proved that the satellite classification was correct.

The more heterogeneous environments result in mixed classes being defined on the scale of 30 meter pixels. There is undoubtedly some overlap in the initial 20 class unsupervised classification. The classes have been lumped with care to meet the purposes of the investigation, however, and it is likely that any misclassifications of mixed pixels will tend to cancel one another. It is suggested that in future environmental evaluations of this type that a hybrid analysis consisting of both unsupervised and supervised classifications be incorporated. This process could be further enhanced by including the measurement of upwelling radiation from the principal habitats of interest. The resulting spectral signatures could be used to more quantitatively establish the composition of mixed pixels.

The satellite did not 'see' into the water, hence we cannot provide estimates of area of two important ecosystem components, submerged aquatic vegetation and kelp. Future attempts including the use of alternative sensors (CASI, SAR), spectral signatures and statistical preprocessing may be able to delineate these habitats. Subtidal submerged aquatic vegetation was observed in a similar investigation in Penobscot Bay using an aircraft borne CASI sensor which employed 12 spectral bands (Larsen and Erickson, unpublished).

Two other studies deal to a greater or lesser extent with habitat areas in Cobscook Bay. These are the CMGE (Maine Geological Survey, 1976) described above and the TRIGOM literature review of 1972 (Shenton and Horton, 1973). In the absence of repeated Landsat surveys, some insights may be gleaned from examining these studies. These studies had different objectives and employed different techniques and scales. Each used an ecological classification of habitats unique to its purposes. For example, the CMGEs map everything visible on the aerial photographs into over 50 defined habitats whereas in the present study polygons of 30 meters square and larger were assigned to one of 13 classes. Direct comparisons of specific habitats are, therefore, limited. It is also unknown where CMGE and TRIGOM set the outer boundary of Cobscook Bay.

Comparable Cobscook Bay area data are presented in Table 4. The three studies are in rough agreement on the total high tide area of the bay. The total area of 11,400 hectares derived from satellite data is ten per cent higher than the TRIGOM estimate and ten per cent lower than the CMGE estimate. There is less agreement on the subtidal area. The satellite data fall within the range provided by TRIGOM and both are roughly 75% higher than the CMGE estimate. A possible explanation is that the CMGEs do not precisely distinguish between intertidal and shallow subtidal habitats and a large area of the latter is included in the intertidal area. This possibility is reflected in the numbers for intertidal habitat area where the CMGEs record twice the area as the present study and over three times the TRIGOM study.

Only three specific habitats are defined sufficiently similarly in the three studies to allow direct comparisons. Each study shows a small amount of marsh area (Table 4). The ratio of the present study to the CMGEs to TRIGOM is roughly 3:2:1 suggesting that the present study may have overestimated this habitat. Better differentiation between marsh and uplands would be a useful goal for future efforts, although the definition of these habitats was not a priority in the present effort because other reliable data sources on marsh area exist. In the present case, the differentiation between marsh and upland vegetation was made more difficult by the season. The image was taken in the autumn when the plants did not contain a full complement of pigments perhaps blurring the distinction between the marsh grasses and deciduous trees.

There is excellent agreement between the present study and the CMGEs on the area of brown algae (Table 4). Comparison of the CMGEs and the satellite derived habitat maps also showed excellent agreement in terms of the locations, sizes and shapes of the brown algae beds.

An intriguing disagreement between the present study and the CMGEs rests in the areas of green algae. The satellite identifies 1,370 hectares compared to only 12.4 hectares recorded on the CMGEs (Table 4). Green algae was very abundant and widespread during the field survey in September 1997 and, apparently, it was equally abundant in October 1993 when the Landsat image was captured. It

Table 4. Comparison of areas of selected Cobscook Bay environments.

Class Name	Hectares		
Water Classes	This Study	CMGE	TRIGOM
Deep Water	6420		
Shallow Water/Pens	747		
Very Shallow Water	212		
Subtidal Area	7379	4144	6475-7770
Intertidal Classes			
Dense Green Algae	436		
Moderate Green Algae	589		
Sparse Green Algae	345		
Green Algae Subtotal	1370	12.4	
Mud (Benthic diatoms)	548		
Mixed Sediment	270		
Moderate Brown Algae	247		
Dense Brown Algae	596		
Ledge/Brown Algae	341		
Brown Algae Subtotal	1184	1231	
Marsh/Upland	350	221	112
Upland/Marsh	299		
Intertidal Area	4021	8584	2590
Total Area	11,400	12,728	10,360

seems highly unlikely that pixels were misclassified to the green algae classes to any great extent. Even the highly characteristic Dense Green Algae class measures 436 hectares. Could green algae have been systematically underrepresented by two orders of magnitude in the processing of the CMGE aerial photographs or does the difference represent a real change in the quarter of a century between the photographic and satellite surveys? The original CMGE photographs were black and white so that the relatively featureless green algal beds may not have been easily distinguishable from the surrounding bare flats. If the latter supposition is true, however, the bay has indeed experienced a remarkable change which could augur profound consequences for the ecosystem. Further investigation of this apparent phenomenon should have a high priority.

Conclusions and Recommendations

1. Recent technological developments in remote sensing of the environment and storing and manipulating diverse environmental data in a spatial framework have greatly advanced our ability to comprehend heretofore unaccessible and/or incompatible data sets.
2. Landsat imagery provided sufficiently detailed, synoptic, and objective information at an affordable cost. Repeated at regular intervals, it would provide a valuable tool for the management and monitoring of macrotidal environments such as Cobscook Bay.
3. The use of digitized aerial photographs proved to be more difficult and costly because of radiological problems and the sheer density of data.
4. Methodological differences limits the ability to make comparisons between Cobscook Bay mapping exercises. The comparisons that can be made legitimately indicate that the unsupervised Landsat classification made a useful contribution to knowledge.
5. Applying other remote sensing instruments would provide finer spatial and spectral resolution than is possible using Landsat.
6. Future iterations of the remote sensing survey should incorporate more detailed field data including spectral signatures.
7. A hybrid analytical approach using statistical pre-processing and an iterative unsupervised and supervised classification scheme is recommended for future efforts.
8. There is a large discrepancy, two orders of magnitude, in the area of green algae between the CMGEs and the present study. This could be the result of methodological differences or it could represent real environmental changes. If real, the implications of this difference will profoundly influence our view of the Bay's dynamics. This result needs to be confirmed and investigated in regard to its causes and consequences.

Acknowledgements

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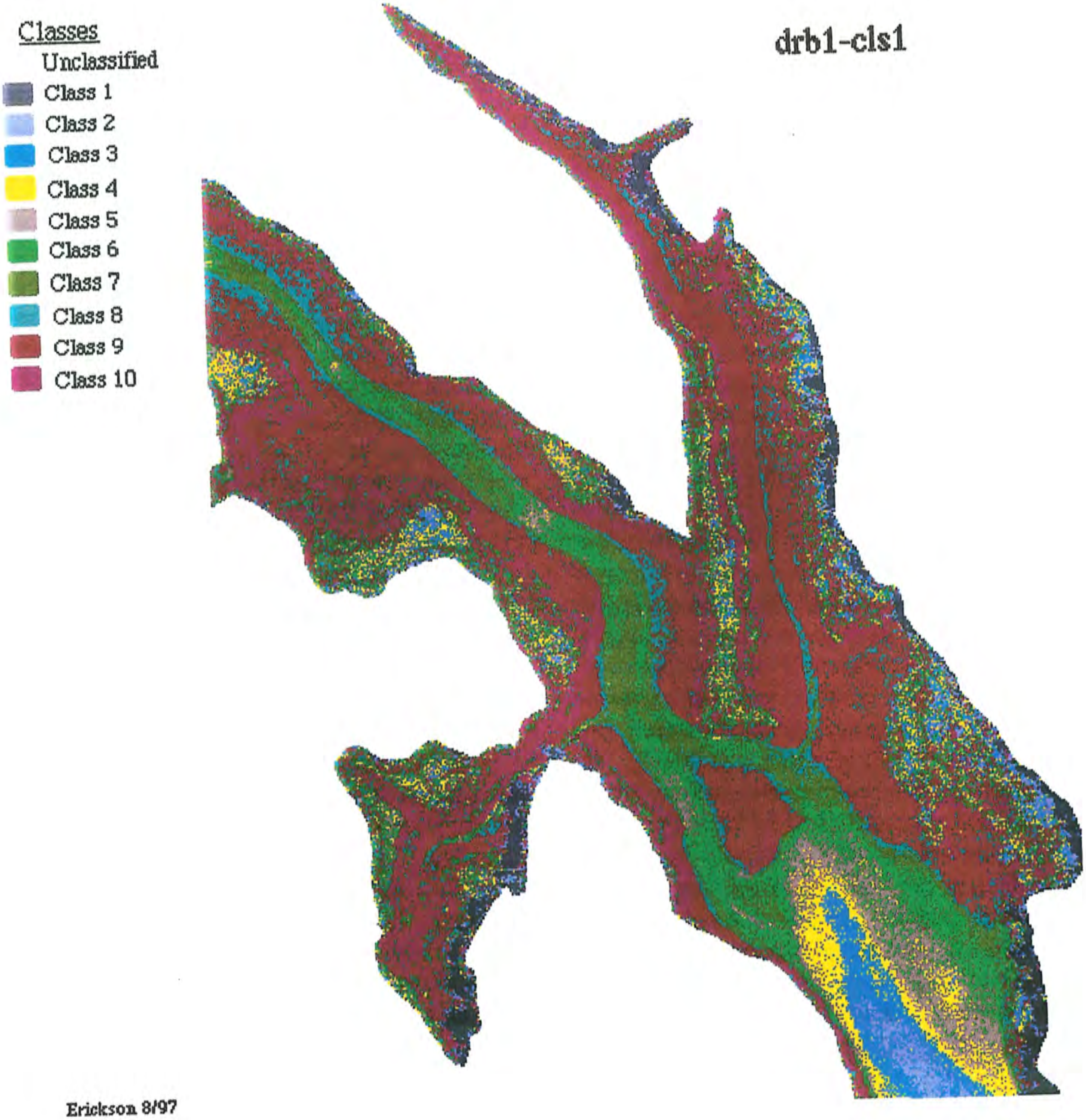
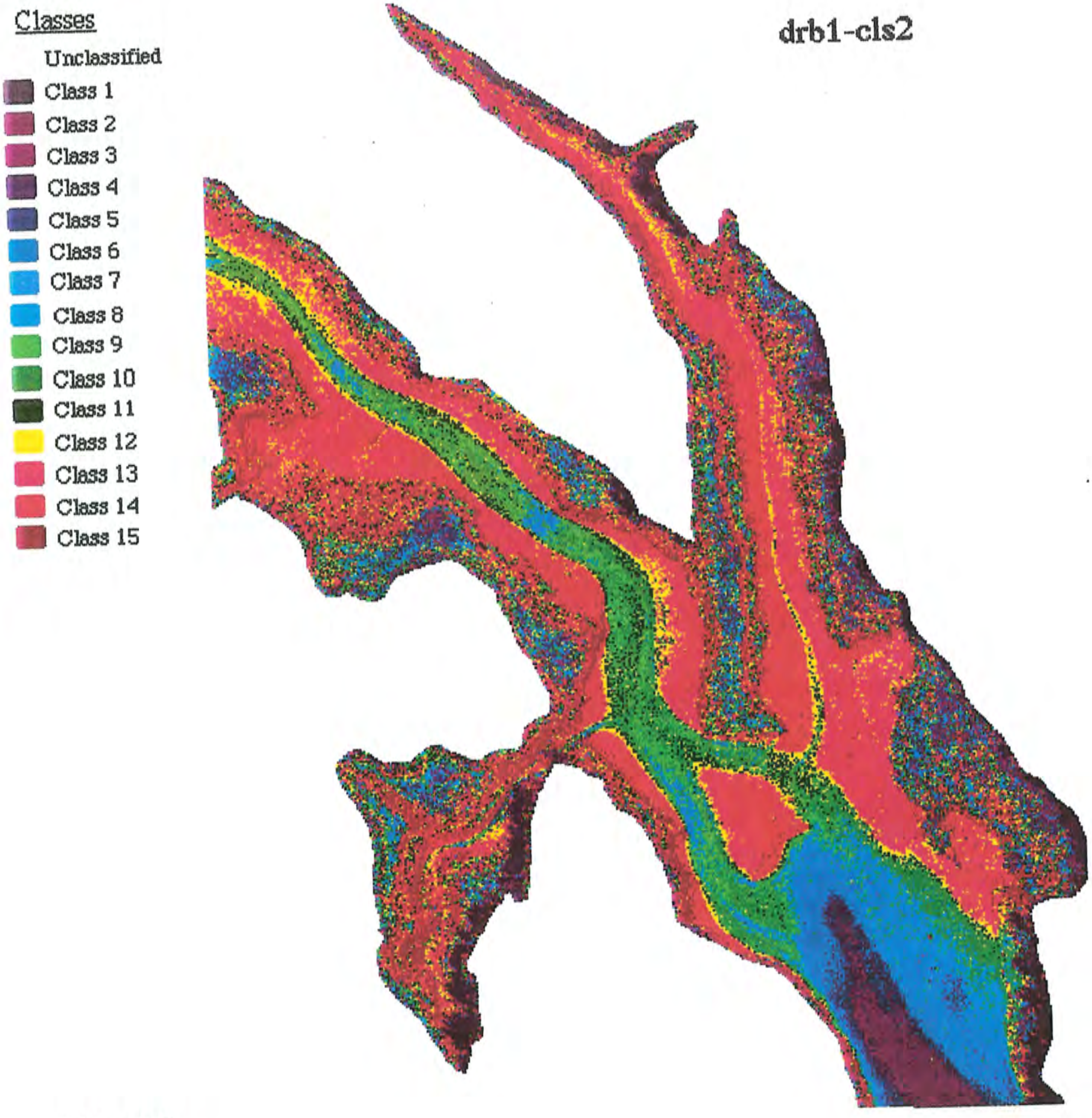
Figure 1. Map of the convoluted Cobscook Bay with many place names indicated (from Brooks, *et al.*, 1997).



