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ABSTRACT

Laboratory responses of sea scallops (*Placopecten magellanicus*) to bentonite and barite were used with the output of a new benthic boundary transport model, called *bblt*, to estimate the potential spatial and temporal effects of water-based drilling mud on scallop growth around hypothetical exploratory well sites on the Canadian sector of Georges Bank. A realistic waste discharge scenario was used that assumed a single exploration well drilled over a three-month period with a water-based mud comprised of an equal (and unvarying) amount of bentonite and barite. Twenty-two applications were run for the mud discharged at different locations and time of year, each at two particle settling velocities (0.1 and 0.5 cm s^{-1}) which bracket the range expected for flocculated water-based mud in seawater. The modelling results suggest that the effects on scallop growth depend very much upon the waste settling velocity and the location of discharge on the Bank. At the higher settling velocities, wastes are more concentrated in the benthic boundary layer, increasing exposure to scallops and therefore potential effects. The greatest potential effects occur on the side of the Bank (water depth > 100 m), where dispersion is low, and it is estimated that on the order of 2-40 days of scallop growth could be lost. Projected growth lost in the more energetic frontal zone, where most of the scallop stocks are located, is in the range of <0.1-15 days. Potential effects in the shallow, well-mixed zone on top of the Bank, where dispersion is high, appear to be negligible. Most of the assumptions in *bblt* are conservative so that dispersion is generally underestimated and therefore waste concentrations and effects are likely to be overestimated. *bblt* is a valuable quantitative tool for improving understanding of the fate of drilling wastes in the benthic boundary layer which can be used in environmental impact assessments, investing mitigative measures and designing environmental effects monitoring programs.

RÉSUMÉ

L'étude en laboratoire des réactions de pétoncles géants (*Placopecten magellanicus*) à la bentonite et à la barytine et les résultats fournis par un nouveau modèle du transport dans la couche limite benthique, appelé *bblt*, ont servi à estimer les effets spatio-temporels potentiels de la boue de forage à base d'eau sur la croissance des pétoncles autour de sites hypothétiques de prospection situés dans le secteur canadien du banc Georges. Un scénario réaliste, supposant le forage d'un seul puits sur une période de trois mois à l'aide de boue à base d'eau à composition stable, constituée à parts égales de bentonite et de barytine, a été utilisé pour 22 applications correspondant aux rejets de boue à différents endroits et moments de l'année, et à deux vitesses de sédimentation des particules (0,1 et 0,5 cm s^{-1}) qui couvrent la plage prévue pour la boue à base d'eau floculée dans l'eau de mer. Les résultats de la modélisation permettent de penser que les effets sur la croissance des pétoncles dépendent beaucoup de la vitesse de sédimentation et du lieu du rejet sur le banc. Aux vitesses élevées, les déchets se concentrent davantage dans la couche limite benthique, ce qui accroît l'exposition pour les pétoncles et donc les effets potentiels. C'est sur le flanc du banc (profondeur de l'eau > 100 m), où la dispersion est faible, que les effets potentiels sont les plus forts, et on estime que la perte de croissance des pétoncles peut être de l'ordre de 2-40 jours. La perte de croissance projetée dans la zone de fort hydrodynamisme du front, où se situent la plupart des stocks de pétoncles, est de l'ordre de < 0,1-15 jours. Les effets potentiels dans la zone peu profonde et bien mélangée du dessus du banc, où la dispersion est forte, semblent négligeables. La plupart des hypothèses du modèle *bblt* sont prudentes, de sorte que la dispersion est en général sous-estimée, et donc que les concentrations et les effets des déchets sont vraisemblablement surestimés. Le modèle *bblt* est un outil quantitatif précieux pour améliorer la compréhension du devenir des déchets de forage dans la couche limite benthique, ce qui peut servir dans les évaluations des impacts environnementaux, pour examiner les mesures d'atténuation et pour concevoir les programmes de suivi des effets environnementaux.

1.0 INTRODUCTION

Georges Bank, which straddles the United States-Canadian boundary, is one of the most productive fishing banks in the North Atlantic Ocean. The productivity of Georges Bank is the result of a unique combination of physical and biological factors. It provides large commercial catches of finfish and shellfish of social and economic importance to numerous communities in the Maritime Provinces and New England States. In the Canadian sector, bottom-dwelling invertebrates account for up to 70% of the total landed value of all resource species harvested. The single most valuable fishery resource is the sea scallop (*Placopecten magellanicus*) which had an annual landed value averaging $44 million between 1992 and 1997 (Boudreau et al. 1999).

Geological studies indicate that the Georges Bank Basin has the potential to contain commercially viable hydrocarbon reserves (Ball et al. 1987). In 1981-82, eight exploratory wells were drilled in the United States sector and all were 'dry holes' (Danenberger 1987). In 1987, Texaco Canada Resources Ltd. proposed to drill two exploratory wells in the Canada sector. This proposal met strong opposition from the fishing industry and environmental organizations. As a result of strong lobbying, the Governments of Canada and Nova Scotia passed joint legislation in April 1988 that created a moratorium on oil and gas drilling activity on Georges Bank until 2000. The legislation called for a public review of the environmental and socio-economic impacts of hydrocarbon exploration to be undertaken by a review panel established in 1996. In June 1999, this review panel recommended that action be taken to have the moratorium remain in place (Anon. 1999). The provincial and federal governments subsequently decided to extend the moratorium until 2012. A similar drilling moratorium was declared earlier for the United States sector, also until 2012.

These moratoria have provided time for additional research, consultation and reflection on the drilling issue. In 1987, the Department of Fisheries and Oceans (DFO) conducted an assessment of the possible effects of drilling on the fisheries resources of Georges Bank (Gordon 1988). A number of recommendations were made for research that should be conducted to help improve scientific understanding of the Georges Bank ecosystem and to reduce uncertainties regarding the effects of hydrocarbon drilling. These included projects that would provide information that could be used to predict the biological effects of drilling wastes for different geographic locations and times of year.

Subsequently, using funding provided by the federal Panel for Energy Research and Development (PERD), DFO established a multidisciplinary program to investigate the fate and effects of operational drilling wastes in energetic continental shelf environments such as found off Atlantic Canada on Georges Bank, Sable Island Bank and the Grand Banks of Newfoundland. It has consisted of a series of integrated projects that have focussed on improving scientific understanding of water and particle dynamics in the benthic boundary layer (the bottom of the water column affected by the seafloor), and sea scallop ecology and toxicology. Individual projects have included physical oceanographic and sedimentological field studies, laboratory studies on the flocculation properties of drilling wastes and the chronic lethal and sublethal effects of drilling wastes on sea scallops, the development of new instrumentation for measuring natural particles and drilling wastes in the benthic boundary layer, measurement of drilling wastes around the PanCanadian Cohasset-Panuke (CoPan) production platform on Sable Island Bank, and the development of numerical circulation and dispersion models. This program has been guided by the Georges Bank Steering Committee that included scientists, regulators, and representatives of the hydrocarbon and fishing industries.

The biological effects component of this program has focused on the sea scallop (*Placopecten magellanicus*). Not only is it economically important but its life history characteristics make it especially vulnerable to adverse effects of drilling wastes. For example, once the juveniles settle to the seabed, mobility is limited so all of their adult life is spent living on the seafloor. As filter-feeders, scallops obtain their food particles from the benthic boundary layer. Drilling waste concentrations would be greatest in the benthic boundary layer and the presence of foreign fine particles could interfere with food utilisation that would affect growth, reproduction and perhaps survival.

As part of this PERD-funded research program, numerical circulation and dispersion models have been developed that can be used to estimate the spatial and temporal extent of impact zones around specific drilling sites on Georges Bank. Physics-based mathematical models can enhance our understanding of drilling waste effects in two important ways. First, they provide a logical and internally consistent quantitative framework for describing and interpreting observations which, in turn, allows the relative importance of different processes to be compared. Second, models can provide a predictive capacity that allows evaluation of the effects of differences in operational or environmental variables, and thus can play an important role in the environmental assessment process. They can also be used to design effective mitigative measures and environmental effects monitoring programs.

In close coordination with laboratory and field studies, DFO has developed a sediment transport model, called *bblt*, which simulates the dispersion and transport of suspended sediment in the benthic boundary layer on the continental shelf. The basic formulation of *bblt* and some exploratory applications are presented by Hannah et al. (1995, 1996, and 1998). Enhancements to *bblt* and additional applications are reported in Loder et al. (2000). Using data collected as part of associated projects and a drilling waste discharge scenario for a hypothetical exploration, Loder et al. (2000) have applied *bblt* to different locations on Georges Bank. They report and discuss the drilling waste concentrations predicted in the bottom 10 cm of the water column for the different applications with focus on the underlying oceanographic processes and model sensitivities.

This technical report, a companion to Loder et al. (2000), provides an interpretation of the lethal and sublethal biological effects to sea scallops of drilling waste concentrations predicted by *bblt* in the Georges Bank applications. It contains background information on the Georges Bank environment and the fate and effects of drilling wastes, describes the methods that were used to run and evaluate the applications, reviews the effects of the predicted drilling waste concentrations on potential sea scallop growth, and discusses the overall significance of the results.

An initial evaluation of the biological impacts of these Georges Bank *bblt* applications was prepared for the DFO Regional Advisory Process on the possible environmental impacts of hydrocarbon exploration activities on the Georges Bank ecosystem and is summarized in Boudreau et al. (1999). This report contains additional information, interpretation and discussion.

2.0 BACKGROUND INFORMATION

2.1 Georges Bank Ecosystem

Because of its importance to commercial fisheries and its proximity to Canadian and United States oceanographic institutes, Georges Bank (Fig. 1) is a well-studied marine system. An exhaustive review of scientific knowledge was published in 1987 (Backus 1987). More recent publications describing the Georges Bank ecosystem include Loder et al. (1993), Horne et al. (1996), Perry et al. (1993), Tremblay et al. (1994), Thouzeau et al. (1991a), Grant et al. (1997), Envirosphere (1997), and a special issue of Deep-Sea Research (Wiebe and Beardsley 1996). A general overview is provided by Boudreau et al. (1999).