drb1-cls1

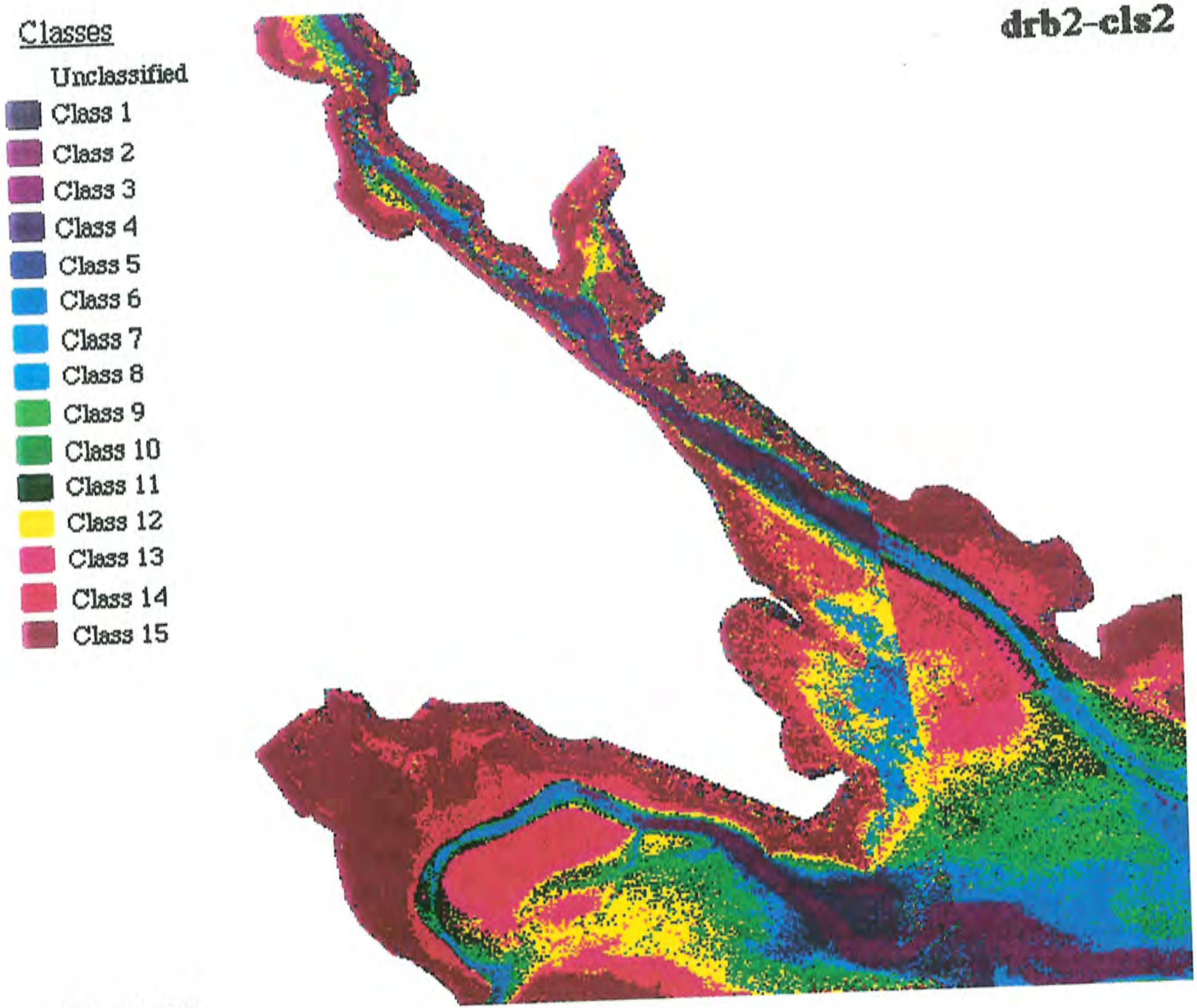
Erickson 8/97

Figure 4. Fifteen class image of digitized aerial photograph of the Hardscrabble River portion of Dennys Bay.



Erickson 8/97

Figure 5. Fifteen class representation of mosiacked digitized photographs of the confluence of the Dennys and Hardscrabble Rivers. Note the discontinuity at the seam between photographic transects.

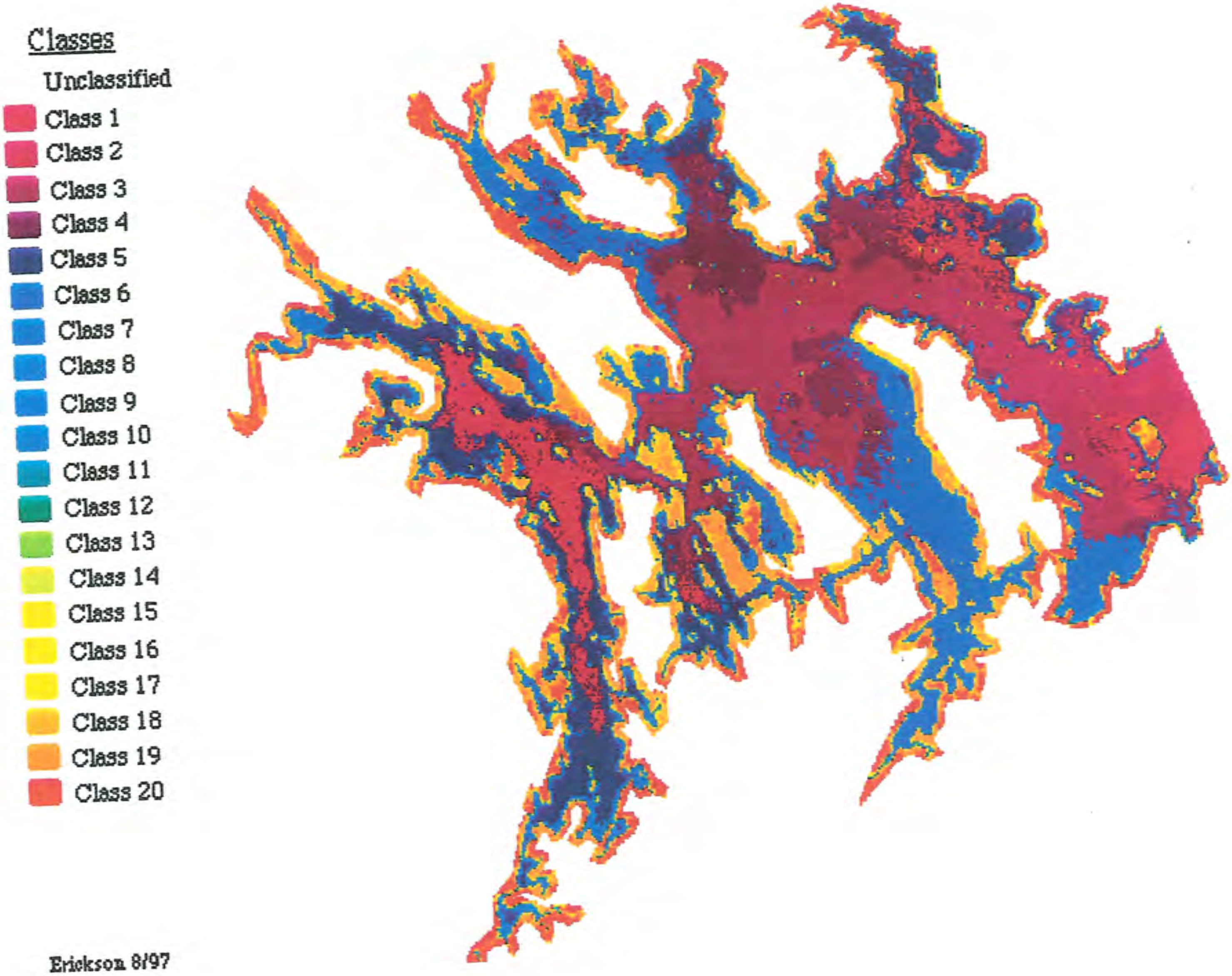


drb2-cls2

Erickson 8/97

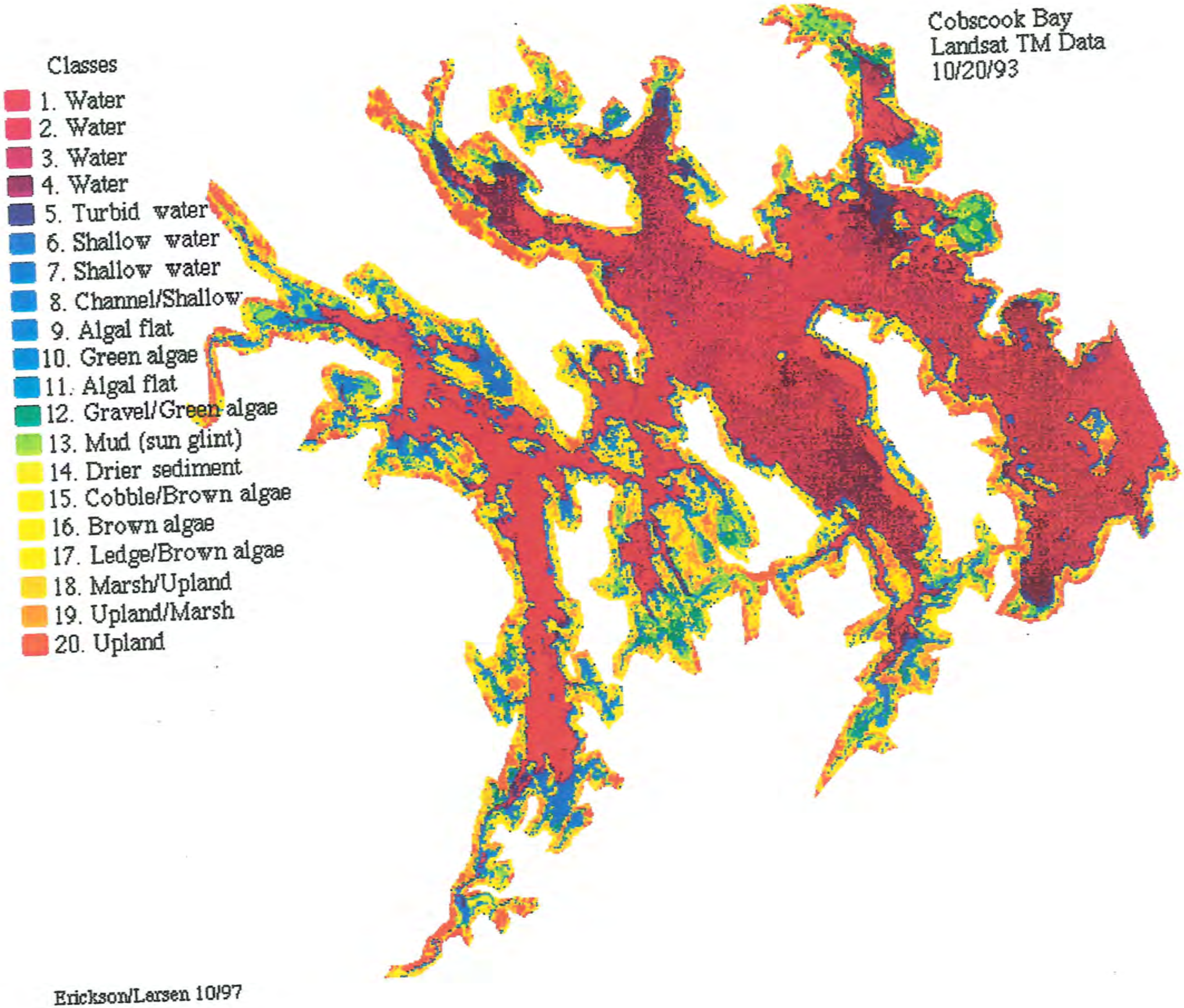
Figure 6. The classified 1991 high tide Landsat Thematic Mapper image of Cobscook Bay.

TM1028-cls3



Erickson 8/97

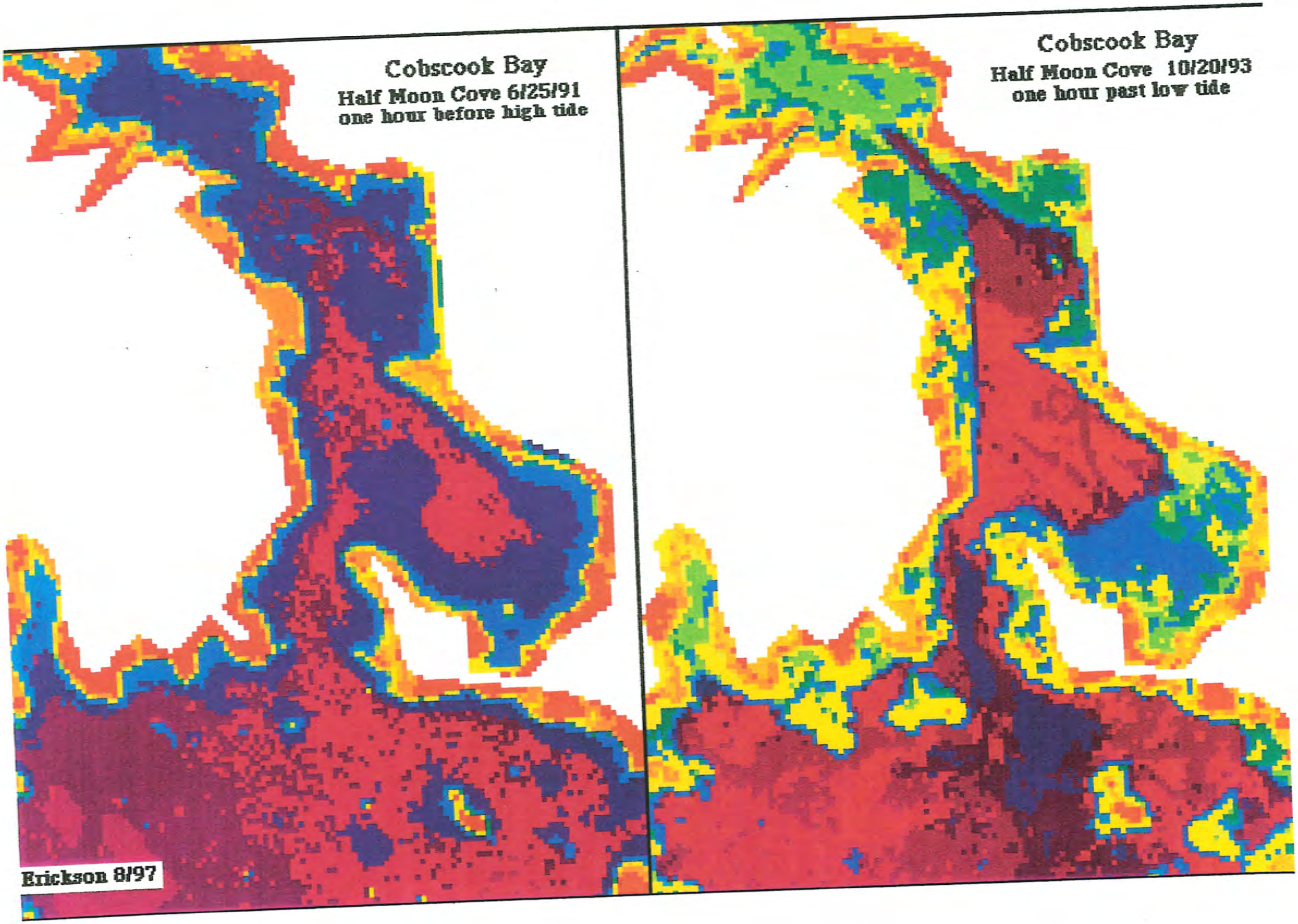
Figure 7. The 20-class representation of the 1993 low tide Landsat Thematic Mapper image of Cobscook Bay. This level of detail gave an intuitively satisfying initial product that was sufficiently detailed without being mottled.



Cobscook Bay
Landsat TM Data
10/20/93

Erickson/Larsen 10/97

Figure 8. Comparing the high tide and low tide images demonstrates the large intertidal area and the apparent suitability of Landsat imagery for investigations of macrotidal systems.



Cobscook Bay
Half Moon Cove 6/25/91
one hour before high tide

Cobscook Bay
Half Moon Cove 10/20/93
one hour past low tide

Erickson 8/97

The Cobscook Bay Ecosystem Model: Evaluation and Analysis

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1.0 Introduction

The primary objective of this part of the study is to develop and evaluate an energy systems model of the marine ecosystem in Cobscook Bay showing the manner in which the forcing functions such as solar radiation, tidal energy, wind, and nutrient sources interact to organize a web of components that account for primary and secondary production in the estuary. Whenever the necessary information was available, the components and processes of the Cobscook Bay ecosystem were evaluated and placed within the context of an energy systems model of the estuary.

There is a considerable amount of information available on Cobscook Bay and the Quoddy Region as evidenced by the 110 specific Cobscook references and 196 Passamaquoddy references found in the index of "Cobscook Bay: An Environmental Bibliography" (Larsen and Webb 1996). Most of this information was obtained during the course of environmental impact studies conducted from the 1930's to 1980 on the possible environmental consequences of developing tidal power in Passamaquoddy Bay. Later, in the 1980's, more data was generated when the consequences of Fundy tidal power development for the Gulf of Maine-Bay of Fundy region were studied (Gordon and Dadswell 1984). Also, a proposal by the Pittston Oil Company to build a refinery at Eastport generated scientific studies of the Quoddy area during the seventies (Trites 1974). The information contained in the literature along with new information gathered in this study have been used to construct and evaluate an Energy Systems model which characterizes the important forcing functions, components and processes of the Cobscook Bay ecosystem.

2.0 Methods

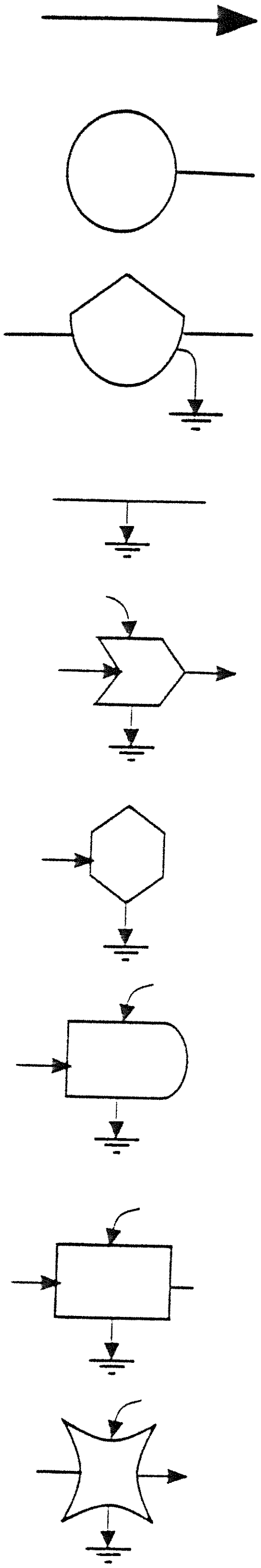
Energy Systems Theory (Odum 1994) provides a comprehensive, self-consistent methodology for evaluating and understanding ecosystems.

field, laboratory or literature research. Once a model has been evaluated it can be simulated by translating the energy systems model into a set of differential equations which in turn are programmed on a computer. The completely evaluated table of forcing functions, flows and storages specifies a value for everything in the model at an initial time. These values are then used to calculate a set of constant coefficients that are used in the model simulation. The evaluated model is then simulated and calibrated by comparing model outputs to observations. Simulations continue until all the relationships in the model for which data exist have been calibrated as evidenced by how well the model simulation represents the available observations. At this point, sensitivity analysis of model parameters and forcing function scenarios is generally used to determine which parameters or forcing functions have the greatest influence on system function as represented by one or more output variables. A further test of the model can be performed by simulating data obtained from a system other than the one used to calibrate the model.

Only the first two steps in building an energy circuit model of Cobscook Bay were carried out in this study and the second step, evaluating the ecosystem model, was not completed. There are two reasons why the table of storages, flows, and forcing functions (Table 1) for the Cobscook Bay ecosystem model (Figure 3) was not fully evaluated: (1) data could not be found on some of the ecosystem components and processes and (2) some critical parameters needed to calculate values for the flows at higher trophic levels were not readily available. The work necessary to obtain these missing data was beyond the scope of this project's objective which was to characterize the physical basis for primary production in Cobscook Bay. The forcing functions, storages and flows pertaining to primary production and its physical basis were all evaluated in the model based on our field work or literature information.

3.0 Results

A preliminary model of the Cobscook Bay ecosystem was constructed in 1993 (Figure 2) and it was used in our initial research planning. After two years of research, and several interactions with the Cobscook Bay stakeholders, the model was revised to the design shown in Figure 3. The results for this part of our project are presented as an evaluated model diagram (Figure 3) and the table of values and definitions that accompanies it (Table 1). Table 1 gives the definitions, values and units for the forcing functions, storages and pathway flows shown on the model diagram. Table 1 also references a series of numbered notes that explain



Energy circuit A pathway whose flow is proportional to the storage or source upstream.

Source A forcing function or outside source of energy delivering forces according to a program controlled from outside.

Tank A compartment of energy storage or state variable within the system storing a quantity as the balance of inflows and outflows.

Heat Sink Dispersion of potential energy into heat accompanies all real transformation processes and storages. This energy is no longer usable by the system.

Interaction Interactive intersection of two pathways coupled to produce an outflow in proportion to a function of both; a work gate

Consumer Unit that transfoms energy, stores it and feeds it back autocatalytically to improve inflow.

Producer Unit that collects and transforms low-quality energy under the control of high quality flows.

Box Miscellaneous symbol to use for whatever unit of function is needed.

Switching Action A symbol that indicates one or more switching actions controlled by a logical program.

Figure 1. Symbols of the Energy Systems Language used to represent the Cobscook Bay Ecosystem. (Adapted from Odum 1994).

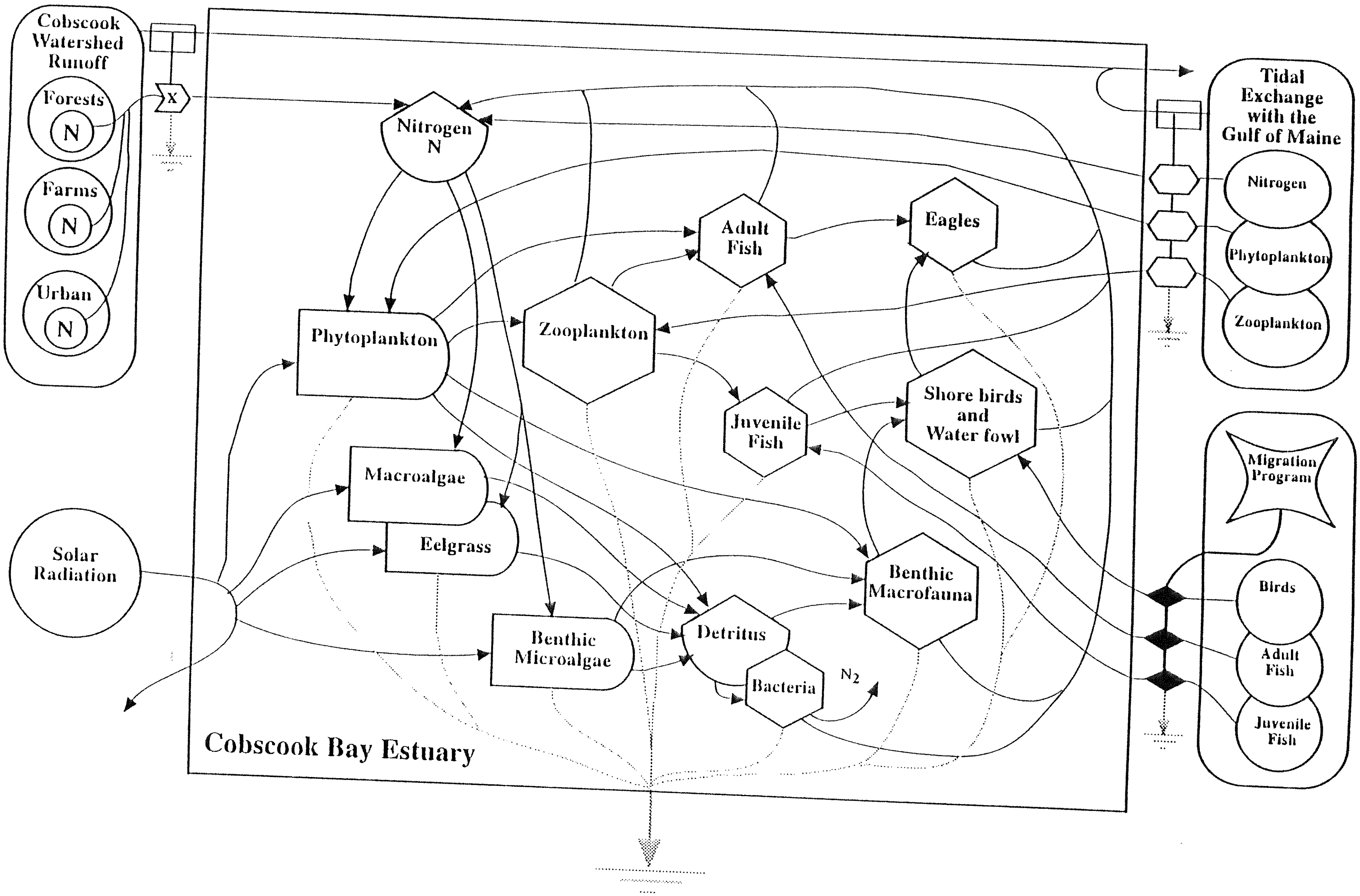


Figure 2. Our initial conceptual model of the Cobscook Bay estuary. The Energy Systems Language symbols are defined in Figure 1.

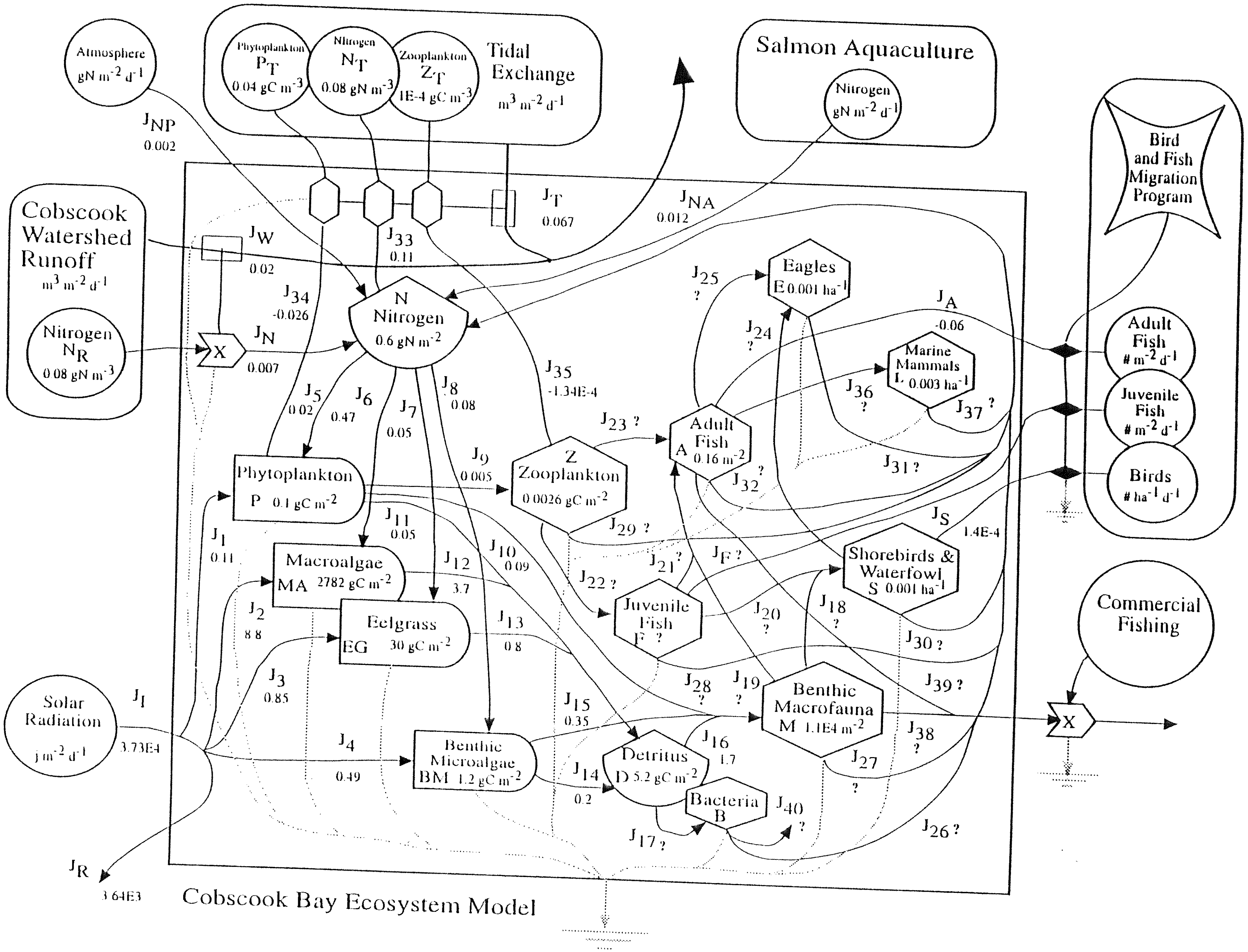


Figure 3. A partially evaluated Energy Systems Language model of the Cobscook Bay ecosystem.

The word "ecosystem" is used in the broad sense to include any system of organized natural and human components. Energy can be used as a common denominator to evaluate ecosystems, because the organization of components and processes in all systems is dependent on the transformation of energy. Energy Systems Theory assumes that ecosystems follow scientific laws and principles including the conservation of energy and mass, the Second Law of Thermodynamics, and the Maximum Power Principle (Lotka 1922) which when taken as a whole provide a set of design principles through which ecosystem organization can be understood and interpreted (Odum 1994). For example, one potentially powerful explanatory hypothesis is that the suite of forcing functions or the energy signature of an estuary uniquely determines the kind and amount of ecological organization produced. In this section, new and existing data from the Cobscook Bay estuarine ecosystem will be analyzed and interpreted within the context of an energy systems model.

The first step in modeling an ecosystem is to construct a conceptual model which represents the network of estuarine interactions, components and forcing functions. In this step, current expert opinion and general knowledge about the system from the literature are used to build the initial model. This model can be refined as research uncovers additional information which may require the model to be modified. The conceptual model in this study is constructed using Energy Systems Language (Odum 1994), a set of mathematically defined symbols that can be used to represent common ecological components and processes. Figure 1 shows the energy systems language symbols used in building the Cobscook Bay Ecosystem Model and gives their definition.

An explanatory table which gives a verbal definition of each component, process, and forcing function always accompanies the model diagram. The definitions in this table are keyed to the model diagram through a set of common symbols. This table contains a column defining the entry, a column for the value of the storage, flow, or forcing function at a specified time, a column for the units of the entry, and a column indicating the note where calculations and sources are listed.

The next step in the modeling process is to evaluate the forcing functions, storages, and flows in the model and place the appropriate value in the table. The completely evaluated table forms the basis for analysis and/or simulation. A partially evaluated table provides some valuable information about the system which may allow some kinds of analyses to be performed. In addition, the partially evaluated table shows the location of data or information gaps that must be filled by further the derivation of the values found in the table. These notes are given in Appendix A and contain the calculations, assumptions, references, and data tables that are necessary to explain how the values in Table 1 were derived. The units for entries in Table 1 are those that were most convenient for the author based on the units of the data source. In many cases enough information is provided to put these values in the same units e.g., gC m^{-2} d^{-1}. In other cases, sufficient information was not readily available to convert the units.