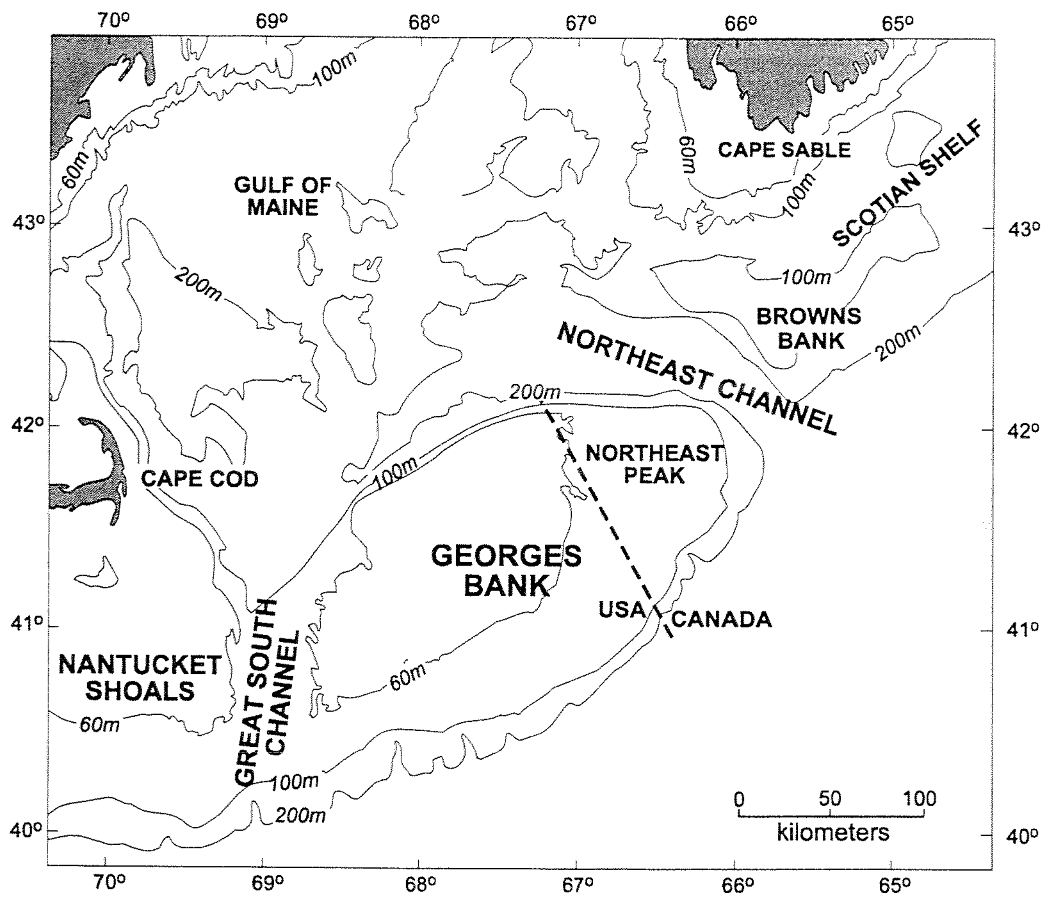

Figure 1. General map of Georges Bank showing its relation to other geographic features in the Gulf of Maine region.

2.2 Geographic Features

Georges Bank is a large, oval-shaped bank located seaward of the Gulf of Maine between Nova Scotia and Massachusetts (Fig. 1). It is separated from the Scotian Shelf by the Northeast Channel and from Nantucket Shoals by the Great South Channel. The surface is generally flat-topped but dips gently to the southeast. Most of the Bank is shallower than 100 m while depths can be as little as 3 m over shoals near the centre. Submarine canyons are found along the seaward edge. The Canadian sector is generally known as the Northeast Peak.

2.3 Sediments

Surficial sediments on Georges Bank were originally glacial in origin and contained a wide range of particle sizes (clay to boulders). Subsequent erosion by currents and waves since the Bank was submerged (starting about 14,000 years ago) has essentially removed all the silt and clay from surficial sediments. As a result, the United States sector is covered with mostly sandy sediments while the Canadian sector is covered primarily with gravel (Valentine and Lough 1991). A gravel pavement and boulders occur along the northern margin. Finer sediments are found in deeper water off the Bank. There are no known depositional areas on the Bank shallower than 100 m for silt or clay. Field observations at several locations on Georges Bank indicate the presence of elevated levels of natural suspended matter in the benthic boundary layer but the absence of fine particulates (Muschenheim et al. 1995).

With the exception of boulders, surficial sediments on Georges Bank are intermittently moved by tidal currents, storms and associated surface waves, wind-driven currents and internal waves. Currents resulting from these processes act in combination or sometimes alone to cause intermittent sediment movement for periods of varying length. The most important processes causing sediment transport on Georges Bank are the strong semi-diurnal tidal currents (exceeding 1 m s^{-1} in shallow water) which are oriented in a northwest-southeast direction. Because they reverse direction during each 12.4 hour tidal cycle, these currents do not usually cause a net transport of sediment but they can put sediment into suspension that can be transported by other currents. Currents caused by intense storms and/or large waves, although much less frequent and generally weaker than tidal currents, can also be a major contributor to sediment suspension and transport, particularly in winter. The overall trend of sediment transport is to remove sediment from the Bank and carry it to deeper water in the Gulf of Maine or along the continental slope. There is also evidence that some of the fine sediment eroded from Georges Bank has accumulated in the Mud Patch, a large area south of Nantucket Shoals with weak tidal currents.

2.4 Water Properties and Movements

Currents and water properties on Georges Bank are strongly influenced by tides, winds, seasonal heating and cooling, freshwater runoff and larger-scale ocean circulation (Butman and Beardsley 1987). This combination makes Georges Bank one of the ocean's more energetic shelf regions and also one with a high level of spatial and temporal variability. Perhaps the most important feature of currents on the Bank is the unique tidal regime that is influenced by the energetic tidal system of the Gulf of Maine and the Bay of Fundy. Tidal currents produce many of the Bank's important physical features such as the persistent well-mixed area over the centre of the Bank and the permanent clockwise current around it. Georges Bank is also near the primary paths of atmospheric storms that produce strong intermittent currents. Its mid-latitude setting with strong spring-summer solar heating and fall-winter atmospheric cooling gives rise to dramatic seasonal changes in the properties and vertical structure of the water column. The Bank is also located in a transition zone between the southward flow of relatively cool and low salinity waters from the Labrador Current and Gulf of St. Lawrence, and the northward flowing waters of the Gulf Stream.

Currents on Georges Bank move water, heat and materials (e.g. sediment, contaminants, larvae, etc.) both horizontally and vertically in the water column. The strongest currents on the Bank are the tidal currents that twice-daily move water and suspended materials through an elliptical path of 2-15 km. The strongest currents and greatest tidal excursions occur in the shallowest water on top of the Bank. Tidal currents are the principal current component affecting the short-term (hours) drift of material. Tidal energy is also channelled into turbulence, including vertical motions, to which it is the primary and most regular energy source. Long-term (subtidal) horizontal movement or drift is predominantly influenced by currents that persist for long time periods, such as the seasonal mean current. Water column structure and vertical transport are primarily affected by short-term and turbulent currents caused by tides and winds.

The current component that has the greatest effect on the long-term drift (days to seasons) of water and materials is the seasonal mean circulation which includes the clockwise gyre-like flow around the edge of Georges Bank. This flow approximately doubles in intensity from winter to summer and is strongest along the Bank's northern edge where a jet-like current approaching 0.5 m s^{-1} spreads around and across the Northeast Peak in summer (Loder et al. 1993). About 50 days is required for a complete circuit of the Bank. However, only a small fraction of the water on the Bank moves completely around in the gyre. Winds and storms also cause irregular current fluctuations and these are strongest in winter and near the sea surface. In addition, large eddies called rings are periodically shed from the Gulf Stream and displace water both onto and off the southern flank of the Bank.

The strong tidal currents on the top of Georges Bank lead to higher vertical mixing rates than in most shelf areas. Consequently, the waters on the central Bank shallower than about 60 m are well-mixed year-round. In winter, the combination of tidal mixing, wind mixing and atmospheric cooling creates a well-mixed region that extends out to the 100 m isobath. Water temperatures are generally 4-6 °C on the Bank in winter. Along the seaward edge of the Bank, the warmer and saltier offshore water meets the cooler and fresher shelf water, creating a shelf-slope front. In spring and summer, solar heating warms the surface waters, resulting in the development of a seasonal surface warm layer over the Bank's deeper areas. A transition zone called a tidal-mixing front between mixed and seasonally stratified water surrounds most of the Bank between the 60 and 80 m contours from late spring to early fall.

A feature of this front is a surface convergence zone for part of the tidal cycle that can be important to retaining and concentrating floating materials (Drinkwater and Loder 2000). Other factors contributing to vertical mixing on Georges Bank include surface waves and currents during storms, and turbulence at the edge of the Bank generated by internal waves during the stratified seasons.

The physical properties of water motion on Georges Bank lead to a tendency for some materials to disperse while others are retained. Whether retention or dispersion will predominate depends upon the characteristics of the material and its discharge time and position. Depending upon their properties (i.e. size, density, motility, etc.), materials can be transported differently in the same flow field when there are strong time and space variations as occur on Georges Bank. The energetic tidal currents generally result in elevated mixing and dilution rates over small distances, while the strong tidal and seasonal mean currents in most instances move materials rapidly away from their discharge sites. On the other hand, the gyre-like flow and large size of the Bank lead to a tendency for a fraction of the water and its suspended materials to have an extended residence time over the Bank. Further, features of the flow that lead to water masses converging can provide concentration mechanisms at least locally and for short durations. Both the properties of the materials and the structure of the currents in the region of interest, both in space and time, must be known in order to adequately evaluate the materials' drift, dilution and fate.