4.0 Discussion

The large amount of carbon fixed each year (50-60,000 MT C y^{-1}) in Cobscook Bay is based on the annual cycle of light and nutrient availability in the Bay. The production of phytoplankton and benthic microalgae is limited by light for much of the year because the Bay is well supplied with inorganic nitrogen, N, imported from Head Harbor Passage by the tide. Table 2 shows that 77% of the new nitrogen entering the Bay over the course of a year comes into the Bay as a net influx during tidal exchange. Salmon aquaculture operations add the second largest amount of new nitrogen to Cobscook Bay or 13% of the total. This is about 1.8 times what enters the Bay in runoff from the watershed and 6 times the nitrogen supplied from the atmosphere. Peak and annual levels of primary production in an estuary depend on the annual influx of new nitrogen (Boynton et. al. 1982). Table 2 also compares the sources supplying new nitrogen to Cobscook Bay with the nitrogen requirements of the plants estimated from our observations of primary production in the Bay.

The annual carbon fixed per meter square of area in a producer and the nitrogen used in making that production are shown for each primary producer in the lower part of Table 2. Multiplying the nitrogen used m^{-2} y^{-1} by the area in a primary producer gives the annual amount of N needed to support that producer in the Bay. The N needed to support the total primary production in the Bay is 1.45 to 2 times greater than the new nitrogen entering the Bay. The excess nitrogen requirement must be made up by nitrogen recycled within the Bay by consumers during the course of a year. Thus, the ratio of recycled nitrogen to new nitrogen is between 0.34:1 and 1:1 for the Bay as a whole. This is a very low ratio compared to the eight estuaries examined by Kemp et al. (1982), who found that this ratio ranged between 2:1 and 8:1 in the eight estuaries they examined. Campbell (1986) showed that this ratio is about 2:1 for the Gulf of Maine as a whole; therefore, Cobscook Bay is even richer in new nitrogen that the Gulf of Maine which is the source of most of the new nitrogen entering the Bay. Even though Cobscook Bay is extremely rich in new nitrogen, the nitrogen required by primary producers still exceeds the new nitrogen supply. Therefore, nitrogen may limit primary production in certain areas of the Bay or at certain times of the year when the supply of new nitrogen is low or when nitrogen recycle is insufficient to meet the local nitrogen demands of the primary producers.

Benthic microalgae are the largest users of nitrogen in the Bay accounting for 43 to 62% of the total N needed to support primary production. Conventional wisdom on primary production in estuaries views marshes, phytoplankton, eelgrass, and macroalgae as the major sources of primary production. Production by benthic diatoms is often considered to be small; and therefore, it has seldom been measured. The standing stock and productivity of benthic diatoms in Cobscook Bay ranged from 1 to 3 gC m^{-2} and from 0.16 to 4.46 gC $m^{-2} d^{-1}$, respectively, for our sample dates in May, July, October and November, 1995. The range of these biomass and productivity values is similar to that measured for intertidal benthic diatoms in the salt marshes of the North Inlet, SC (Pinckney and Zingmark 1993). However, the upper bound of biomass and productivity measured in Cobscook Bay exceeds the highest values measured in the North Inlet. Brown algae are the second greatest users of N followed by phytoplankton. The N requirements for brown algae increase to 19×10^6 kg y^{-1} if areas with medium velocity flows are assigned the productivity measured at high flow (see Table A13). This nitrogen demand is equal to the minimum N demand calculated for benthic microalgae.

The annual carbon production in Cobscook Bay is shown for each primary producer in Table 3. Brown algae fix the largest amount of carbon per year followed by benthic diatoms, using either their low or high production scenarios. Phytoplankton fix the third largest amount of carbon followed by minor contributions from green algae, eelgrass, and kelp. The possible fate of carbon fixed in the Bay is also shown in Table 3. The estimates for primary production are all based on measurements performed during this study; and therefore, we have a high degree of confidence in their accuracy. However, estimates of the fate of this primary production rely on literature values of ecosystem components and processes obtained by other investigators in other studies at other times. In addition, the estimates shown are predicated on assumptions that grossly simplify a given problem (see the Table 1 and Appendix A). Nevertheless, we feel that these estimates can provide a rough idea of the fate of the annual primary production in Cobscook Bay. Thought exercises such as this help identify data gaps and assist in formulating plans for future research.

In the right half of Table 3 we have identified the major components and processes that consume or distribute the annual primary production in Cobscook Bay and made rough estimates of their annual consumption of fixed carbon. In constructing a budget such as this one for the fate of Cobscook primary production, one value can always be calculated by difference. This must be true because matter and energy can not be created or destroyed; and therefore, all of the carbon fixed annually must be consumed or passed on by some component or process within the system. Based on our knowledge of the structure and function of other estuarine ecosystems, we identified the primary producers that supply two major pathways of consumption in estuaries, the grazing and detritus trophic pathways. In the Cobscook Bay ecosystem, phytoplankton and benthic microalgae are the major sources of suspended material for grazing by either pelagic or sedentary feeders. On the other hand, brown algae, eelgrass, green algae and kelp supply an abundance of carbon to the detritus trophic pathway. This division of producers according to the manner in which they supply carbon to consumers is not mutually exclusive because a portion of macrophyte carbon is grazed by benthic macrofauna e.g. periwinkles, and a small percentage of the suspended phytoplankton and benthic microalgae die and become part of the detritus carbon pool. In addition, some detritus of macrophyte origin is suspended in the water column where it is eaten by filter-feeding consumers. We made estimates of the fate of primary production in Cobscook Bay based on the general overview of system structure given above.

Legare and MacLellan (1960) measured the zooplankton abundance in Cobscook Bay during 1957 and 1958 and we have no reason to believe that zooplankton are more or less abundant today than they were then. Therefore, we estimated a grazing rate of 0.05 X 10^6 kgC y^{-1} for 1995 based on their earlier biomass values. This grazing rate accounts for only a small fraction of the carbon fixed by phytoplankton and benthic diatoms. The remainder must be either consumed by suspension feeders or settle into the detritus pool (note 30,32,33). Assuming that around 10% of this carbon becomes detritus, suspension feeding falls between 12.6 and 16.8 X 10^6 kgC y^{-1}. Thus, benthic suspension feeders are the largest consumers of Cobscook Bay primary production in the grazing trophic pathway. We estimated that about 12.5 X 10^6 kgC y^{-1} or between 21 and 25% of the total primary production is exported from Cobscook Bay as detritus, mostly of macroalgal origin. Finally, we estimated the detritus consumed by filter feeders to be 15.6 X 10^6 kgC y^{-1} using several assumptions which are documented in Note 33. Suspension feeders consume around 55% of the total carbon fixed annually in Cobscook Bay under both high and low productivity scenarios. The remainder of the fixed carbon goes into the detritus pool which supports diverse and abundant benthic infauna populations (see Table A21). The detritus deposited directly can range from 14 to 26% of the annual primary production depending on how high and low annual production and consumption scenarios are matched. In summary, this analysis indicates that roughly half of the annual primary production is consumed by suspension feeders, one fourth is exported and the other fourth goes into the detritus trophic pathway or is grazed by benthic macrofauna. The final quantity of carbon that ends up in the detritus pool must be considerably larger than 25% because much of the fixed carbon grazed by benthic suspension feeders and zooplankton is shunted to the detritus pool via feces, pseudofeces and fecal pellets.

The dominant forcing function for Cobscook Bay is the tide. Tidal exchange controls ecological processes in the Bay through the transport of materials into and out of the estuary in proportion to their concentration difference inside and outside of the Bay. Table 4 shows the material fluxes of NO_3, NH_4, PO_4, SiO_3, and phytoplankton C for the five sampling trips on which transect measurements were taken. The October 24-26 sample dates stand out because all five quantities are being exported from the Bay and the largest amounts of NO_4, PO_4, and SiO_3 are being transported at this time. This pattern is very different from that displayed by nitrate and ammonia during most of the year. Nitrate is being imported on all dates except the October sampling and ammonia is being imported on the May and July sample dates but not in October or November. Phosphorus is exported on all dates except those in November, but the amount being exported in October is 2 to 8 times larger than that exported on the other sampling dates. Approximately 1.0 X 10^7 g Si d^{-1} are imported or exported on the dates in May and July; however, twice this amount is exported in November and the export of silicate increases to 5.5 X 10^7 gSi d^{-1} in October. Phytoplankton carbon is exported in the spring and fall and imported in the summer. The largest phytoplankton carbon flux is the import of carbon from Head Harbor Passage during the July spring tide sample dates.

This import-export data can be interpreted by considering the ecological context of the observed fluxes. In October, the distribution of concentrations shows that the Outer Bay is serving as a source of nitrate for both the Inner Bay and Friar Roads. Furthermore, the stations with high nitrate values are grouped along the northern shore of the Outer Bay. Boats were observed dragging this area for urchins during the October sample dates and at least one sample was taken in the plume from a dragger (D. Phinney, personal communication). The fact that the largest fluxes of NO_4, PO_4, and SiO_3 occur at this time supports our position that the extreme values present in October are due to the roiling of the bottom by draggers. Surface and bottom nutrient samples for NO_3, PO_4 and SiO_3 taken in Friar Roads in October show that the offshore water column has not yet been overturned by fall winds. Thus, the nutrient concentrations in the water entering the Bay from offshore are near their annual low. By the November sample dates the stratification offshore has broken down and large quantities of NO_3 and PO_4 are present in the water entering Cobscook Bay accounting for the import of these substances in November. Scallop dragging begins in November and the disturbance of the bottom that accompanies this activity must have been sufficient to account for the continued export SiO_3 from the Bay despite a doubling of the offshore concentration of this substance. High concentrations of silicates are found in the Outer Bay which was being dragged for urchins during October and in November the silicate concentrations are high in the Central and South Bays where the scallop draggers fish. The typical pattern in spring and summer is for NO_3, NH_4, and SiO_3 to be imported into the Bay and for PO_4 to be exported. The import and export of phytoplankton carbon to and from the Bay is probably driven by the annual cycle of production offshore. Phytoplankton carbon is imported during July when there is an offshore bloom and exported in the spring and fall when Bay chlorophyll concentrations exceed those in the offshore waters.

The upper trophic levels in Cobscook Bay as represented in Figure 3 have been partially documented in this study using sources from the literature (see Appendix A). The standing stock of some members of the higher trophic levels are shown in Table 5 along with the primary production required to support them. These ratios are only approximate because the production values are from our 1995 measurements and the estimates for standing stocks of the higher trophic animals were calculated from measurements that were made in Cobscook Bay between 1957 and 1992. The only samples that were not located in Cobscook Bay were those used to represent the adult fish community and these were were taken from adjacent Passamaquoddy Bay near the Western Passage (Tyler 1971). The higher trophic level animals are arranged in descending order based on the number of animals supported by a kg of fixed carbon. This ratio gives a rough idea of what is necessary to support each group in the Cobscook Bay ecosystem. All the higher trophic level groups are poorly documented, but we found little information on benthic suspension feeders and other epifauna and no information on the juvenile fish community.

The sea scallop, *Placopecten magellanicus*, the soft clam, *Mya arenaria* and the sea urchin, *Strongylocentrotus droehbachiensis,* are benthic macrofauna which feed on the abundant benthic microalgae and support major commercial fisheries in Cobscook Bay. An early report on the commercial fisheries of Cobscook Bay by Dow (1959) gave evidence to show that the commercial production of intertidal soft clams in Cobscook Bay was poor to fair when compared to other areas of Washington Co., Maine. He also stated that mussels were abundant in the Bay but for the most part were too small to be commercially valuable. The extent and importance of subtidal mussel beds was not known at that time. We estimated in this study that benthic suspension feeders consume half of the total carbon fixed annually in the Bay. The fact that benthic suspension feeders play a large role in the natural economy of the Bay does not necessarily mean that their productivity will be realized in large commercially exploitable populations. Many small animals consume just as much food as a few large ones. In the case of the sea scallop, high primary production appears to be translated into the production of a commercially valuable population because the Bay has supported a scallop fishery at least since the 1940's (Dow and Baird 1960) albeit with large variations in the abundance of year classes. On the other hand, soft clams appear to grow slowly in the large intertidal area which is not particularly good habitat for the commercial production of clams (Dow 1959). The factors responsible for low clam productivity should be investigated in the future. In light of the apparent importance of benthic suspension feeders in the natural as well as the human economy of the Bay, it would be prudent to investigate the role of this component within the Cobscook Bay ecosystem in future studies.

5.0 Conclusions

(1) Primary producers in Cobscook Bay fix between 50 and 60 thousand metric tons of carbon a year.
(2) About half of this quantity is consumed by the benthic suspension feeders which support two major commercial fisheries in the Bay.
(3) Benthic microalgae are the chief users of nitrogen in the Bay and together with phytoplankton they account for 44 to 52% of the annual carbon fixed. The majority of this carbon is apparently consumed by benthic filter feeders.

(4) Annual production in Cobscook Bay is high because the ratio of new to recycled nitrogen in the Bay is great enough that the available light is the only limit on primary production most of the time. Since the nitrogen required to support primary production exceeds the new nitrogen input, nutrients may limit production in certain local areas or at times of the year when the supply of new nitrogen is limited and local recycle is unable to keep pace with the nitrogen demands of the producers.
(5) Cobscook Bay is an example of a naturally eutrophic ecosystem. It receives high nutrient concentrations from the deep waters of the Gulf of Maine via tidal exchange rather than from sewage or non-point runoff like other estuaries on the Atlantic coast. Unlike many other estuaries Cobscook Bay has had time to build an efficient ecosystem capable of safely exploiting high nutrient levels. The tremendous daily volume of tidal exchange cleanses the estuary of impurities as it resupplies it with new nitrogen fuel for the primary producers.
(6) While nature is resilient, human beings have the capacity to push her beyond even the most liberal limits. Salmon aquaculture is now the second largest source of new nitrogen to Cobscook Bay supplying more than 17% of the net amount brought in annually by the tide. Local effects of this nutrient addition are seen on the bottom near salmon pens. Establishing a baseline for ammonia and then monitoring the ammonia level in the Bay during the late summer and early fall may give us an early warning if salmon aquaculture begins to have major effects on the nutrient cycles in the Bay.

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Table 1. Values for the forcing functions, storages, and flows in the Cobscook Bay Ecosystem model presented in Figures 1 and 3. If possible average values from our May 2,3,4, 1995 sample dates are given. Some of the forcing functions are specified as annual average values. Values from the literature are given as close to early May as possible. Supporting information and additional details about each measurement are specified in the accompanying note.

Symbol	Definition Note	Value	Units	
	Forcing Functions			
JI	Incident solar radiation	3.73E+04	j $m^{-2} d^{-1}$	1
JR	Albedo	0.0975	nondim	2
JW	Runoff from the watershed	0.02	$m^3 m^{-2}$ d-1	3
JN	Nitrogen from the watershed	0.007	gN m^{-2} d-1	4
JNA	Nitrogen from Aquaculture	0.012	gN m^{-2} d-1	5
JNP	Nitrogen added in rainfall	0.002	gN m^{-2} d-1	6
JT	Tidal exchange volume	0.067	$m^3 m^{-2} d^{-1}$	7
NT	NO_3 conc. in seawater	0.08	gN m-3	8
PT	Phytoplankton conc. in seawater	0.036	gC m-3	9
ZT	Zooplankton conc. in seawater	1.04E-4	gC m-3	10
NR	NO_3 conc. in river water	0.08	gN m-3	11
JS	Bird migration	1.4E-4	# $ha^{-1} d^{-1}$	12
JA	Adult fish migration	-0.055	# $m^{-2} d^{-1}$	13
JF	Juvenile fish migration	no data	# $m^{-2} d^{-1}$	14
	System Components or Storages			
P	Phytoplankton	0.1	gC m^{-2}	15
BM	Benthic Microalgae	1.15	gC m^{-2}	16
N	Nitrogen, NO_3,NO_2,NH_4	0.6	gN m^{-2}	17
MA	Macroalgae by species type			
MAk	Macroalgae, Kelp	139	gC m^{-2}	18
MAr	Macroalgae, Fuciods	2626	gC m^{-2}	18
MAg	Macroalgae, Greens	17	gC m^{-2}	18
EG	Eelgrass	30	gC m^{-2}	18
Z	Zooplankton	0.0026	gC m^{-2}	19
D	Detritus	5.2	gC m^{-2}	20
M	Benthic Macrofauna	1.14E4	# m^{-2}	21
F	Juvenile fish	no data	# m^{-2}	14

S	Shorebirds and waterfowl	0.001	# ha-1	12
A	Adult fish	0.16	# m^{-2}	13
E	Eagles	0.0013	# ha^{-1}	22
L	Marine mammals	0.0029	# ha^{-1}	23
	Pathway flows			
J1	GPP for phytoplankton	0.11	gC m^{-2} d^{-1}	24
J2k	NPP for macroalgae, kelp	1.46	gC m^{-2} d^{-1}	18
J2f	NPP for macroalgae, fucoids	7	gC m^{-2} d^{-1}	18
J2g	NPP for macroalgae, greens	0.36	gC m^{-2} d^{-1}	18
J3	NPP for eelgrass	0.85	gC m^{-2} d^{-1}	18
J4	GPP for benthic microalgae	0.49	gC m^{-2} d^{-1}	25
J5	N uptake by phytoplankton	0.018	gN m^{-2} d^{-1}	26
J6k	N uptake by macroalgae, kelp	0.11	gN m^{-2} d^{-1}	27
J6f	N uptake by macroalgae, fucoids	0.356	gN m^{-2} d^{-1}	27
J6g	N uptake by macroalgae, greens	0.002	gN m^{-2} d^{-1}	27
J7	N uptake by eelgrass	0.047	gN m^{-2} d^{-1}	27
J8	N uptake by benthic microalgae	0.082	gN m^{-2} d^{-1}	28
J9	Zooplankton grazing	0.005	gC m^{-2} d^{-1}	29
J10	Benthic macrofauna grazing	0.09	gC m^{-2} d^{-1}	30
J11	Phytoplankton settling to bottom	0.05	gC m^{-2} d^{-1}	30
J12	Macroalgal detritus production	3.7	gC m^{-2} d^{-1}	31
J13	Eelgrass detritus production	0.76	gC m^{-2} d^{-1}	31
J14	Benthic microalgae detritus	0.2	gC m^{-2} d^{-1}	32
J15	Macrofauna grazing on microalgae	0.35	gC m^{-2} d^{-1}	30
J16	Detritus eaten by macrofauna	1.72	gC m^{-2} d^{-1}	33
J17	Carbon processed by bacteria	no est.	gC m^{-2} d^{-1}	34
J18	Macrofauna consumed by birds	no est.	gC m^{-2} d^{-1}	35
J19	Macrofauna eaten by adult fish	no est.	gC m^{-2} d^{-1}	36
J20	Juvenile fish eaten by shorebirds	no est.	gC m^{-2} d^{-1}	37
J21	Juvenile fish eaten by adult fish	no est.	gC m^{-2} d^{-1}	14
J22	Zooplankton eaten by juv. fish	no est.	gC m^{-2} d^{-1}	14
J23	Zooplankton eaten by adult fish	no est.	gC m^{-2} d^{-1}	36
J24	Waterfowl consumed by eagles	no est.	gC m^{-2} d^{-1}	38
J25	Adult fish consumed by eagles	no est.	gC m^{-2} d^{-1}	38
J26	Nitrogen recycled by bacteria	no est	gN m^{-2} d^{-1}	39
J27	Nitrogen recycle by macrofauna	no est.	gN m^{-2} d^{-1}	39
J28	Nitrogen recycle by juvenile fish	no est.	gN m^{-2} d^{-1}	39

J29	Nitrogen recycle by zooplankton	no est.	gN m^{-2} d^{-1}	39
J30	Nitrogen recycle by shorebirds	no est.	gN m^{-2} d^{-1}	39
J31	Nitrogen recycle by eagles	no est.	gN m^{-2} d^{-1}	39
J32	Nitrogen recycle by adult fish	no est.	gN m^{-2} d^{-1}	39
J33	Nitrogen export or import	0.11	gN m^{-2} d^{-1}	40
J34	Phytoplankton export or import	-0.026	gC m^{-2} d^{-1}	41
J35	Zooplankton export or import	-0.00013	gC m^{-2} d^{-1}	42
J36	Fish eaten by marine mammals	no est.	gC m^{-2} d^{-1}	43
J37	Nitrogen recycle by mammals	no est.	gN m^{-2} d^{-1}	43
J38	Benthic macrofauna harvested	no est.	kg wt. y^{-1}	44
J39	Fish harvested	no est.	kg wt. y^{-1}	44
J40	Denitrification	no est.	gN m^{-2} d^{-1}	45

Table 2. Inputs of new nitrogen to Cobscook Bay compared to the estimated nitrogen requirements of primary producers. GPP is measured for phytoplankton and benthic microalgae as the average of summer and winter values. The annual average NPP was measured for all macroalgae and eelgrass.

Nitrogen source	N inflow kg N y^{-1} X 10^5
Runoff from the watershed	2.47
Salmon Aquaculture	4.39
Wet and Dry deposition from the Atmosphere	0.72
Net influx of inorganic N in tidal exchange	25.1
Total new N inflows	32.7

Primary producer	GPP or NPP gC m^{-2} y^{-1}	N used gN m^{-2} y^{-1}	Area m^2 X 10^6 kg	N needed N y^{-1}X10^5
Phytoplankton	86.7	14.6	71.6	10.5
Benthic diatoms, high*	438	73	56.3	41.1
Benthic diatoms, low*	290	33.7	56.3	19.0
Eelgrass	310	17	1.9	0.32
Browns	2640	130	9.95	12.9
Greens	132	8.2	7.25	0.59
Kelp	534	36.3	0.96	0.35
Total N required to support primary production, High estimate				65.8
Low estimate				43.7

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* The difference between high and low diatom production scenarios is that the November value in Table A22 was used for winter in the low scenario and the average of November and May values was used for winter in the high scenario.

Table 3. Annual primary production in Cobscook Bay and its possible fate.

Producer	Annual Production Kg C y^{-1} X 10^6	Consumer	Annual Consumption Kg C y^{-1} X 10^6
Phytoplankton	6.2	Zooplankton grazing	0.05
Benthic diatoms, low	16.3	Suspension Feeders, high#	16.8
Benthic diatoms, high	24.6	Suspension Feeders, low#	12.6
Brown algae	26.3	Macroalgae grazed	2.84
Green algae	0.96	Detritus export	12.5
Kelp	0.51	Detritus filtered	15.6
Eelgrass	0.59	Detritus deposited, high*	11.4
		Detritus deposited, low*	7.3
Total production, high	59.2	Total consumption, high	47.8
Total production, low	50.9	Total consumption, low	43.6

The difference between high and low suspension feeding is that the July value for macrofaunal grazing (note 30) was applied throughout the year in the high scenario, whereas, in the low scenario winter grazing was assumed to be 1/2 of the July grazing rate.

* The detritus deposited is calculated as the difference between total production and total consumption. Much of the deposited detritus is consumed by benthic deposit feeders. Detritus deposited might be as great as 15.6 Kg C y^{-1} X 10^6 if high production is matched with low consumption.

Table 4. Import(+) and export (-) balance for materials moving across the Eastport to Lubec transect on the sample dates in 1995.

Date	NO_3 gN d^{-1}	NH_4 gN d^{-1}	PO_4 gP d^{-1}	SiO_3 gSi d^{-1}	Phyto. C gC d^{-1}
May 2,3,4	1.0E7	1.6E6	-4.3E5	1.0E7	-2.7E6
July 11,12,13	4.2E6	8.9E6	-1.5E6	-1.1E7	9.8E6
July 21,22,32	4.4E6	1.2E7	-3.0E6	1.3E7	3.2E7
October 24,25,26	-3.0E7	-3.9E5	-8.2E6	-5.5E7	-1.1E7
November 7,8,9	5.0E6	-4.8E6	1.1E6	-2.2E7	-7.8E6

Table 5. Standing stock of animals in higher trophic levels supported by the annual primary production of Cobscook Bay. Average primary production from Table 3 is 5.5E7 kgC y^{-1}.

Animal	Standing Stock in the System	Quantity per kg C of Primary Production
Benthic Infauna	1.25E13	2.3E5 animals
Benthic Epifauna	?	?
Zooplankton*	2.16E9	39 animals
Juvenile Fish	?	?
Adult Fish	1.2E7	0.22 animals
Shorebirds	1.1E4	2.0E-4 animals
Seals	300	5.5E-6 animals
Eagles	14	2.5E-7 animals

*Assuming that the dominant zooplankter in Cobscook Bay, *Calanus finmarchicus*, 0.27 mgC per animal calculated from mean dry weight and numbers in Table 2 of Wischner et. al. (1994) and assuming 0.47 to convert dry wieght to carbon (Vinogradov 1953).

7.0 Appendix A

1. The solar radiation received at Eastport was estimated using two data sources.
A. NOAA measured incident solar radiation at Portland and Caribou, Maine from 1961 to 1990 using a flat plate 0 degree tilt solar collector. This data is available at the NOAA site on the World Wide Web. We estimated the solar radiation received at Eastport (44.9°N) by linearly interpolating the data from Caribou (46.9°N) and Portland (43.7°N).
B. The percent possible solar radiation was measured daily at Eastport from 1893 to 1951 (Shenton and Horton 1973). Three sets of estimates for the solar radiation received at Eastport were obtained by substituting monthly average values of the percent possible sunlight into Angstrom's equation (List 1977) using the clear day light, Q0, received for atmospheric transmission coefficients, a, of 0.7, 0.8, and 0.9 (Table A1). Divide the annual average insolation by 365 to get the daily average on the diagram.

2. Estimated as a decimal fraction of the solar radiation incident on the sea at latitude 44.9°N from (Von Arx 1962).

3. Daily discharge data for the Denny's River gauging station is available from October 1955 to the present. The average water discharge from a 240.6 km^{-2} gauged area of the Denny's River from 1956 to 1994 was 5.44 $m^3 s^{-1}$ (USGS 1993). If this discharge is prorated over the entire watershed area (962.6 km^{-2}), 6.864 $X10^8 m^3 y^{-1}$ enter the estuary from the watershed. Divide this number by 365 and again by 1.04 $X10^8 m^2$ the high tide area of the Bay U.S. Army Corps of Engineers (1980), to get the m^3 fresh water inflow per $m^{-2} d^{-1}$ shown in Figure 3.

4. Because water quality data has been seldom measured in the Cobscook watershed, USGS data from the nearby Narraguagus River watershed was used under the assumption that total N discharged from the two watersheds per unit area was similar. The total N discharged from the Narraguagus River was 0.48 gN m^{-3} over 5 years from 1982-1986 and 0.36 gN m^{-3} for the 38 year record from the Storet data base available at the USEPA site on the World-Wide Web. The estimated total N input to the Cobscook Bay estuary is: (6.864 $X10^8 m^3 y^{-1}$) (0.36 g N m^{-3}) = 2.47 X 10^5 kgN y^{-1}. Multiply kgN y^{-1} by 1000 mg kg^{-1} and divide by 365 d y^{-1} and 1.04 $X10^8 m^2$ to get 0.0065 gN $m^{-2} d^{-1}$.

5. An estimate of the nitrogen, N, input to the estuary as a result of salmon aquaculture can be obtained by subtracting the nitrogen removed in the fish harvested from the nitrogen added in feed plus smolts. The following information is calculated from data on salmon aquaculture in Cobscook Bay which was supplied by L. Churchill of the Maine Department of Marine Resources. From July 1994 through June 1995 the total feed given was 16,549,897 lbs., 1,081,522 fish were harvested weighing 9,909,998 lbs, and 498,729 mortalities were counted. Assuming that salmon aquaculture operations in Cobscook Bay are in steady state, the smolt added in this calendar year will equal the fish harvested plus any mortality. We estimate that a minimum of 1,580,251 smolt were added. The smolt added weighed about 143 g each (L. Churchill, personal communication), thus 2.26×10^5 kg live weight of fish were added. Assuming that *Salmo salar* smolt have the same chemical composition as the adults 3.25 % of the live weight of these fish was nitrogen (Vinogradov, 1953). Thus, 7,345 kg N y^{-1} were added in the smolt. Salmon feed contains from 46% to 50% crude protein depending on the age of the fish. Assuming an average crude protein content of 48% (personal communication Dan Mcphee of Sure Gain Feed Co.) and that Kjeldahl N is 0.16 of crude protein (Moreau et al. 1995), then

$(1.6550 \times 10^7 \text{ lbs } y^{-1})$ $(0.45454 \text{ kgs lb}^{-1})(.48)$ $(0.16) = 5.7774 \times 10^5$ kg N y^{-1} enters in feed. The N removed in fish harvested is:

$(9.910 \times 10^6 \text{ lbs } y^{-1})$ $(0.45454 \text{ kgs lb}^{-1})$ $(.0325) = 1.464 \times 10^5$ kg N y^{-1}

$(5.7774 \times 10^5 \text{ kg N } y^{-1}) - (1.464 \times 10^5 \text{ kg N } y^{-1}) + (7345 \text{ kg N } y^{-1}) =$ 4.3869×10^5 kg N y^{-1} are added to Cobscook Bay as a consequence of salmon aquaculture. This converts to 0.0116 gN m^{-2} d^{-1}. This estimate is in the same range as those made by Sowles in the section on Salmon Aquaculture in this report.

6. The nitrogen added directly to Cobscook Bay as a result of wet and dry deposition from the atmosphere was estimated using data from the National Atmospheric Deposition Program, NADP, available on the World-wide Web. The area of the Bay at high water is approximately 103.6×10^6 km^{-2}. The average wet deposition of NH_4 and NO_3 from 1982 to 1995 at the NADP station in Acadia National Park, Bar Harbor, Maine was 3.46 kg N ha^{-1} y^{-1}. If dry deposition is approximately equal to the measured rate of wet deposition approximately 6.92 kg N ha^{-1} y^{-1} would have been deposited directly on Cobscook Bay from the atmosphere. The atmospheric deposition of N on the bay surface is $(6.92 \text{ kg N ha}^{-1} y^{-1})$ $(10{,}360 \text{ ha}) =$ 0.717×10^5 kg N y^{-1} or 0.002 gN m^{-2} d^{-1}.

7. The tidal exchange coefficient is defined as the fraction of water from Head Harbor Passage that remains in the Bay after each tidal cycle. From Brooks et al. (1997) we know that the tidal prism is approximately 1/3 of the mean estuary volume. We assumed that each incoming tide brings in only new water from Head Harbor Passage. This is a reasonable assumption if the volume of Head Harbor Passage, as defined by the depth of the passage and the area of the tidal excursion, is large compared to the tidal prism of Cobscook Bay (Fogeron 1959) and if the waters in the Passage are completely mixed. If the tidal prism is 1/3 of the Bay's volume and if Cobscook Bay waters are well-mixed, then 2/3 of the Head Harbor Passage water that enters the Bay on and incoming tide must remain in the Bay and the tidal exchange coefficient is approximately 0.67. The tidal prism volume was estimated as 0.54 m^3 X 10^9 (Brooks et al. 1997). The tidal exchange volume is then 0.67 * 0.54 m^3 X 10^9 = 3.61 X 10^8 m^3. Multiply by 1.934 tides d^{-1} and divide by the area of the Bay to get the daily exchange per m^{-2} which is 0.067 m^3 m^{-2} d^{-1}.