2.5 Biological Productivity

Primary productivity on Georges Bank is carried out by phytoplankton. It fuels the growth of the zooplankton living in the water and the benthic organisms found on the seafloor. Also important in the Georges Bank food web is the productivity of bacteria and other micro-organisms that remineralize dissolved and particulate organic matter (e.g. detritus). A combination of physical and chemical factors results in elevated levels of primary productivity on the Bank (on the order of 450 g C m^{-2} y^{-1}). On an annual basis, the primary productivity is about 30 % higher than the Scotian Shelf and also higher than the Gulf of Maine (Sherman et al. 1996). The highest productivity occurs in the shallowest waters at the centre of the Bank and is comparable to levels observed in coastal areas. Some of the primary productivity may be carried off the Bank but most is thought to be retained and utilized on the Bank. For reasons not understood, the available data suggest the secondary productivity of zooplankton and benthic organisms on the Bank is not elevated in relation to other adjacent areas. However, the fisheries productivity is clearly greater than in adjacent areas.

2.6 Scallop Populations and Ecology

Georges Bank has a diverse benthic community that includes numerous species of commercial importance such as the sea scallop, lobster and ocean quahaug. Many finfish species utilize the benthic habitat of the Bank for certain stages of their life history (e.g. herring, cod, haddock, etc.). The distributions of benthic organisms are related to sediment type, depth and oceanographic factors. Suspension feeding bivalves, which feed on a mixture of phytoplankton and detritus, account for most of benthic biomass on northern and south-central parts of the Bank. Commercial concentrations of ocean quahaug occur on south-central Georges Bank while the major scallop beds are found on the Northeast Peak (Black et al. 1993). There is evidence that the benthic habitat and biological communities on Georges Bank have been substantially altered in recent years by mobile fishing gear (Collie et al. 1997).

Sea scallops are currently the most valuable fishery on the Canadian sector of Georges Bank. The major spawning event takes place in August-October but there also can be a minor spawning event in the spring. Fertilized eggs develop into planktonic larvae that spend one to two months in the water column before settling to the seafloor. Numerical modelling studies of larval drift indicate that Georges Bank scallop populations appear to be self-sustaining (Tremblay et al. 1994). Growth rates of sea scallops are higher on Georges Bank than in other regions off Atlantic Canada. Adult scallops are found in discrete patches on the Northeast Peak (Black et al. 1993). Being suspension feeders, scallops feed on suspended phytoplankton and detritus in the benthic boundary layer. Feeding experiments demonstrate that they can utilize resuspended organic matter at high efficiency (Grant et al. 1997, Shumway et al. 1987). Due to the strong tidal currents on the Bank, resuspension occurs with sufficient frequency to provide an almost constant supply of high quality food for scallops.

2.7 Offshore Drilling Procedures

Exploratory hydrocarbon drilling on Georges Bank, if permitted, would likely be done from either a semi-submersible or jackup drilling platform on location for 3-4 months. The operating procedures would most likely be similar to those employed in drilling the US exploration wells in 1981-82 (Neff 1987) and, more recently, on Sable Island Bank on the nearby Scotian Shelf. Actual drilling may only occur for one-third to one-half of the time that the platform is on location. Two major particulate wastes are discharged during drilling of exploratory hydrocarbon wells: muds and cuttings.

Drilling muds are a suspension of solids and dissolved material in a carrier fluid. The carrier fluid generally used in drilling exploration wells is either fresh or salt water. Therefore, these muds are known as water-based muds (WBM). Drilling muds perform numerous functions while circulating from the platform through the drill string. They remove rock cuttings from around the drill bit and transport them to the platform, lubricate and cool the drill bit, balance subsurface and formation pressure, prevent blow-out and seal the borehole wall. During drilling, the composition of drilling muds is adjusted continuously to account for changes in down-hole conditions. The major particulate components added to the carrier fluid are barite (barium sulphate) and clay (bentonite). Other common ingredients are lignosulfonate, lignite and sodium hydroxide. These five ingredients usually account for over 90% (by weight) of the materials added to the water. Other special chemicals, including hydrocarbons, can be added in small amounts to address specific problems. No two drilling fluids are the same. The composition of the drilling muds used for the eight exploratory wells drilled in the United States sector of Georges Bank in 1981-82 is given in Neff (1987). Spent WBM is discharged overboard intermittently. Additional discharges, known as bulk dumps, occur when new rock strata are encountered and mud composition must be changed, at the completion of a planned well section, and upon attaining the final depth. Most of the particles in WBM are small (less than 50 μm) but tend to flocculate when discharged in seawater, potentially increasing the settling velocity of the particles by 1-2 orders of magnitude.

Cuttings are particles of the formation rock being drilled (shale, sandstone, limestone, etc.). They are mechanically separated from the drilling mud on the platform and discharged overboard, either directly into surface water or at some depth through a pipe. While a wide range of particle sizes is possible, most are sand-sized and have relatively rapid sedimentation rates. Therefore, they tend to accumulate, at least initially, on the seafloor under and near the platform. While some of the finer cuttings may become incorporated into flocs, most will behave as discrete particles. The total amount of cuttings discharged is roughly equivalent to the volume of the hole being drilled plus washout.

Existing Canadian guidelines (Anon. 1996) allow the discharge of spent and excess WBM from offshore installations without treatment. However, operators are encouraged to develop procedures that reduce the need for the bulk disposal of muds following either drilling mud change-over or drilling program completion. If re-injection is not technically or economically feasible, cuttings from WBM may be discharged at the drill site without treatment.

It is estimated that approximately 9200 metric tonnes of drill cuttings and 5000 metric tonnes of drilling fluid solids containing 3000 metric tonnes of barite and 1500 metric tonnes of bentonite clay were discharged on Georges Bank during the drilling of the eight exploratory wells on the United States sector in 1981-82 (Neff 1987).

Oil-based (OBM) and alternative (ABM) drilling muds are commonly used in drilling development wells that are generally larger in diameter and often deviated (i.e. drilled at an angle). These muds are more toxic than water-based muds (GESAMP 1993) and are not allowed to be discharged into Canadian waters. Canada Nova Scotia Offshore Petroleum Board regulations, which apply to the Canadian sector of Georges Bank, state that, starting in 2000, the content of OBM or ABM on discharged cuttings must be less than 1% by weight, which effectively means no discharge at sea of cuttings produced using these muds.

2.8 Fate of Discharged Drilling Wastes

Field observations made around active drilling platforms indicate that roughly 10% of the discharged wastes is neutrally buoyant and forms a surface plume (NRC 1983). The remainder of the wastes (on the order of 90%) is denser than seawater and, if discharged at or near the sea surface, forms a plume that descends through the water column until it either reaches the seafloor or becomes neutrally buoyant (Fig. 2). Therefore, in shallow water, a large fraction of the discharge will reach the seafloor close to the platform (Andrade and (Loder 1997). The resuspension, dispersion, drift and final deposition site of this material will depend upon such physical variables as water depth, currents (tidal and residual), waves and storms, and settling velocity. Most of this lateral transport takes place in the lower part of the benthic boundary layer (the bottom of the water column affected by the seafloor) where sea scallops obtain their particulate food resources.

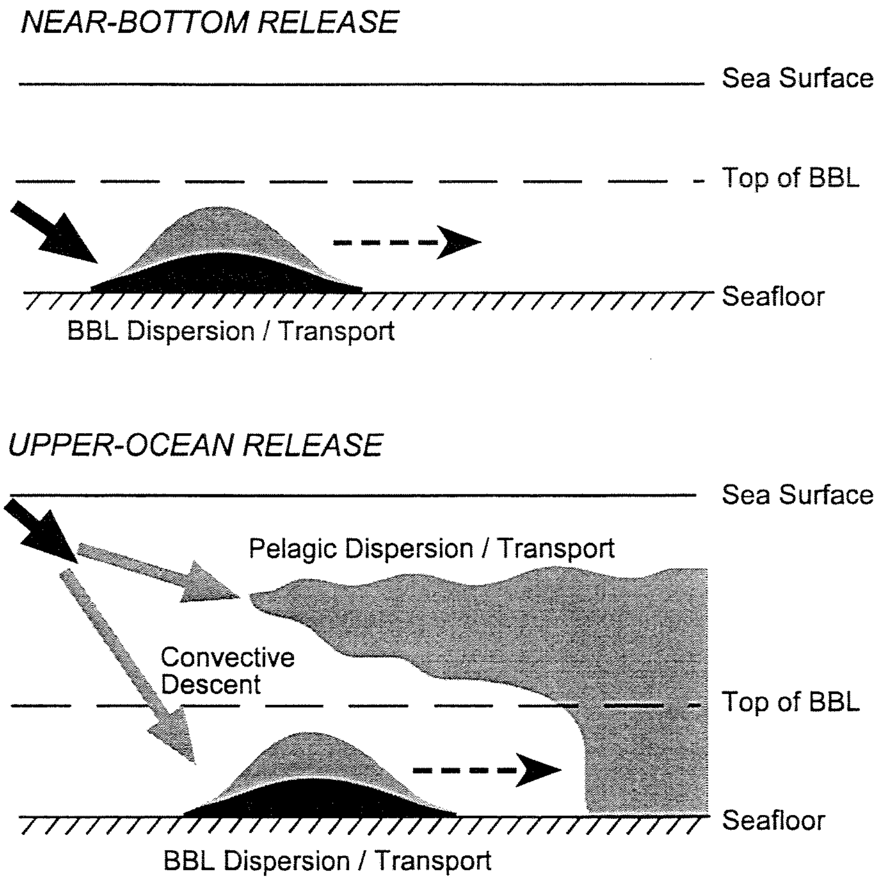

Figure 2. Schematic diagram showing potential pathways of muds and cuttings from a drilling rig reaching the benthic boundary layer (BBL).

Many of the case studies on the fate of discharged drilling wastes have used barium as a tracer (e.g. Boothe and Presley 1989, Coats 1994, Neff et al. 1989), although Hartley (1996) advises caution in interpreting barium data. Barium is a major component of barite, a mineral commonly used as a weighting agent in drilling muds. Another approach for tracing drilling muds in the environment is to measure the particle size spectra of inorganic sediment particles. In theory, bentonite and barite particles from drilling wastes should be readily detectable in water samples from high energy environments that are naturally devoid of small particles, such as Georges Bank (Muschenheim et al. 1995). This concept has been proven in studies conducted on Sable Island Bank (Muschenheim and Milligan 1996). Observations using different kinds of oceanographic instrumentation around the CoPan oil field (34 m water depth) on Sable Island Bank have confirmed that discharged drilling wastes flocculate, sediment rapidly and concentrate in the benthic boundary layer (Muschenheim and Milligan 1996). On at least one occasion during developmental drilling, fine particulates from drilling wastes were present in the benthic boundary layer up to 8 km from the platform.