8. The nitrate concentration at high tide along the Eastport to Lubec line sampled in this study was used to estimate NO_3 in the offshore water entering Cobscook Bay (Table A2). An average of the surface and bottom values on May 2,3,4 taken at 6 stations along the line was 5.75 µmoles NO_3 (5.75 ÊM * 62 µg NO_3 ÊM^{-1} = 356 µg NO_3 l^{-1} * 14/62 = 80.4 µg N l^{-1} = 0.08 g N m^{-3}).

9. Phytoplankton carbon in the waters entering Cobscook Bay is estimated from the average concentration of chlorophyll a at high tide along the Eastport - Lubec line (Table A3). The average of surface and bottom chlorophyll for May 2-4, 1995 was 0.12 µg l^{-1} which is multiplied by 30 µg C per µg chl a (Strickland 1960) to give 36 µg C l^{-1} or 0.036 gC m^{-3}.

10. The zooplankton entering Cobscook Bay from the sea (Table A4) was estimated from the average displacement volume at the three Passage stations sampled monthly in 1957 and 1958 by Legare and MacLellan (1960). Zooplankton displacement volume was expressed per volume of water by assuming that the towing speed used was about 3 knts, giving approximately 1000 m^3 of water filtered in a 15 min tow. Displacement volume in cc per m^{-3} was converted to mg C m^{-3} using the regression relationship established by Wiebe et al. (1975).

11. Water quality data from the Cobscook watershed is minimal;

therefore, USGS data from the neighboring Narraguagus River watershed was used under the assumption that the N discharged from the two watersheds per unit area was similar. Nitrate measurements of 0.01 g m^{-3} in Denny's River water and 0.13 g m^{-3} in water from the Hobart stream (Shenton and Horton 1973) compared to nitrite plus nitrate concentrations ranging from <0.1 g m^{-3} to 0.26 g m^{-3} (average 0.077 ± 0.47 g N m^{-3} assuming that <0.1 g m^{-3} = .05 g m^{-3}) measured in the Narraguagus River from 1981 - 1986 (USGS 1982, 1983, 1984, 1985, 1986, 1987) indicate that the N input from the Narraguagus watershed may be similar to the N input from the Cobscook Bay watershed.

12. McCollough and May (1980) observed the number of shorebirds for the six most abundant species in Cobscook Bay during 1979 (Table A5). The numbers in Table 6 can be used to estimate the relative abundance of shore birds during the northward and southward migration. I was not able to find the area information needed to convert these counts to numbers per m^2 of mudflat surface. The numbers in Table A6 are taken as a minimum estimate for the total number of shorebirds using Cobscook Bay mud flats during the southward migration. The number of feeding birds inside Cobscook Bay was taken as the most accurate estimate of the number of shore birds using mud flats within the Bay during the fall migration. At the peak use, August 10 - 20, 14,384 birds were feeding in the Bay or 14,384 birds / 1.81E3 ha mud flat (U.S. Army Corps 1980) = 8 birds ha^{-1} of mudflat. If shorebirds roosting in the area (not counting the 65,000 birds that briefly stopped at Carrying Place Cove) are taken as the measure of potential use of Cobscook Bay mudflats as many as 19 birds ha^{-1} might be expected to use mudflats within the Bay at least part of the time. Occasional use increases to 55 birds ha^{-1} when roosting birds including the 65,000 stop-overs are considered. Table A7 combines the information in Tables A5 and A6 to estimate the number of birds ha^{-1} mudflat moving in or out of Cobscook Bay each day.

13. The fish community on a 2 by 1 mile area of mud bottom near Western Passage just inside Passamaquoddy Bay was characterized by Tyler (1970). This fish community is assumed to be similar to the fish community found in Cobscook Bay. Tyler's mean numbers per 1/2 mi. tow were converted to number m^{-2} assuming his 3/4 - 35 Yankee trawl with a 40 ft. groundline had a net opening of about 20 ft. between the wings and that the trawl's fishing efficiency was 25% (Table A8).

14. Tyler did not catch a large number of juvenile fish possibly because juvenile fish could escape through the liner mesh size of 1 in. Most fish

caught were larger than 10 cm. Species that appeared to have young of the year (fish < 10 cm length) present in the size distributions presented by Tyler were alewives, redfish, and longhorn sculpin, and silver hake. Size distributions from seine samples taken along the inner Passamaquoddy shore (MacDonald et al. 1984) show that juvenile winter flounder and cod use Passamaquoddy Bay in the spring. I am unable to evaluate the movements or stock of juvenile fish in Cobscook Bay based on the data available in these papers. Estimates for processes dependent on juvenile fish biomass could not be made.

15. Average chlorophyll a from surface and bottom measurements taken throughout the Bay (Table A9) was converted to carbon using 30 mg C per mg Chl a (Strickland 1960). Larsen, *et al.* (this volume) areas for Deep Water and Shallow Water/Pens (7,167 ha) are used to calculate phytoplankton stock and production in the Bay.

16. The benthic microalgae carbon m^{-2} was estimated based on benthic chlorophyll a measured in this study and a carbon to chlorophyll ratio calculated in the phytoplankton section of this report (Table A10). Only 71% of the bottom samples attempted had suitable benthic diatom habitat; therefore, 71% of Larsen, *et al.* (this volume) areas for the three water classes and the Mudflat Class were used to calculate benthic microalgal stock and production in the Bay.

17. Surface and bottom concentrations of nitrate, nitrite, ammonia, phosphate and silicate were measured at 32-36 stations throughout Cobscook Bay at six times during 1995 (see Tables A11 and A12 for inorganic nitrogen). On May 2,3,4 there were 0.6 gN m^{-2} in the Bay.

18. Macrophyte biomass and productivity in Cobscook Bay was measured in this study by Robert Vadas of the University of Maine (this report). This note uses data on the annual average biomass and productivity provided by him to evaluate the model (Table A13). Data on the areas covered by the various plants were determined by Larsen, *et al.* (this volume) from a recent satellite image (Table A14) and by Barker based on modifications to Timson's 1976 CMGE classification. I distributed the productivity and biomass which Vadas found at high and low flow across the areas of greens and fucoids measured by Larsen et al. (1998) according to the proportion of area in a flow type determined by Barker who applied the velocity predictions of Brook's hydrodynamic model to Timson's data on bottom communities (Table A15). I used Barker's estimates for subtidal eelgrass and kelp (Table A16). Larsen *et al.* (this volume) found

that the two area estimates agreed within 10% of the total (see the remote sensing section of this report). The annual estimates of macrophyte biomass and production by species group in Cobscook Bay are given in Table A17. Use the conversion factors in Note 31 to change the wet weight biomass and productivity values in Table A17 to the carbon storages or flows shown on Figure 3 and in Table1.

19. The zooplankton in Cobscook Bay was estimated from the average displacement volume at the two Cobscook stations sampled monthly in 1957 and 1958 by Legare and MacLellan (1960). Zooplankton displacement volume was expressed per volume of water by assuming that the towing speed used was about 3 knts, giving approximately 1000 m^3 of water filtered in a 15 min tow. Displacement volume in cc per m^{-3} was converted to mg C m^{-3} using the regression relationship established by Wiebe (1975). Using data in Table A18 and assuming an average depth of 8.5 m, the 1957 - 1958 average value for May zooplankton concentrations in Cobscook Bay was 2.6 mg C m^{-2}. The annual average biomass from is 0.73 mgC m^{-3} X 8.0E8 m^{-3} average volume of the Bay = 5.84E5 gC is the annual average standing stock in the Bay.

20. Some information on the concentration of suspended matter in Cobscook Bay is available from a summer project by P. A. Schroeder. Table A19 summarizes his data as reported in U.S. Army Corps (1980). Detritus export from Cobscook Bay in July was estimated as 0.15 mg l^{-1} detritus $tide^{-1}$ by subtracting the average concentration on ebb tide from the average concentration on flood. The average stock of detritus suspended in the water column for July 1975 was 1.85 mg l^{-1} or 15.7 g m^{-2} X 0.33 C/dwt. = 5.2 gC m^{-2} assuming 8.5 m is the average depth of the Bay. Additional data from Schroeder (1977) presented in U.S. Army Corps (1980) shows that the inner bay exported 1.5 mg l^{-1} of detritus per tide to the outer bay during July 1977. Detritus export from the Bay in July can be estimated by multiplying the detritus concentration difference by the tidal exchange volume, 0.15 g m^{-3} * 3.61E8 m^{-3} $tide^{-1}$ = 5.42E7 g dwt. * 1.9342 tides d^{-1} = 1.05E8 g dwt. d^{-1} ÷ 1.04E8 m^{-2} = 1 g m^{-2} d^{-1} * 0.33 gC/gdwt (Table A19) = 0.33 gC m^{-2} d^{-1}. The 0.33 C to dwt. ratio assumes that the detritus is mostly derived from macroalgae. If this gradient is maintained over the year 120 gC m^{-2} y^{-1} of detritus are exported which is equal to 12.5 X 10^6 kg C y^{-1} if the area of the Bay is taken as 1.04 X10^6. During the first July 1995 sampling period, I observed numerous fragments of macroalgae of all sizes suspended in the water and present on the millipore filters.

21. Invertebrate counts from Cobscook Bay intertidal areas were made by McCollough and May (1980) but they were not reported. Larsen et al. (1979) reported the benthic invertebrates found on a low energy rocky intertidal area near Dennysville. The most extensive information that I could find on the benthic invertebrate infauna of subtidal Cobscook Bay was in Heinig and Bohlin (1995). Selected stations from their report on benthic infauna and sediment characteristics around salmon aquaculture sites in Cobscook Bay are summarized in Table A20. These benthic communities were sampled during October of 1992 and 1993. I have used the numbers of *Capitella capitata* as an index of the degree of alteration of the natural infauna community. Samples with low numbers of *Capitella capitata* away from or upstream from pens were assumed to represent the natural abundance of benthic infauna in Cobscook Bay. The average number of infauna m^{-2} in the Outer Bay is 113,630 ± 137,480 animals based on data in Table A20. We might expect to find 39 ± 15.5 species m^{-2} in a typical Outer Bay infauna community based on this data.

22. Todd (1979) studied the ecology of bald eagles in Maine. He found that Cobscook Bay supported a dense population of eagles which included seven occupied breeding sites in 1977 and 1978. Of these seven pairs five bred successfully in 1977 but only three were successful in 1978. Seven young chicks were fledged from these nests in 1977 and six in 1978. In the winter of 1977 Cobscook Bay supported ten adult and three immature eagles and in 1978 12 adults and two immature birds overwintered there. From this information, I estimate that in the late seventies Cobscook Bay supported approximately 14 birds or one bird for every 742 ha of the water surface at high tide.

23. The breeding population of harbor seals, *Phoca vitulina,* in Cobscook Bay was estimated at several hundred individuals (U.S. Army Corps, 1980). We take 300 as a rough estimate of the resident seal population in 1980. Their numbers are expressed ha^{-1} of water surface in Table 1. A population of the harbor porpoise, *Phocoena phocoena*, is known to reside in Cobscook Bay but it was not assessed for this study.

24. Phytoplankton production was estimated in this study (see section on phytoplankton) based on water column chlorophyll a and light (Table A21).

25. The primary production of benthic microalgae was estimated based on benthic chlorophyll a measurements made throughout Cobscook Bay and irradience at the sediment surface (Table A22).

26. Strickland (1960) suggested a C/N ratio of 6± 2 for phytoplankton. Applying this ratio to our primary production estimates for phytoplankton in Cobscook Bay gives 0.018 gN $m^{-2} d^{-1}$ nitrogen uptake by phytoplankton in May. Divide the numbers in Table A21 by 6 to estimate N uptake by phytoplankton at other times.

27. Vinogradov (1953) gave factors for converting wet weight of algae to dry weight, carbon or nitrogen (Table A23).

These factors are applied to production values in Table 18 as follows:

(1) Browns, 26.4 kg wwt. $m^{-2} y^{-1}$ * 0.266 dwt/wwt. * 0.019 fraction N = 0.13 kg N $m^{-2} y^{-1}$.

(2) Greens, 1.53 kg wwt. $m^{-2} y^{-1}$ * 0.256 dwt/wwt. * 0.021 fraction N = 0.0082 kg N $m^{-2} y^{-1}$.

(3) Kelp, 11.5 kg wwt. $m^{-2} y^{-1}$ * 0.158 dwt/wwt. * 0.02 fraction N = 0.0363 kg N $m^{-2} y^{-1}$.

(4) Eelgrass, 6 kg wwt. $m^{-2} y^{-1}$ * 0.15 dwt/wwt. * 0.019 fraction N = 0.017 kg N $m^{-2} y^{-1}$.

28. Strickland (1960) suggested a C/N ratio of 6±2 for phytoplankton. We assume that this ratio also applies to benthic diatoms. Dividing the May primary production estimate for benthic microalgae in Table A22 by 6 gives 0.082 gN $m^{-2} d^{-1}$ for the nitrogen uptake by benthic microalgae.

29. Large zooplankton were assumed to eat approximately 20% of their body weight per day (Parsons and Tagahashi 1973). We estimate that the May zooplankton concentration is 0.3 mg C m^{-3} * 8.5 m = 2.55 mg C m^{-2} * 0.2 = 0.5 mg C $m^{-2} d^{-1}$ phytoplankton carbon grazed by zooplankton in May.

30. Table 24 shows that during July there was a net influx of chlorophyll a into Cobscook Bay from Head Harbor Passage. A minimum estimate for the carbon consumed in the estuary can be made for this time. The excess chlorophyll which comes into the Bay in this month must have been consumed by suspension feeders or settled to the bottom. In May and October there is a net export of chlorophyll indicating that phytoplankton production in the Bay exceeded grazing by suspension feeders. Using a chl a : carbon ratio of 30 gives 14.1 and 46.2 mg C m^{-3} used within the Bay on the first and second sample periods in July, respectively. An average of 256 mg C m^{-2} $tide^{-1}$ (z = 8.5 m) or 495 mg C $m^{-2} d^{-1}$ (for 1.9342 tides d^{-1}) are lost to grazing and settling in Cobscook Bay during July. In a dynamic environment such as Cobscook Bay we might expect that the net

loss to settling would be a small fraction (< 10% is a conservative estimate) of this total. Thus, we estimate that approximately 445 mg C m^{-2} d^{-1} are consumed by suspension feeding in Cobscook Bay during July. Subtracting out our July estimate of zooplankton grazing (3 mg C m^{-2} d^{-1} based on assumptions given above) gives 442 mg C m^{-2} d^{-1} grazed by the benthic community in July. If this grazing is nonselective (in proportion to the abundance of suspended food items) 80% of the chlorophyll a consumed is from benthic microalgae and 20% from phytoplankton. Chlorophyll a was exported from Cobscook Bay to the Head Harbor Passage in May and October, therefore, no estimate of benthic consumption could be made. If winter consumption is 1/2 of that in the summer then benthic community grazing on suspended phytoplankton and benthic diatoms is 331 mg C m^{-2} d^{-1}.

31. The contribution of macroalgae to the detritus pool in Cobscook Bay can be estimated, assuming that direct grazing on macroalgae is small. Allowing 10% of net production for direct grazing by benthic invertebrates on macroalgae, 90% of macroalgal net production would go to the detritus pool.

Net production per m^{-2} of surface covered by algae of a given type:

(1) Browns, 26.4 kg wwt. m^{-2} y^{-1} * 0.266 dwt/wwt. * 0.367 C/dwt = 2.58 kg C m^{-2} y^{-1} .

(2) Greens, 1.53 kg wwt. m^{-2} y^{-1} * 0.256 dwt/wwt. * 0.338 C/dwt = 0.132 kg C m^{-2} y^{-1}.

(3) Kelp, 11.5 kg wwt. m^{-2} y^{-1} * 0.158 dwt/wwt. * 0.294 C/dwt = 0.534 kg C m^{-2} y^{-1}.

(4) Eelgrass, 6 kg wwt. m^{-2} y^{-1} * 0.15 dwt/wwt. * 0.339 C/dwt = 0.31 kg C m^{-2} y^{-1}.

Decreasing these values by 10% to account for grazing and multiplying by the area in algae of a given type gives an estimate of detritus production in kgC y^{-1} for Cobscook Bay.

(1) Browns, 2.58 kg C m^{-2} y^{-1} *0.9 * 9.95 X 10^6 m^2 = 23.1 X 10^6 kgC y^{-1}
(2) Greens, 0.132 kg C m^{-2} y^{-1} *0.9 * 7.25 X 10^6 m^2 = 0.86 X 10^6 kgC y^{-1}
(3) Kelp, 0.534 kg C m^{-2} y^{-1} *0.9 * 0.96 X 10^6 m^2 = 0.46 X 10^6 kgC y^{-1}
(4) Eelgrass, 0.31 kg C m^{-2} y^{-1} *0.9 * 1.9 X 10^6 m^2 = 0.53 X 10^6 kgC y^{-1}

We estimate that macroalgae and eelgrass can potentially supply a total of 25 X 10^6 kgC y^{-1} or 3.7 gC m^{-2} d^{-1} of detritus from area covered by macroalgae and 0.76 gC m^{-2} d^{-1} from area in eelgrass.

32. Primary production of benthic microalgae averaged between 290 and

438 gC m^{-2} y^{-1} (Table 2) or an average of 1.0 gC m^{-2} d^{-1} in areas with suitable habitat. If 56.3 X 10^6 m^2 of the intertidal and subtidal area is suitable for benthic microalgae between 16.3 and 24.7 X 10^6 kg C y^{-1} is consumed by suspension feeders or goes into the detritus pool of Cobscook Bay. We assume that 90% of benthic algae are regularly suspended in the water column (Campbell and Newell, 1998) and therefore they are subject to the same processes that govern phytoplankton. We assume that 90% of resuspended benthic microalgal production could be grazed by dense shellfish beds (Newell et. al. 1998) or an average of 16.6 X 10^6 kg C y^{-1} and the remainder or 4.1 X 10^6 kg C y^{-1} or 0.2 gC m^{-2} d^{-1} enters the detritus pool. Export of benthic algae is assumed to be small.

33. During July detrital carbon is about 1.65 times greater than the carbon in suspended phytoplankton. There are 1.85 g dwt. m^{-3} (Table A19)*0.33 C/dwt. = 0.62 gC m^{-3} of organic matter in the water column which included 0.057 gC m^{-3} of phytoplankton (Table A9) and 0.22 gC m^{-3} of benthic algae (Table A10) if 90% are resuspended. Subtracting our July 1995 measurements from Schroeder's earlier estimates of July organic matter gives 0.46 gC m^{-3} of detritus in the water column. We might expect benthic suspension feeders to consume food in proportion to its abundance. We don't know how much detritus is consumed by benthic macrofauna based on the information available, but a maximum estimate for July based on nonselective feeding and a benthos which consumes 90% of the available food would be 0.41 gC m^{-3} d^{-1}. If the benthos feed selectively so that detritus is consumed at 50% of the rate algae is eaten then only 0.2 gC m^{-3} d^{-1} of detritus is eaten. Detritus consumption by the benthos for selective and nonselective feeding ranges from 465 to 792 gC m^{-2} y^{-1} assuming that the winter consumption rate is 25% of the summer or July consumption rate. If the area of potential shellfish beds is taken as 1/2 of the subtidal area 35.8 X 10^6 m^2 then between 16.6 and 28.4 kgC y^{-1} X 10^6 or 1.72 gC m^{-2} d^{-1} of detritus are consumed by suspension feeders.

34. The consumption of detrital carbon by bacteria was not estimated. An estimate could be made by applying decomposition rates from the literature to our estimate of the detritus stock in Cobscook Bay.

35. An estimate for the macrofauna eaten by shorebirds could be made using the bird populations given here, the data in McCullough (1981), and literature estimates of the metabolic requirements for the various shorebird species. This is beyond the scope of our present study.

36. An estimate of the macrofauna eaten by fish might be made from the fish densities and feeding data manipulated from Tyler (1971,1972). This calculation is beyond the scope of the present work.

37. McCollough (1981) did not observe shorebirds feeding on juvenile fish.

38. Eagle diet in coastal Maine is described in Todd (1979). Using literature estimates for the metabolic requirements of eagles or similar raptors, Todd's dietary data and the eagle population estimates given above and estimates for water fowl and fish consumption by Cobscook Bay eagles might be made. This calculation is beyond the scope of work for this project.

39. Nitrogen recycled by the various consumer groups important in Cobscook Bay follows directly from the calculation of the metabolic requirements for each group using an appropriate C to N ratio for each group. These calculations are beyond the scope of this work.

40. The concentration differences inside and outside Cobscook Bay on the sample dates in 1995 were determined for NO_3, Table A25, NH_4 Table A26, NO_2, Table A27, PO_4, Table A28, and SiO_3, Table A29. Import-export fluxes were calculated from these concentration differences (Table 4) by multiplying these concentration differences by the tidal exchange volume (3.61×10^8 m^3 $tide^{-1}$. For example, the May NO_3 concentration difference was 1.03 Êmoles NO_3 which equals 14.4 mg N m^{-3} X 3.61 X 10^8 m^3 $tide^{-1}$ = 5.2 X 10^6 gN per tide and multiplying by 1.934 tides d^{-1} gives 1.0 X 10^7 gN d^{-1} or, dividing by area, 0.097 gN m^{-2} d^{-1} exported as NO_3 in May. Table A30 combines data on NO_3, NO_2, and NH_4 to determine the net flux of inorganic nitrogen which was 0.11 gN m^{-2} d^{-1} for May 1995. Table A31 shows the net inorganic N exchange as a weighted average of the concentration differences over the course of a year.

41. Table A24 shows the chlorophyll a concentration difference along the Eastport to Lubec line on the sample dates in 1995. Converting Êg chl a l^{-1} to gC m^{-3} and multiplying by the tidal exchange volume gives the phytoplankton carbon imported or exported per tide. In May, 0.13 Êg chl a l^{-1} * 30 C:Chl a gives a concentration difference of 3.9 mg C m^{-3} between inside and outside the Bay or an export of phytoplankton carbon equal to 1.41 X 10^6 gC $tide^{-1}$ or 2.72 X 10^6 gC d^{-1} or 0.026 gC m^{-2} d^{-1} in May.

42. Zooplankton import or export may be calculated from the information in Table A32 in a manner similar to that used for NO_3 and phytoplankton. In May, we estimate that approximately 1.4×10^4 gC d^{-1} or 1.35×10^{-4} gC m^{-2} d^{-1} of zooplankton is exported from the Bay through tidal exchange. This assumes that the zooplankton behave like passive particles which is probably not true.

43. Estimating food consumption and remineralization work of seals and other marine mammals is limited by the amount of information available on the size of the Cobscook Bay population. Such estimates would also rely on literature studies of the Harbor seal and are beyond the scope of this study.

44. Landings data for Washington County in 1996 were supplied by K. Lyons of the Maine Department of Marine Resources. The major fin fish species taken in that year were white hake (49,962 lbs.), cod (34,992 lbs.), pollack (38,756 lbs.), and herring (291,550 lbs.). Commercial shellfisheries for soft clams, sea scallops, periwinkles, sea cucumbers and urchins presently exist in Cobscook Bay. The live weights of these species landed in Washington Co. in 1996 were 2,064,360 lbs. soft clams, 2,210,212 lbs. sea scallops, 6,350,826 lbs. urchins, 2,561,388 lbs. sea cucumbers, and 317,347 lbs. periwinkles. Landings reported for Washington Co. are not given by the location in the county where they were caught; therefore, we can not determine the portion of the 1996 landings that were caught in Cobscook Bay. The U.S. Army Corps of Engineers (1980) reported that Cobscook Bay did not appear to have significant commercially valuable fish stocks. Dow (1959) reported that the Cobscook Bay clam harvest averaged 9.5% of Washington Co. landings from 1948 to 1957. Quoddy scallop landings which are mostly taken from Cobscook Bay averaged 43.3 % of the county landings over a similar time span. We do not have enough information to determine the commercial landings of fish and shellfish captured in Cobscook Bay.

45. We were unable to find estimates of denitirfication for Cobscook Bay.

Table A1. Day of the Year and Annual Average Values for Solar Radiation received at Eastport in joules m^{-2} d^{-1}.

Day of the Year	Flat Plate	a =0.7	a=0.8	a=0.9
15	6.42E+06			
30	9.80E+06			
35		6.33E+06	7.07E+0	8.06E+06
60	1.37E+07			
80		1.25E+07	1.37E+07	1.51E+07
90	1.68E+07			
120	1.96E+07			
126		1.83E+07	1.99E+07	2.16E+07
151	2.14E+07			
173		2.08E+07	2.25E+07	2.44E+07
182	2.10E+07			
212	1.86E+07			
220		1.89E+07	2.06E+07	2.24E+07
243	1.43E+07			
266		1.25E+07	1.37E+07	1.52E+07
274	9.60E+06			
304	5.92E+06			
312		5.76E+06	6.45E+06	7.35E+06
335	4.98E+06			
356		3.77E+06	4.27E+06	4.96E+06
Annual Average	1.36E+07	1.24E+07	1.35E+07	1.49E+07

Table A2. Average NO_3 concentrations at high tide along the Eastport-Lubec line on the dates given.

Date (1995)	µmoles NO_3
May 2,3,4	5.75
July 11,12,13	1.85
July 21,22,32	1.85
October 24,25,26	1.40
November 7,8,9	7.63

Table A3. Average phytoplankton chlorophyll measured at high tide along the Eastport-Lubec line on the dates given.

Date (1995)	µg chl a l^{-1}
May 2,3,4	0.12
July 11,12,13	1.84
July 21,22,32	2.37
October 24,25,26	0.24
November 7,8,9	0.22

Table A4. Average monthly zooplankton displacement volumes in cc for 1957 and 1958 at the Passage stations of Legare and MacLellan (1960).

Month m^{-3} *	1957	1958	Avg. cc m^{-3}	mgC
January	18	40	0.029	0.734
February	9	15	0.012	0.246
March	6	9	0.0075	0.138
April	5	12	0.0085	0.161
May	5	7	0.006	0.104
June	6	30	0.018	0.407
July	5	85	0.045	1.26
August	3	16	0.0095	0.184
September	17	10	0.0135	0.285
October	36	8	0.022	0.52
November	8	26	0.017	0.380
December	10	52	0.031	0.797

* Log (DV cc m^{-3}) = -1.429 + 0.808 (Log mg C m^{-3}) Wiebe (1975)

Table A5. Maximum counts of feeding and roosting shorebirds using Cobscook Bay in ten day periods during the spring migration 1980 and fall migration 1979. Both inner and outer shorelines are included in these estimates (McCullough 1981, McCullough and May 1980).

Date	SpS	Sa	YL	RT	SpP	BbP	Total
Spring 1980							
April 14-27	0	0	1	0	0	0	1
April 28-May 4	0	0	14	0	0	0	14
May 5-11	0	0	11	0	0	5	16
May 12-21	34	0	2	1	2	87	126
May 22-25	54	0	3	2	5	38	102
May 26-June 1	144	0	0	0	0	69	213
June 2-8	42	0	0	0	0	5	47
Summer 1979							
July 1-10	11	0	31	0	0	0	42
July 10-20	748	0	36	0	3	0	787
July 20-30	24093	123	71	10	1012	4	25313
Aug. 1-10	23600	70	20	11	1206	11	24918
Aug. 10-20	75782	51	10	134	928	2066	78971
Aug. 20-30	25900	395	40	15	2816	369	29535
Sep. 1-10	2505	0	0	0	7	55	2567
Sep. 10-20	5448	6	10	4	222	132	5822
Sep. 20-30	76	0	0	0	16	0	92

SpS = semipalmated sandpipers, Sa = sanderlings, YL = greater and lesser yellow legs, RT = ruddy turnstone, SpP = semipalmated plover, BbP = black-bellied plover.

Table A6. Maximum number of the six dominant shorebird species on the major and minor mudflats inside and outside Cobscook Bay during the 1979 southward migration (McCullough 1981, McCullough and May 1980).

Location	Maximum Number	
	Feeding	Roosting
Outside		
Lubec Flats	2900	
Lubec Center	864	13691
Town of Lubec	1100	5084
Lubec gravel bar		6775
Lubec salt marsh		1525
International Bridge	400	
Johnson Cove		6800
Carlow Island	3480	300
Gleason Cove	2000	
Subtotal	10744	34175
Inside		
Broad Cove	1758	
Carrying Place Cove	6000	65000
Half Moon Cove	4160	
Birch Point	400	250
Goose Island		200
East Bay	500	
Sipp Bay	469	
Pennamaquan River	46	
Hersey Cove	300	
Hardscrabble River	18	
Denny's River	8	
Hobart Stream	20	
Edmunds	187	
Whiting Bay	482	
Nutter Cove	0	
Federal Harbor	a few	
Hallowell Is.		150
Subtotal	14348	600
Total	25092	99775

Table A7. Estimates of shore birds entering and leaving feeding grounds in Cobscook Bay by combining the information in Tables 5 and 6.

Date	Relative Use Number	Feeding inside Number ha^{-1}	Gain or Loss Number ha^{-1} da^{-1}
Spring 1980			
April 14-27	1	0.0001	+ 0.00001
April 28- May 4	14	0.001	+0.00013
May 5-11	16	0.002	+0.00014
May 12-21	126	0.013	+0.00081
May 22-25	102	0.010	-0.00043
May 26-June 1	213	0.022	+0.0022
June 2-8	47	0.005	-0.0024
Summer 1979			
July 1-10	42	0.004	+0.0004
July 10-20	787	0.08	+0.0076
July 20-30	25313	2.56	+0.248
Aug. 1-10	24918	2.56	+0
Aug. 10-20	78971	8.00	+0.544
Aug. 20-30	29535	2.99	-0.500
Sep. 1-10	2567	0.26	-0.273
Sep. 10-20	5822	0.590	+0.033
Sep. 20-30	92	0.009	-0.0581

Table A8. Fish abundance of all species by month from a mud bottom in Passamaquoddy Bay assuming that the net swept approximately 5000 m^{-2} (Tyler 1970). In and out migration are calculated based on these abundance measurements.

Month	# m^{-2}	# m^{-2} entering (+) or leaving (-)
April	0.26508	-0.10272
May	0.16236	-0.05488
June	0.10748	0.07208
July	0.17956	0.13436
August	0.31392	-0.05404
September	0.25988	-0.11428
October	0.1456	0.05632
November	0.20192	0.00748
December	0.2094	-0.11452
January	0.09488	-0.02252
February	0.07236	0.00888
March	0.08124	0.18384

Table A9. Average of surface and bottom chlorophyl measured in Cobscook Bay was converted to carbon using a ratio of 30 mgC mgchl a^{-1} (Strickland 1960). The average sonic depth, 8.5 m, was used to calculate biomass m^{-2}.