2.9 Biological Effects of Drilling Wastes

There is a large literature on the biological effects of drilling wastes based on both field and laboratory studies. General references include NRC (1983), Engelhardt et al. (1989) and GESAMP (1993). Extensive studies have been done in the North Sea (e.g. Kingston 1992, Daan and Mulder 1996), and there continues to be strong debate as to how far away from a platform effects on benthic communities can be detected (e.g. Olsgard and Gray 1995).

The potential effects of drilling wastes on the marine organisms of Georges Bank were reviewed by Neff (1987). A three-year monitoring program was run to assess the environmental impacts of the US exploration wells drilled on Georges Bank in 1981-82 (Phillips et al. 1987 and Neff et al. 1989). Barium was the only element in bulk sediments to increase during drilling, and elevated levels could be found as far as 65 km downcurrent from the drill site. However, no changes in benthic communities were detected that could be attributed to drilling activities.

An extensive series of experiments have been conducted by the DFO on the effects of drilling wastes on the sea scallop. Cranford and Gordon (1991) investigated the sublethal effects of oil based drilling mud cuttings under static laboratory conditions. Cranford and Gordon (1992) studied the influence of dilute bentonite suspensions on feeding activity and tissue growth in a laboratory flume tank. Using the same experimental setup, Cranford et al. (1999) have conducted similar studies using barite, used water-based mud and used oil-based mud. These studies have clearly demonstrated that chronic intermittent exposure of sea scallops to dilute concentrations of operational drilling wastes, characterized by acute lethal tests as practically non-toxic, can affect growth, reproductive success and survival.

2.10 Plume Dispersion Modelling

Using an industry-standard plume descent model, simulations were carried out to determine the depth of descent of the waste discharge plume under different discharge conditions, densities and environmental conditions on Georges Bank (Andrade and Loder 1997). The factors that significantly affect the depth of descent were found to be mud density, depth of discharge, initial downward volume flux of the discharge, current strength and water column stratification. This information was subsequently used to estimate the portion of drilling wastes discharged at or near the sea surface that could be expected to reach the benthic boundary layer under the different application scenarios developed for Georges Bank (Loder et al. 2000).

2.11 Development and Properties of *bblt*

After initial deposition following the plume descent phase, particulate drilling wastes can be resuspended and redistributed by currents and waves. A new model called *bblt* (benthic boundary layer transport) has been developed to study the dispersion and transport of suspended sediment in the benthic boundary layer of tidally energetic continental shelf environments. Formulation and initial exploratory applications are described by Hannah et al. (1995, 1996, and 1998). Numerous improvements have been made and the model is now available in two versions (Loder et al. 2000). Local *bblt* neglects spatial variability in the physical environment around the discharge site and can be forced by either a measured (time-varying) current profile or a 3-D time-varying circulation model field (Hannah et al. 1998). A second and more complex version, called spatially-variable *bblt* (Xu et al. 2000), allows for spatial structure in the physical environment and is forced by a 3-D time-varying circulation model field, in our case from Naimie (1995, 1996). The specifications of forcings and the choice of model parameters draw upon the results of other PERD projects.

3.0 METHODS

3.1 Drilling Waste Discharge Scenario

The hypothetical drilling waste discharge scenario used was prepared specifically for these Georges Bank applications of *bblt* with the assistance of Texaco Canada Petroleum Ltd. It represents a reasonable approximation of the amount and timing of mud and cuttings discharged from a typical exploration well, and is based upon recent drilling experience on the Scotian Shelf.

The drilling scenario is broken down into five separate sections (Table 1). Water-based drilling muds are used for the entire well. The major particulate components are bentonite (gel) and barite. During the first two sections (0-850 m), drilling muds and cuttings are discharged directly to the seafloor around the wellbore. During the deeper three sections (850-4600 m), material is circulated back to the drilling platform through the marine riser before discharge at a water depth of 10 m.

Full details of day-by-day activities and discharges are provided in Appendix A. The tabulated data include estimates of:

- Discharge Volume
  - Total (including carrier fluids)
  - Cuttings (solids only)
  - Muds (solids only)

- Density
  - Total (including carrier fluids)
  - Cuttings (solids only)
  - Muds (solids only)

- Dry Weight
  - Cuttings (solids only)
  - Muds (solids only)

The cuttings (rock) density is assumed to remain constant at 2.600 g cm^{-3}, while the mud density changes with depth in the well. The mud density generally is held at 1.075 g

cm^{-3} for Sections 1-4 (except when setting casing at the end of a section) and at 1.230 g cm^{-3} for Section 5.

The daily discharges of drilling mud are summarized in Fig. 3. Discharge is not continuous but occurs on 59 days of the 93 day drilling period (Table 1). In general, the largest discharges take place during the first week. Substantial bulk dumps occur at the end of Sections 4 and 5.

Table 1. Summary of the hypothetical drilling waste release scenario used in these Georges Bank applications. It represents an exploration well drilled using water-based mud. Depths are relative to the Kelly bushing reference elevation (RKB) on the rig. The actual depth drilled below the seabed is obtained by adding 20 m to the water depth and subtracting the result from the RKB depth.

Section	Depth (m)	Total Days	Drilling Days
1	0-240	5	2
2	240-850	7	3
3	850-2250	20	13
4	2250-4000	31	24
5	4000-4600	30	17
Total		93	59

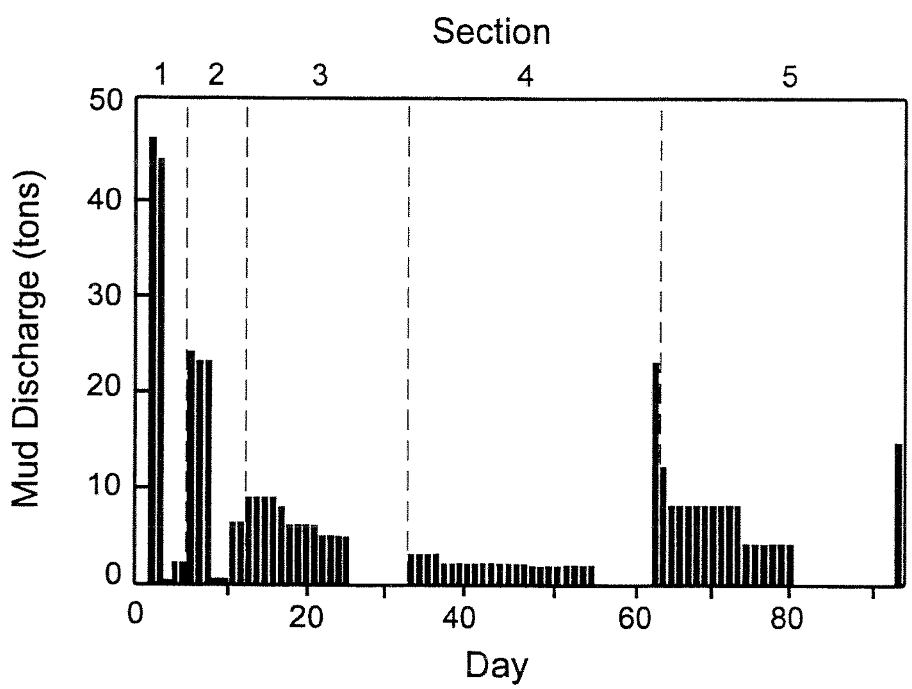

Figure 3. Daily water-based mud release from the hypothetical drilling waste release scenario used in these model applications.

3.2 Conceptualization of Drilling Wastes in Model Applications

From the outset, the focus of this project has been on understanding the potential environmental effects of drilling hydrocarbon exploration wells on Georges Bank. With current technology, exploration wells are drilled using water-based muds. The major particulate components are bentonite and barite.

Bentonite and barite have quite different properties. Bentonite consists mostly of the clay mineral montmorillonite, an aluminium silicate with considerable ion exchange capacity. It is used in drilling muds because of the gel-like suspension it forms in water. Barite is a crystalline mineral composed of barium sulphate. Most of the bentonite used in drilling mud is composed of fine particles less than 10 µm while barite particles have a broader size distribution up to at least 40 µm (Muschenheim and Milligan 1996). Bentonite has a density of 2.0-2.7 g cm^{-3} (decreasing with increasing water content) while barite has a density of 4.5 g cm^{-3}. Bentonite will flocculate readily, especially at concentrations exceeding 200 mg l^{-1} (Milligan and Hill 1998), and, once it reaches the seafloor, it can be easily resuspended. Laboratory settling experiments have shown that small barite particles (< 5 µm) can flocculate to some degree like bentonite. However, the majority of barite particles behave as individual grains and, once deposited, are more likely to become incorporated into the sediment matrix (Muschenheim et al. in prep.).

The hypothetical drilling waste scenario used also includes information on the discharge of drill cuttings from an exploration well (Appendix A). Their composition will depend upon the kind of rock being drilled (e.g. sandstone, shale, limestone, etc.). Most cutting particles are larger than 30 µm and should settle out of suspension rapidly near the discharge location. A small but unknown portion could be in the same size range as bentonite and barite, and have similar behaviour and effects once suspended in seawater. Cranford et al. (1999) observed that a mixture of used water-based mud and cuttings did affect scallop growth at concentrations less than 10 mg l^{-1}, but this effect is thought to be due primarily to the presence of bentonite. On the basis of the available evidence, it was assumed that cuttings will not affect the growth rate of scallops and therefore they were not included in the *bblt* simulations.

Therefore, in this report, the drilling wastes modelled by *bblt* are conceptualized as a water-based mud with the particulate component comprised of a 50/50 mixture of bentonite and barite that does not change with time. There are some changes in the relative amounts of bentonite and barite with depth (and time) in a well, but these are minor and the use of a variable proportion of waste constituents would require additional assumptions regarding the time-lag for each component to be transported to each sampling location at each site. Because of their different densities, it was initially proposed to run separate *bblt* simulations for bentonite and barite, which would have doubled the computational requirements. Fortunately this proved unnecessary when it was realized that bentonite and barite, despite marked differences in density, appear to have similar ranges of effective settling velocities.

3.3 Determination of Settling Velocities

Preliminary runs of *bblt* illustrated a strong sensitivity to the choice of effective particle settling velocity (w_s) used in a particular simulation (Hannah et al. 1995, 1996). This arises from the incorporation of a Rouse-type balance between boundary-layer turbulence, parameterized by the friction velocity (u_*), and w_s. While local variations in u_* values are generally constrained to within an order of magnitude, the range of possible settling velocities for fine particulate matter can vary over three orders of magnitude. The degree to which this actually occurs depends on the density, particle size distribution and surface chemistry of the material, the degree to which they promote or inhibit flocculation, and the turbulence level.

In choosing a representative range of w_s to use in these Georges Bank applications of *bblt*, we relied on four sources of information:

- Laboratory studies of drilling waste settling velocities, in both unflocculated and flocculated states;
- Published literature values of *in situ* observations of settling velocities of naturally flocculating material;
- Stokes' settling velocities for individual, unflocculated barite grains;
- Field observations of drilling waste discharge and dispersion at the CoPan site on Sable Island Bank made between July 1991 and September 1993.

Our aim was to determine low and high "effective" settling velocities for both barite and bentonite, approximately delimiting the upper and lower 20th percentiles. Our rationale for these determinations is as follows.

Very little barite was employed in drilling the development wells at CoPan and therefore we have no direct field evidence for the *in situ* settling velocity of pure or predominantly barite mud discharges. Consequently, our estimate of the most likely range of w_s for barite was heavily based on laboratory results (Muschenheim et al. in prep.). Barite has a high density (ρ=4.5 g cm^{-3}) and a particle size spectrum which is depauperate in very fine particles (< 2 μm). In their studies it was evident that, in pure suspensions of 200 mg l^{-1} or less, barite particles larger than 10 μm settled as single grains and particles smaller than 10 μm settled as flocs. Direct estimates of w_s for 10 μm barite grains were on the order of 0.04 cm s^{-1}, which compares favourably with a calculated w_s of 0.02 cm s^{-1} for a 10 μm grain with ρ=5.0 (Gibbs et al. 1971). The maximal size of the barite particle size spectrum is around 50 μm. The observed w_s for these particles was 0.47 cm s^{-1}, whereas the calculated w_s for 50 μm grains of density ρ=5.0 g cm^{-3} is 0.49 cm s^{-1} (Gibbs et al. 1971). Thus, in pure suspensions, barite grains smaller than 10 μm have their settling velocity determined by floc dynamics while grains 10-50 μm settle as single grains with rates varying by an order of magnitude from 0.04 to 0.49 cm s^{-1}.

Although we have no direct evidence about the behaviour of a mixed suspension of bentonite and barite, settling experiments with whole drilling waste shows that even 50 μm particles may be involved in flocculation when significant amounts of particles less than 2 μm are present in suspension. Thus, the lower range of w_s for barite is likely controlled by floc dynamics while the upper range is determined by the single-grain settling velocity (max ≅ 0.5 cm s^{-1}). A significant caveat is that in suspensions that are composed primarily of barite, there may be a fraction (between 10-50 μm) which settles as single grains.

From the laboratory experiments (Muschenheim et al. in prep) it is evident that bentonite and drilling wastes from water-based muds flocculate rapidly, significantly increasing their w_s over the single grain velocity. Although w_s values ranged from 0.3 to 1.5 cm s^{-1} for flocculated drilling wastes, the flocs formed were densely packed and not completely like the "fluffy" drilling waste flocs observed using video at CoPan (Muschenheim and Milligan 1996). This results from the difficulty in scaling turbulence in a laboratory setting (Milligan and Hill 1998). Thus the upper end of the observed laboratory w_s range, 1.5 cm s^{-1}, is likely an overestimate for "naturally-occurring" drilling waste flocs.

There is a growing body of literature indicating that a diversity of naturally occurring particles flocculate and settle over a rather narrow range of w_s (Dyer et al. 1996, Hill et al. 1998). This is generally on the order of a few millimeters per second. To obtain a rough estimate of the *in situ* w_s of flocculated drilling wastes, data from *Parizeau* Mission 93-029 were fitted to Rouse profiles (Rouse 1937, Hannah et al. 1995). The particle size spectra from BOSS and Niskin bottle samples taken at CoPan were split into fractions greater than and less than 10 μm. Total suspended concentration for the <10 μm fraction within 5 m of the seabed was fitted to Rouse profiles, using u_* values estimated from current measurements made at 1 m (above bottom) during the sampling period. Although there were too few data points to generate statistical confidence intervals, the observations reflected the form of the Rouse profiles, and the calculated w_s values consistently fell between 0.1 and 0.2 cm s^{-1} for $u_* = 0.4\text{-}0.7$ cm s^{-1}. These results are in agreement with published literature values for naturally occurring flocculated material. The analysis also suggested that between 20-80% of the wastes would be found within 0.5 m of the seabed if $u_* = 0.4$ cm s^{-1} and $w_s = 0.1\text{-}0.2$ cm s^{-1}, or if $u_* = 0.7$ cm s^{-1} and $w_s = 0.2\text{-}0.5$ cm s^{-1}.

Because the laboratory results showed conclusively that bentonite settles wholly in flocculated form in the marine environment, we accept that the settling velocity is controlled by floc dynamics and that the calculation of single-grain settling velocities is irrelevant to this application. Field data from river discharges studied during the Strataform project indicate that the upper limit of w_s for flocculated riverine sediment in the benthic boundary layer on the continental shelf is on the order of 0.5 cm s^{-1} (Sternberg et al. 1999). Other published marine data are in agreement with this value. Our estimates of the *in situ* w_s of flocculated drilling wastes indicate that an appropriate lower value would be on the order of 0.1 cm s^{-1} while 0.5 cm s^{-1} is an appropriate upper bound. This value coincides with the observed and calculated upper values for barite settling as single grains (10-50 μm) and is thus the upper value selected for our Georges Bank simulations. As discussed above, even in pure suspension, the fine barite fraction (<10 μm) settles as flocs and w_s is determined by the same dynamics as for bentonite. Other experimental evidence suggests that, in a mixed suspension

(>50% bentonite), most or all of the barite will be incorporated into flocs. Thus a lower limit of w_s=0.1 cm s^{-1} is selected for this fraction.

A final question then arises as to what the appropriate w_s range is for a pure (or nearly so) discharge of barite. As shown above, in the absence of flocculation, the w_s of 10-50 μm barite ranges from 0.04-0.5 cm s^{-1}. This raises the possibility that some portion of the barite could settle at a considerably slower velocity than the overall range (0.1-0.5 cm s^{-1}) selected above. Is this justification for extending the selected range of w_s downward from 0.1 to 0.04 cm s^{-1}? It was decided that it is not for the following reasons:

- In all preliminary *bblt* runs for Georges Bank conditions, w_s values lower than 0.1 cm s^{-1} resulted in particle distributions that were virtually uniformly mixed in the vertical. The high current shears (u_* up to 6.0 cm s^{-1}) in the benthic boundary layer on Georges Bank result in material with such a low settling velocity rarely being deposited on the seabed. As a result, this fraction of the material leaves the model domain without impact.

- Although some hypothetical well sections could be drilled with a heavily-weighted and predominantly barite mud, formation fines will add material and change the particle size spectra. The result is that there likely will be more fine particles available to initiate flocculation and extend the size range of barite that will be incorporated into flocs. Even an increase in the barite floc limit to 20 μm would raise w_s to close to 0.1 cm s^{-1} (i.e. 0.08 in Gibbs et al. 1971).

- The barite size spectrum indicates that very little of the material is less than 10 μm.

In summary, for the majority of discharge conditions expected on Georges Bank, especially the shallow well sections where discharge occurs at the seabed, it was decided that an effective settling velocity in the range of w_s= 0.1-0.5 cm s^{-1} was the most appropriate for a drilling waste composed of a 50/50 mixture of bentonite and barite.

3.4 *bblt* Applications

As described by Loder et al. (2000), using the hypothetical drilling waste discharge scenario, local *bblt* was used to run twenty-two applications on Georges Bank. The total daily amount of discharged mud in the waste discharge scenario (Appendix A) was used as input. Each application was run at two effective settling velocities (0.1 and 0.5 cm s^{-1}) which, as described above, bracket the expected range for water-based mud composed of a 50/50 mixture of bentonite and barite under tidally energetic conditions. The twelve applications forced by current meter data (Loder and Pettipas 1991, Smith et al. 2000) are summarized in Table 2. They considered the waste discharged while drilling an entire exploration well (i.e. Sections 1-5). The ten applications forced by currents predicted by the 3-D model circulation model (Naimie 1995, 1996) are summarized in Table 3. They considered only the waste discharged while drilling Sections 1-4 (i.e. 62 days).

These applications were run at nine different locations on Georges Bank (Fig. 4). One application site is in the well-mixed area on the top of the Bank (water depth < 65 m), five sites are in the frontal zone (65-100 m), and three sites are located in the permanently stratified area the side of the Bank (> 100 m). The results of the water column plume dispersion modelling (Andrade and Loder 1997) were used to estimate the fraction of waste discharged at 10 m below the sea surface in Sections 3-5 that would reach the benthic boundary layer (f in Tables 2 and 3). Most applications were run under summer conditions but four were run during winter (Tables 2 and 3).

The *bblt* model simulations provide predictions of drilling waste concentrations in the bottom 10 cm of the water column (i.e. where sea scallops are feeding) as a function of space and time around the discharge location. Standard model output is time series of bulk properties, contour plots of the horizontal distribution of near-bottom concentrations at selected time intervals, and time series of near-bottom concentrations at specific locations (Hannah et al. 1995, Loder et al. 2000). Loder et al. (2000) should be referred to for more detailed description and physical oceanographic interpretation of these *bblt* applications.