Dates	Avg. mg chl a l^{-1}	mgC m^{-3}	gC m^{-2}
May 2,3,4	0.39±0.22	11.8	0.10
May 16,17,18	0.69±0.51	20.8	0.18
July 11,12,13	2.08±0.81	62.3	0.53
July 21,22,32	1.70±0.83	50.9	0.43
October 24,25,26	0.68±0.43	20.5	0.17
November 7,8,9	0.54±0.32	16.2	0.14

Table A10. Average benthic carbon was estimated from benthic chlorophyl a measured in Cobscook Bay (Phinney and Yentsch, this report).

Dates	gC m^{-2}
May 2,3,40.10	1.15
May 16,17,18	2.26
July 11,12,13	1.13
July 21,22,32	3.11
October 24,25,26	1.90
November 7,8,9	2.35

Table A11. Average of surface and bottom concentrations of nitrate, nitrite and ammonia in moles measured in Cobscook Bay (Phinney and Yentsch, this report).

Dates	NO_3 moles	NO_2 moles	NH_4 moles
May 2,3,4	3.81±0.87	0.11±0.1	1.13±0.32
May 16,17,18	3.66±1.07	0.11±0.1	3.11±1.07
July 11,12,13	0.86±0.86	0.12±0.11	1.89±1.14
July 21,22,32	0.87±0.60	0.23±0.13	2.32±0.98
October 24,25,26	2.60±2.67	0.33±0.23	1.98±0.86
November 7,8,9	6.91±0.70	0.48±0.15	3.16±1.79

Table A12. Average nitrate, nitrite and ammonia nitrogen m^{-2} if the average depth is 8.5 m.

Dates	NO_3 gN m^{-2}	NH_4 gN m^{-2}	NO_2 gN m^{-2}	Total
May 2,3,4	0.45	0.13	0.01	0.60
May 16,17,18	0.44	0.37	0.01	0.82
July 11,12,13	0.14	0.23	0.01	0.38
July 21,22,32	0.10	0.28	0.03	0.41
October 24,25,26	0.31	0.24	0.04	0.58
November 7,8,9	0.82	0.38	0.06	1.26

Table A13. Average biomass and productivity of the major types of aquatic macrophytes in Cobscook Bay (Vadas, Personal Communication). High flow values for greens are given first for low and next for high nutrient supply.

Macrophyte Biomass or Productivity	Low flow kg wwt. m^{-2}	Highflow kg wwt. m^{-2} y^{-1}
Kelp (*Laminaria longicruris*)		
Biomass	4.6	2.0
Productivity	11.3	11.6
Productivity Range	1.3 - 25.6	5.3 - 15.7
Fucoids (*Ascophyllum nodosum*)		
Biomass	25	36.7
Productivity	20	60
Productivity Range	13 - 34	33 - 93
Greens (*Enteromorpha* and *Ulva*)		
Biomass	0.218	0.069/0.285
Productivity	1.52	1.04/2.14
Productivity Range	0.1 - 2.9	0.233-0.81/0.97-3.77
Eelgrass (*Zostera marina*)		
Biomass	0.54	0.59
Productivity	5.76	6.66
Productivity Range	1.07 - 11.9	1.11 - 8.46

Table A14. Area weighted average intertidal macrophyte cover for browns and greens from Larsen, *et al.*'s analysis (this report).

Cover Class	% Cover	Area ha	Weighted Cover
Brown Algae (Fucoids)			
Algal Flat	25	589.4	0.072
Mixed Sediment	5	270.5	0.007
Cobble/Brown Algae	50	247.4	0.061
Dense Brown Algae	90	595.7	0.263
Ledge/Brown Algae	50	340.6	0.084
Total		2043.5	0.487
Green Algae			
Dense Green Algae	90	435.5	0.266
Algal Flat	25	589.4	0.090
Moderate Green Algae	50	344.9	0.105
Mixed Sediment	5	270.5	0.008
Total		1640	0.442

Table A15. Fraction of macrophyte area that was found in each flow type (Barker, Personal Communication). Low flow type includes medium and low flow areas identified using results from the hydrodynamic model (Brooks, 1997)

Macrophyte Flow type	Area ha	flow type fraction	Covered area (ha) in flow type*
Brown Algae (Fucoids)			
Low flow	1028	0.84	836
High flow	203	0.16	159
Green Algae			
Low flow	10.4	0.84	609
High flow	2.0	0.16	116

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* the covered area in a flow type was calculated by applying fraction of area in a flow type (Barker, Personal Communication) to Larsen, *et al.* (this report) estimate of area covered.

Table A16. The area weighted average for the subtidal macrophyte cover of eelgrass and kelp for two flow types (Barker, Personal Communication). Medium and high flow areas identified by Barker using Brook's model are combined.

Cover Class type	% Cover	Area ha	Covered Area	fraction in flow
Kelp				
Low flow				
Cover Class 1	5	0.4	0.02	
Cover Class 2	15	110.0	16.5	
Cover Class 3	55	14.3	7.8	
Cover Class 4	85	14.6	12.4	
Subtotal		139.3	36.7	0.38
Med. and high flow				
Cover Class 1	5	0.8	0.04	
Cover Class 2	15	100.7	15.1	
Cover Class 3	55	28.0	15.4	
Cover Class 4	85	33.8	28.7	
Subtotal		163.3	59.2	0.62
Eelgrass				
Low flow				
Cover Class 1	5	44.9	2.24	
Cover Class 2	15	114.5	17.2	
Cover Class 3	55	160.1	88.1	
Cover Class 4	85	35.2	29.9	
Subtotal		354.7	137.4	0.74
Med. and high flow				
Cover Class 1	5	10	0.5	
Cover Class 2	15	28.7	4.3	
Cover Class 3	55	61	33.6	
Cover Class 4	85	11.7	9.9	
Subtotal		111.4	48.3	0.26

Table A17. Average macrophyte biomass and productivity per m^{-2} of covered area weighted by the fraction of area in a flow type. Medium flow areas were grouped with low flow for browns and greens and with high flow for kelp and eelgrass (Barker, Personal Communication).

Macrophyte	Avg. Biomass kg wwt. m^{-2}	Avg. Productivity kg wwt. m^{-2} y^{-1}	Area X 10^6 m^{-2}
Intertidal			
Brown Algae	26.9	26.4	9.95
Green Algae	0.2	1.53	7.25
Subtidal			
Kelp	3.0	11.5	0.96
Eelgrass	0.6	6.0	1.86

Table A18. Average monthly zooplankton displacement volumes in cc for 1957 and 1958 at the Cobscook Bay stations from Fig. 4 in Legare and MacLellan (1960).

Month	1957	1958	Avg. cc m^{-3}	mgC m^{-3} *
January	22	125	0.074	2.34
February	12	20	0.016	0.35
March	2	11	0.0065	0.12
April	11	8	0.0095	0.18
May	10	18	0.014	0.30
June	25	15	0.020	0.46
July	14	100	0.057	1.69
August	3	95	0.049	1.40
September	12	38	0.025	0.61
October	18	20	0.019	0.43
November	10	30	0.020	0.46
December	9	30	0.0195	0.45

* Log (DV cc m^{-3}) = -1.429 + 0.808 (Log mg C m^{-3}) Wiebe (1975)

Table A19. Concentrations of suspended matter and the % organic fraction in Cobscook Bay during July 1977.

Quantity	Ebb Tide		Flood tide	
	Surface	Bottom	Surface	Bottom
	mg l^{-1}		mg l^{-1}	
Mean	3	4	3	3
Range	8	9	5	5
% organic	60	50	70	50
Detritus	1.8	2.0	2.1	1.5
Std. Deviation	0.6	0.8	1.2	0.9

Table A20. Selected benthic stations in the Outer Bay (Heinig and Bohlin, 1995) with low to moderate impacts on the benthic community from salmon aquaculture.

Location	Individuals # 0.1 m^{-2}	Species #	Silt-clay %	TOC %	Capitella %
Broad Cove					
1	41401	45	6.6	2.22	31.4
7	11081	37	79.3	3.13	30.6
11	3492	23	87.3	3.30	7.1
Seward Neck - Treat Is.					
1	28678	53	8.1	1.44	56
4	11390	31	7.9	0.9	47
6	9564	29	7.7	1.83	63
Deep Cove					
2	19300	48	42.2	1.73	9.1
3	12315	62	42.3	2.11	1.3
7	32491	70	24.1	2.62	4.9
8	32615	69	10.2	1.42	8.3
Johnson Bay					
1	234	26	84.1	1.56	0.4
5	57	22	82.2	1.92	1.8
9	279	25	58.9	1.53	0.4
10	191	27	85.5	1.61	0.0
Dudley Is.					
1	529	27	16.0	0.97	6.4
Shakelford Head					
6	310	34	6.0	1.35	11.9
1	415	41	9.0	1.24	19.8
Birch Point					
1	181	35	20.0	1.44	10.5

Table A21. Average phytoplankton primary production in the waters of Cobscook Bay during six sample times in 1995 (Phinney, Personal Communication).

Date	Phytoplankton Production gC m^{-2} d^{-1}	n
May 2,3,4	0.11 ± 0.12	16
May 16,17,18	0.17 ± 0.17	18
July 11,12,13	1.08 ± 0.44	17
July 21,22,23	0.83 ± 0.50	17
October 24,25,26	0.09 ± 0.08	18
November 7,8,9	0.06 ± 0.06	17

Table A22. Average primary production of benthic microalgae on the bottom of Cobscook Bay measured at stations during six sample times in 1995 (Phinney, Personal Communication).

Date	Benthic Microalgae Production gC m^{-2} d^{-1}	n
May 2,3,4	0.49 ± 0.60	12
May 16,17,18	1.55 ± 1.98	12
July 11,12,13	1.17 ± 1.17	11
July 21,22,23	4.46 ± 3.97	12
October 24,25,26	0.74 ± 2.28	15
November 7,8,9	0.16 ± 0.17	14

Table A23. Conversion factors from Vinogradov (1953).

Species of Algae	% H_2O	C as % dwt.	N as % dwt.
Fucoids			
Ascophyllum nodosum	74.4	38.0	2.12 (n=3)
Fucus vesiculosus	72.3	35.3	1.64 (n=14)
Average	73.4	36.7	1.88
Greens			
Enteromorpha	70.8	31.5	1.57 (n=5)
Ulva	78.0	36.1	2.66 (n=8)
Average	74.4	33.8	2.12
Kelp			
Laminaria digita	81.2	31.9	2.23 (n=20
Laminaria saccharina	87.1	26.8	1.80 n=13)
Average	84.2	29.4	2.02
Eelgrass			
Zostera marina	85	33.9 (n=12)	1.91 (n=22)

Table A24. The difference between average phytoplankton chlorophyll a measured at high tide and low tide along the Eastport-Lubec line.

Date (1995)	High tide	Low tide	Difference
		µg chla l^{-1}	
May 2,3,4	0.12	0.25	- 0.13
July 11,12,13	1.84	1.37	0.47
July 21,22,32	2.37	0.83	1.54
October 24,25,26	0.24	0.76	- 0.52
November 7,8,9	0.22	0.59*	- 0.37

* Data from low tide on the Birch Point to Gove Point line.

Table A25. The difference between the average NO_3 concentrations at high tide and low tide along the Eastport-Lubec line.

Date (1995)	High tide	Low tide	Difference
		µmoles NO_3	
May 2,3,4	5.75	4.72	1.03
July 11,12,13	1.85	1.42	0.43
July 21,22,32	1.85	1.40	0.45
October 24,25,26	1.40	4.49	-3.09
November 7,8,9	7.63	7.12*	0.51

* Data from low tide on the Birch Point to Gove Point line.

Table A26. The difference between the average NH_4 concentrations at high tide and low tide along the Eastport-Lubec line.

Date (1995)	High tide	Low tide	Difference
		µmoles NH_4	
May 2,3,4	1.55	1.39	0.16
July 11,12,13	2.72	1.81	0.91
July 21,22,32	3.41	2.18	1.23
October 24,25,26	2.19	2.23	- 0.04
November 7,8,9	1.36	1.85*	- 0.49

* Data from low tide on the Birch Point to Gove Point line.

Table A27. The difference between the average NO_2 concentrations at high tide and low tide along the Eastport-Lubec.

Date (1995)	High tide	Low tide	Difference
	µmoles NO_2		
May 2,3,4	0.17	0.18	- 0.01
July 11,12,13	0.10	0.05	0.05
July 21,22,32	0.22	0.16	0.06
October 24,25,26	0.16	0.48	- 0.32
November 7,8,9	0.38	0.48*	- 0.10

* Data from low tide on the Birch Point to Gove Point line.

Table A28. The difference between the average PO_4 concentrations at high tide and low tide along the Eastport-Lubec line.

Date (1995)	High tide	Low tide	Difference
	µmoles PO_4		
May 2,3,4	0.52	0.50	0.02
July 11,12,13	0.27	0.34	- 0.07
July 21,22,32	0.33	0.47	- 0.14
October 24,25,26	0.14	0.52	- 0.38
November 7,8,9	0.76	0.71*	0.05

* Data from low tide on the Birch Point to Gove Point line.

Table A29. The difference between the average SiO_3 concentrations at high tide and low tide along the Eastport-Lubec line.

Date (1995)	High tide	Low tide	Difference
		µmoles SiO_3	
May 2,3,4	8.20	7.68	0.52
July 11,12,13	3.32	3.86	- 0.54
July 21,22,32	4.42	3.75	0.67
October 24,25,26	3.65	6.46	- 2.81
November 7,8,9	9.63	11.49*	- 1.15

* Data from low tide on the Birch Point to Gove Point line.

Table A30. The net difference in concentrations of inorganic nitrogen at high tide and low tide along the Eastport-Lubec line. Positive values have higher concentrations on the flood.

Date (1995)	NO_3	NH_4	NO_2	Net Change
			mg N m^{-3}	
May 2,3,4	14.4	2.24	- 0.14	16.5
July 11,12,13	6.0	12.7	0.7	19.4
July 21,22,32	6.3	17.2	0.84	24.3
October 24,25,26	- 43.3	- 0.56	- 4.48	- 48.3
November 7,8,9	7.1	- 6.86	- 1.14	- 1.12

Table A31. The weighted average inorganic nitrogen concentration difference between flood and ebb tide along the Eastport to Lubec line over a year.

Fraction of days X	Avg. N concentration mg N m^{-2}	= Weighted fraction mg N m^{-2}
175/365	(-1.12+16.5)/2	3.69
70/365	(16.5 + 19.4)/2	3.44
10/365	(19.4 + 24.3)/2	0.60
95/365	(24.3 + 0)/2	3.16
15/365	(-48.3 - 1.12)/2	- 1.02
Sum of Weighted Fractions		9.87

Table A32. The difference between average monthly zooplankton concentrations in mgC m^{-3} at the Passages and Cobscook Bay stations of Legare and MacLellan (1960).

Month m^{-3}	Passages mgC m^{-3} *	Bay mgC m^{-3}	Difference mgC
January	0.734	2.34	- 1.60
February	0.246	0.35	- 0.10
March	0.138	0.12	0.02
April	0.161	0.18	- 0.02
May	0.104	0.30	- 0.02
June	0.407	0.46	- 0.05
July	1.26	1.69	- 0.43
August	0.184	1.40	- 1.22
September	0.285	0.61	- 0.33
October	0.52	0.43	0.09
November	0.380	0.46	- 0.08
December	0.797	0.45	0.35

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* $\text{Log}(\text{DV cc m}^{-3}) = -1.429 + 0.808\ (\text{Log mg C m}^{-3})$ Wiebe (1975)