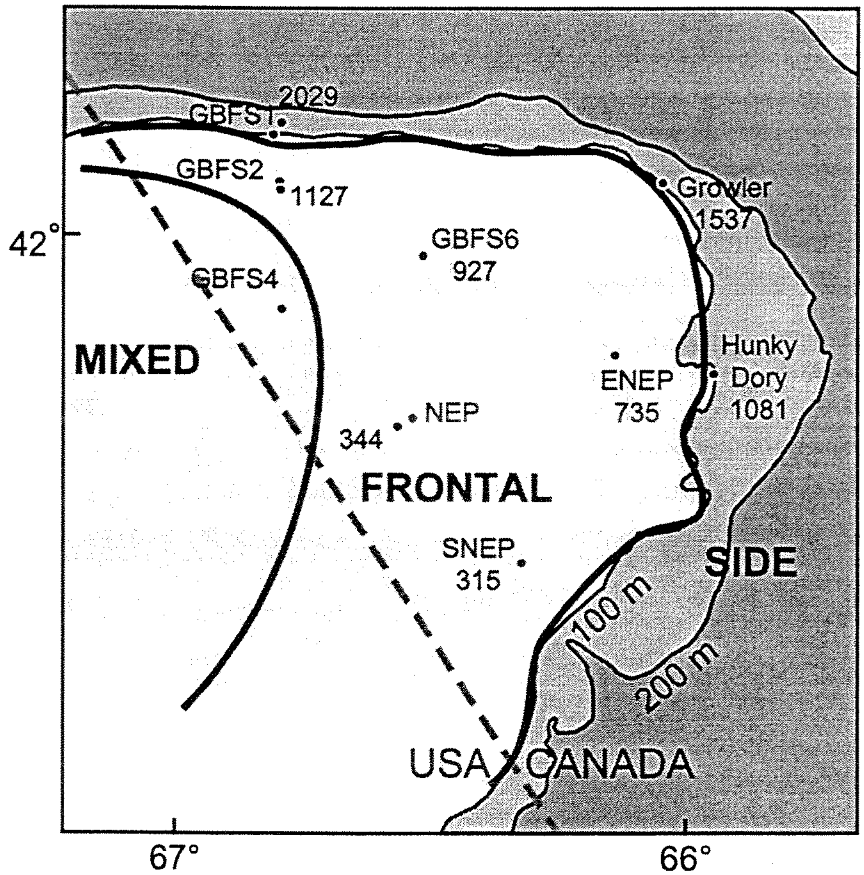

Figure 4. Map of the Canadian sector of Georges Bank (Northeast Peak) showing the nine hypothetical waste discharge sites. Applications at GBFS1, GBFS2, GBFS4 and NEP sites were forced by observed currents. Those at the other sites were forced by currents predicted by the 3-D model and the numbers refer to model nodes. The heavy solid lines indicate the approximate boundaries between different oceanographic zones (Mixed, Frontal and Side).

Table 2. Summary of local *bblt* applications using observed currents and the hypothetical waste discharge scenario. Each was run at two effective settling velocities (0.1 and 0.5 cm s^{-1}). Details of wastes released in each well section are provided in Appendix A and daily releases of mud are summarized in Fig. 3. Site locations and oceanographic zones are indicated in Fig. 4. Start day is Julian day. 'f' represents the fraction of wastes released at 10 m below the sea surface in Sections 3-5 that is estimated to reach the benthic boundary layer. Drift indicates the net direction of the waste patch during the simulation.

Section	Site	Zone	Water Depth (m)	Season	Start Day	f	Drift (°T)
1-4 (62 days)	GBFS1	Side	155	Summer	189	0.2	60
				Summer	217	0.2	50
	GBFS2	Frontal	67	Summer	189	0.4	140
				Summer	217	0.4	160
	NEP	Frontal	73	Summer	208	0.8	225
				Winter	8	1.0	200
	GBFS4	Mixed	63	Summer	189	1.0	180
				Summer	217	1.0	180
5 (50 days)	GBFS1	Side	155	Summer	189	0.2	50
	GBFS2	Frontal	67	Summer	189	0.8	140
	NEP	Frontal	73	Summer	208	1.0	225
				Winter	8	1.0	200

Table 3. Summary of local *bblt* applications using currents predicted by the 3-D model and the hypothetical waste discharge scenario. Each was run at two effective settling velocities (0.1 and 0.5 cm s^{-1}). These simulations only include wastes released during Sections 1-4. Details of wastes released in each well section are provided in Appendix A and daily releases of mud are summarized in Fig. 3. Node locations and oceanographic zones are indicated in Fig. 4. 'f' represents the fraction of wastes released at 10 m below the sea surface in Sections 3 and 4 estimated to reach the benthic boundary layer. Drift indicates the net direction of the waste patch .

Model Node	Zone	Water Depth (m)	Season	f	Drift (°T)
2029 (GBFS1)	Side	126	Summer	0.2	65
2029 (GBFS1)	Side	126	Winter	0.4	60
1537 (Growler)	Side	147	Summer	0.2	190
1081 (Hunky Dory)	Side	107	Summer	0.2	5
1127 (GBFS2)	Frontal	74	Summer	0.4	145
1127 (GBFS2)	Frontal	74	Winter	1.0	90
927 (GBFS6)	Frontal	80	Summer	0.4	161
344 (NEP)	Frontal	72	Summer	0.8	200
735 (ENEP)	Frontal	91	Summer	0.2	148
315 (SNEP)	Frontal	91	Summer	0.2	253

3.5 Calculation of Potential Effects on Scallop Growth

The biological interpretation of the total drilling waste concentrations predicted by *bblt* is based on the results of laboratory toxicity experiments reported by Cranford and Gordon (1992) and Cranford et al. (1999). These experiments exposed sea scallops to different concentrations of various drilling wastes in raceway tanks and determined the lethal and sublethal effects, including tissue growth, of intermittent exposure. The results are summarized in Fig. 5. Only the results from the bentonite and barite experiments have been used for these Georges Bank applications.

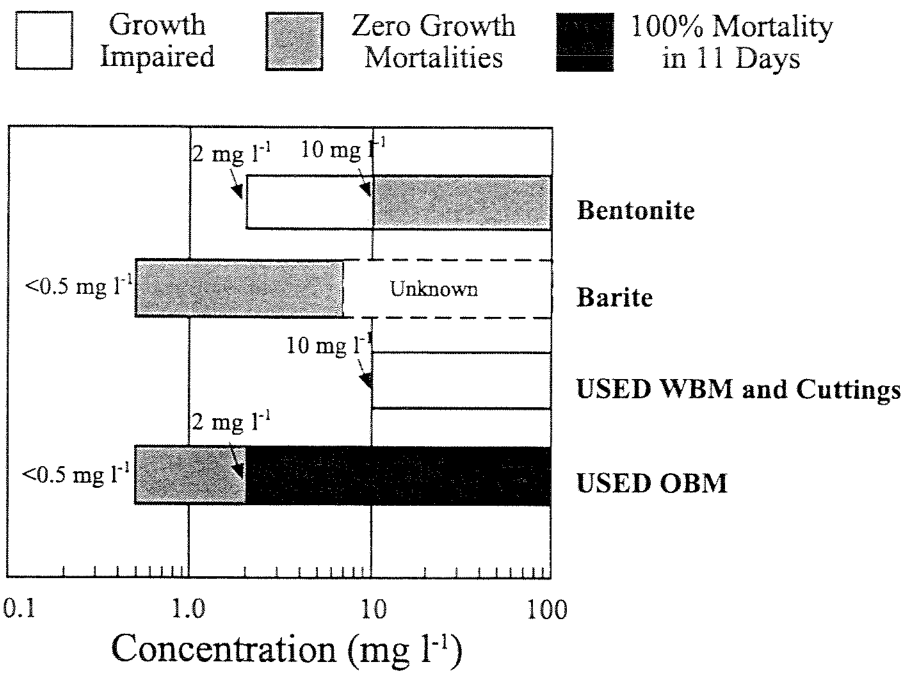

Figure 5. Summary of effects of bentonite, barite, used water-based mud (WBM) and cuttings, and used oil-based muds (OBM) on Atlantic sea scallops (*Placopecten magellanicus*) from Cranford and Gordon (1992) and Cranford et al. (1999). Samples of barite, WBM and OBM were provided by PanCanadian Resources from their development drilling operations at CoPan on Sable Island Bank.

Two kinds of effects thresholds were estimated from the exposure data. The first is the *zero growth concentration* (C_0). There is no scallop tissue growth for concentrations at or above this threshold. The second is the *no effects concentration* (C_1). There is no significant effect on scallop growth for concentrations at or below this threshold. For bentonite, zero growth was observed at 10 mg l^{-1} and no effects were detected at 2 mg l^{-1} (Fig. 5). The effects thresholds had to be estimated for barite as laboratory experiments showed zero growth at the lowest concentration tested (0.5 mg l^{-1}). Other biological effects indices (ingestion rate and absorption efficiency) indicated that growth would occur at barite concentrations below 0.5 mg l^{-1} (Cranford et al. 1999), and this value was adopted as the zero growth concentration.

The no effects concentration for barite was estimated to be 0.1 mg l^{-1} by assuming the ratio C_1/C_0 was the same as observed for bentonite. The thresholds are substantially lower for barite than for bentonite, indicating its greater effect on scallop growth. Observed sublethal effects from both wastes result from the negative influence of fine inorganic particles on scallop feeding processes, but chemical toxicity may also be a factor with barite.

The effects on scallops of the different drilling waste discharge scenarios (Tables 2 and 3) are estimated at each site based on calculations of *the number of potential growth days lost over the exposure time*. This quantitative index was computed separately for high (0.5 cm s^{-1}) and low (0.1 cm s^{-1}) effective settling velocities in Lotus 123 spreadsheets. The first step was to separate each waste concentration time-series predicted by *bblt* simulations into barite and bentonite components, assuming each contributed equal and constant proportions to the total mass.

The second step was to calculate a relative growth index (G) that can be expected for each 30-min time-step with limits between 0 (zero growth at or above C_0) and 1 (normal growth at or below C_1). This was accomplished by first defining a growth reduction index (R) with limits between 0 (normal growth) and 1 (zero growth). Growth reductions from barite and bentonite exposure were calculated from waste concentration estimates (C) and the effect thresholds using the equations

$$R_{\text{barite}} = 2.5C_{\text{barite}} - 0.25, \quad (1)$$

$$R_{\text{bentonite}} = 0.125C_{\text{bentontite}} - 0.25, \text{ and} \quad (2)$$

$$R = R_{\text{barite}} + R_{\text{bentonite}}. \quad (3)$$

Equations 1 and 2 assume a linear relation between growth and waste concentration as observed by Cranford et al. (1999), and Equation 3 accounts for additive effects of simultaneous bentonite and barite exposure. However, as R cannot be above 1 or below 0, the following qualifiers were applied to the results of Eq. 3.

$$\text{If } R > 1, \text{ then } R = 1, \text{ and} \quad (4)$$

$$\text{if } R < 0, \text{ then } R = 0.^{[1]} \quad (5)$$

The growth index for each time-step (i) is then

$$G_i = 1 - R_i. \quad (6)$$

[1] During the final review of this report, it was realized that the equations implemented in the calculation of R can, under some conditions, underestimate growth days lost on the order of a few days. Values for R_{barite} and $R_{\text{bentonite}}$ should have been clipped to between 0 and 1 before being added together. This error is not expected to change any of the major conclusions of this report.

The number of potential growth days lost over the exposure time (G_{lost}) was calculated by subtracting the sum of the G_i's over all time-steps (n) from the total number of time steps, and dividing by 48 (the number of time-steps each day).

$$G_{lost} = \frac{n - \sum_{i=1}^{n} G_i}{48}, \tag{7}$$

The percentage of potential growth lost over the exposure time ($\%G_{lost}$) was calculated as

$$\%G_{lost} = \frac{n - \sum_{i=1}^{n} G_i}{n} \times 100. \tag{8}$$

These calculations assume that every day is a potential growth day when in fact natural conditions (e.g. storms, spring tidal currents, etc.) can periodically resuspend sand and inhibit scallop feeding. They also assume there are no decomposition processes operating that would change toxicity with time and thereby alter individual effects threshold values. It is also assumed that the physical effects of both bentonite and barite do not change with time when in actuality they could be influenced by changes in flocculation. However, microbial activity may alter the speciation of trace metal impurities in barite to more bioavailable and toxic forms. We considered taking a more precautionary approach by adjusting the effects thresholds to account for the possibility of synergistic effects, as is commonly done in the regulatory business, but decided against this since a conservative approach was taken in interpreting model results.

The results of these applications are expressed as days of scallop growth lost assuming that scallops are present everywhere in the model domain and that growth is continuous throughout the year. Therefore, the predicted biological impacts are directly related to waste concentrations, the higher the concentrations the greater the potential impacts. In actuality, as discussed later in this report, scallops are very patchy in distribution and growth rate varies seasonally so that the predicted impacts of a given application depend upon the location of scallop beds relative to the discharge location and the timing of drilling.

To illustrate the calculation steps and model output, detailed results are provided using the high settling velocity ($w_s = 0.5$ cm s^{-1}) for a site located 2 km from the GBFS1 discharge location on the northern edge of Georges Bank (Fig. 4). It can be seen that the predicted waste concentrations in the bottom 10 cm of the water column fluctuate considerably over consecutive tidal cycles, reflecting the simulated resuspension and deposition processes (Fig. 6A). Concentrations of waste often exceed 10 mg l^{-1} during the first 10 days of drilling. During the same time period, the relative scallop growth index (G_i) seldom exceeded zero (Fig. 6B). G_i fluctuated rapidly between minimum and maximum values over the next 20 days as the predicted barite concentrations fluctuated between the effects thresholds. Further growth reductions are predicted between Days 30 and 45. The cumulative G_i curve (Fig. 6C) shows that most of the 17 potential growth days lost during the 62 day summer period (27 %

of total potential growth) occurred during the first 20 days of drilling when the bulk of the discharge takes place (Fig. 3) and waste concentrations were greatest.

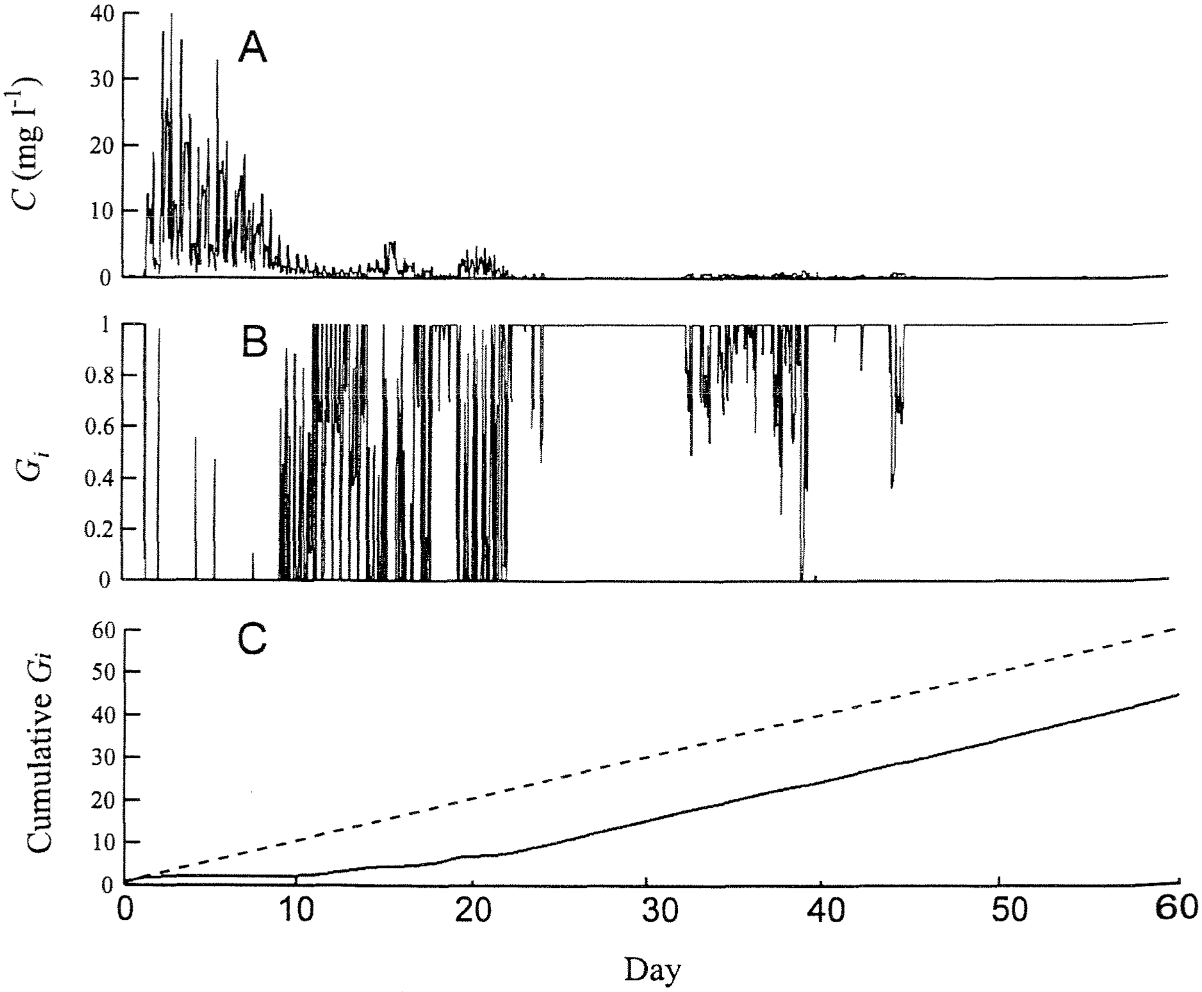

Figure 6. Example of *bblt* model output of (A) drilling waste concentration and (B) predicted effects on the relative growth index (G_i) of scallops. Cumulative growth over the simulation period is shown (C) for the model application (solid line) and assuming no effect on growth (dashed line). Growth days lost is the difference between the number of exposure days and the total number of days that growth was not inhibited.

3.6 Summary of Assumptions

As is evident from the methods described above, the application of numerical models to predict biological effects in a complex natural environment requires many assumptions to be made. The major assumptions made in this modelling project are summarized as follows:

- *bblt* includes the major physical factors affecting the transport of fine sediment in the benthic boundary layer and therefore provides a reasonable approximation of processes in the real world.

- The local version of *bblt*, which has uniform physical forcing functions over the entire model domain, generally provides conservative waste concentrations for a spatially-varying environment such as Georges Bank.

- The 3-D circulation model provides reasonable forcing functions for application sites where current observations are not available.

- The waste discharge scenario is reasonable.

- Suspended coarse cuttings particles have no significant effects on scallop growth.

- Exploration drilling will be done with a water-based mud.

- The particulate component of the water-based mud is comprised of comparable amounts of bentonite and barite which do not change with depth in the well.

- Bentonite and barite particles in the mud will flocculate when discharged into seawater.

- The particulate waste mixture can be represented by an effective settling velocity which is controlled by floc dynamics and ranges between 0.1 and 0.5 cm s^{-1}.

- The amount of bentonite and barite incorporated into sediments is negligible and the only loss is export from the model domain.

- The effects thresholds for barite and bentonite measured or estimated from laboratory experiments can be used to estimate scallop response to drilling wastes under natural conditions.

- The toxicity of bentonite and barite does not change with time after discharge.

- Average waste concentration in the bottom 10 cm of the water column is a reasonable estimate of exposure condition for scallops.

- Scallops would normally exhibit positive tissue growth during the drilling period.

4.0 RESULTS

4.1 Drilling Waste Concentrations

The drilling waste concentrations predicted in these applications are presented by Loder et al. (2000). The scale of the drift and dispersion of the near-bottom waste patch is illustrated by snapshots at different time intervals at three locations: GBFS1 (Fig. 7) and Growler (Fig. 8) on the side of the Bank, and NEP (Fig. 9) in the frontal zone. The main physical results of these applications are summarized as follows:

- The spatial patterns and near-bottom concentrations of drilling muds predicted by observed and modelled currents are remarkably similar in most cases. This demonstrates the oceanic realism of the 3-D circulation model that has been used to force *bblt* for those sites and seasons at which suitable current meter data are not available. However, there are significant differences in some cases (e.g. NEP site in winter) which appear to reflect limitations of both the 3-D model and observational current data (Loder et al. 2000).

- The predicted near-bottom concentrations of drilling muds are very sensitive to the choice of effective settling velocities. Those at the higher velocity (0.5 cm s^{-1}) are about an order of magnitude greater than those at the lower velocity (0.1 cm s^{-1}).

- In general, predicted near-bottom concentrations decrease rapidly over distances of 2-10 km from the discharge location. In some applications, substantial waste concentrations are carried as far as 20-50 km from the discharge location at the higher settling velocity. These more distant concentrations must be interpreted with considerable caution because the assumption in local *bblt* of a uniform physical environment over the entire model domain breaks down with increasing distance from the discharge location.

- The predicted near-bottom concentrations of drilling waste are very dependent upon geographic location of the discharge. Due to high bottom stress (high suspension) and strong dispersion, predicted near-bottom concentrations are lowest in the shallow water on the top of the Bank (less than 65 m). Near-bottom concentrations are higher in the frontal area (65-100 m) due to relatively lower bottom stress and dispersion. The highest concentrations occur in the deeper water on the side of the Bank (greater than 100 m) where bottom stress and dispersion are lowest.

- Both the observed and model current applications indicate that the predicted mean drift of the near-bottom drilling waste patch is generally along depth contours except over the Bank's side where more variability in drift direction is found (Tables 2 and 3). This pattern is consistent with the residual circulation. Results for the Growler site indicate that drift from the side of the Bank up into the frontal zone is possible under some conditions (Table 3).

- Applications forced by the 3-D model at GBFS1 and GBFS2 indicate that waste concentrations in winter would be lower than in summer. The reduced winter concentrations at the GBFS2 site (also expected for other frontal sites) reflect the increased boundary layer thickness associated with reduced stratification and increased vertical mixing in winter. The reduced winter concentrations at the GBFS1 site are associated with stronger model tidal currents in winter, the reliability of which is unclear. However, waste concentrations at NEP, where *bblt* was forced by observed currents, were higher in winter than summer.

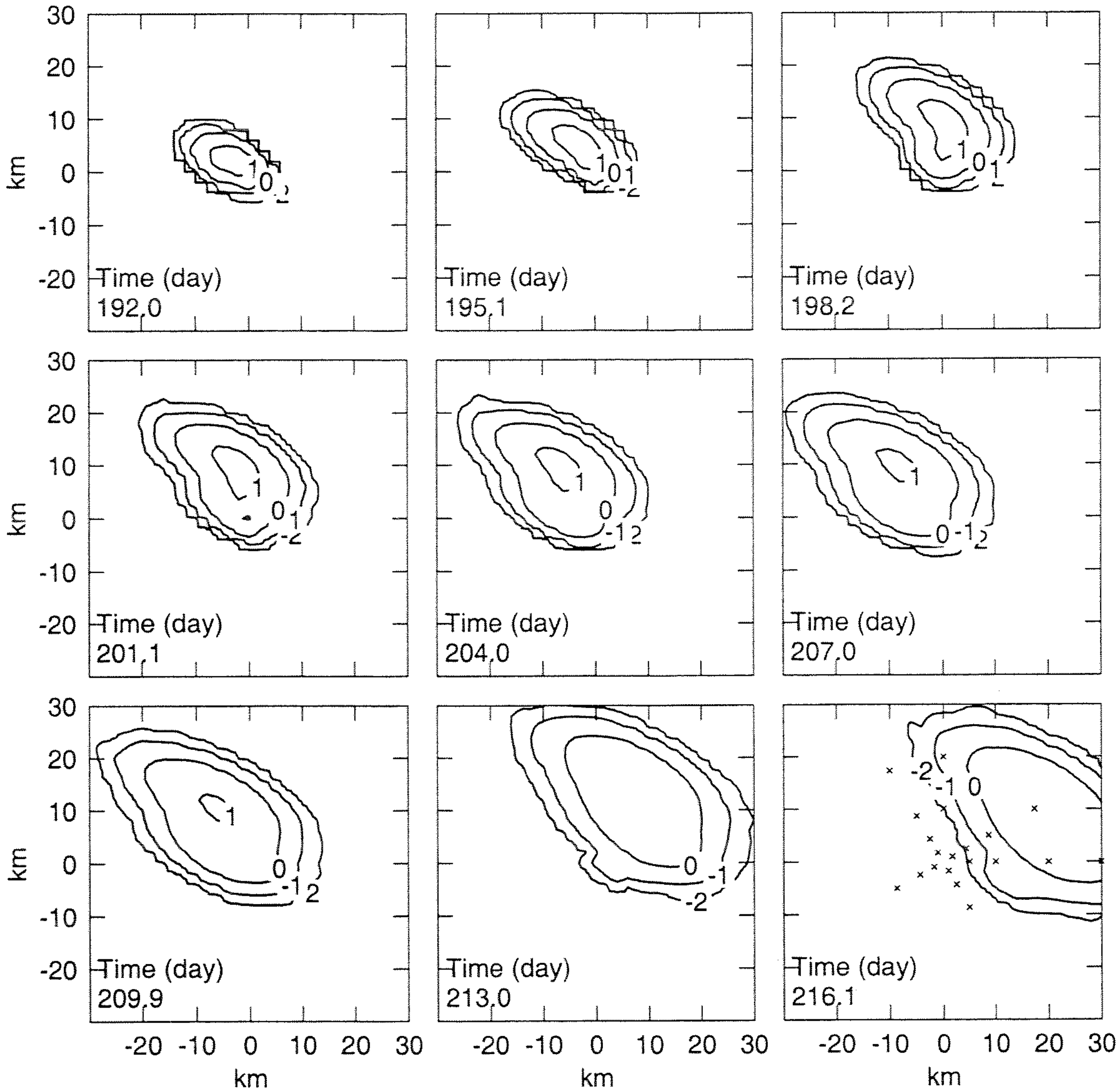

Figure 7. Snapshots of predicted waste concentrations (base 10 logarithm, mg l^{-1}) with time around the discharge location at (0,0) km for the GBFS1 application (side of the Bank). North is up. This application was forced with observed summer currents starting on Day 189 and used the higher settling velocity of 0.5 cm s^{-1}. The X's in the last panel indicate the time series sampling positions for near-bottom sampling and biological effects interpretation (Fig. 16).

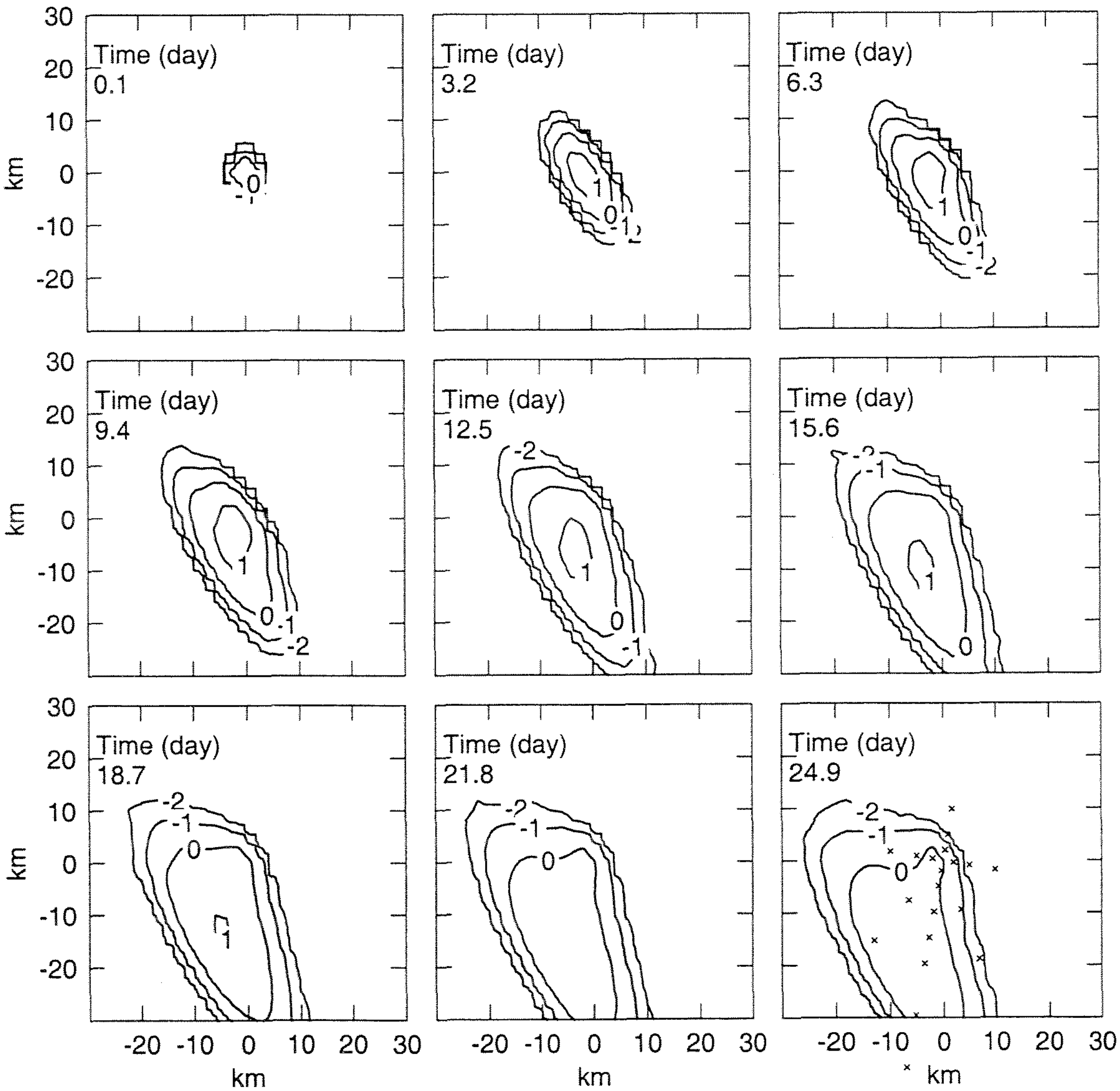

Figure 8. Snapshots of predicted waste concentrations (base 10 logarithm, mg l^{-1}) with time around the discharge location at (0,0) km for the Growler (Node 1537) application (side of the Bank). This application was forced with model summer currents and used the higher settling velocity of 0.5 cm s^{-1}. The X's in the last panel indicate the time series sampling positions for near-bottom sampling and biological effects interpretation (Fig. 18).

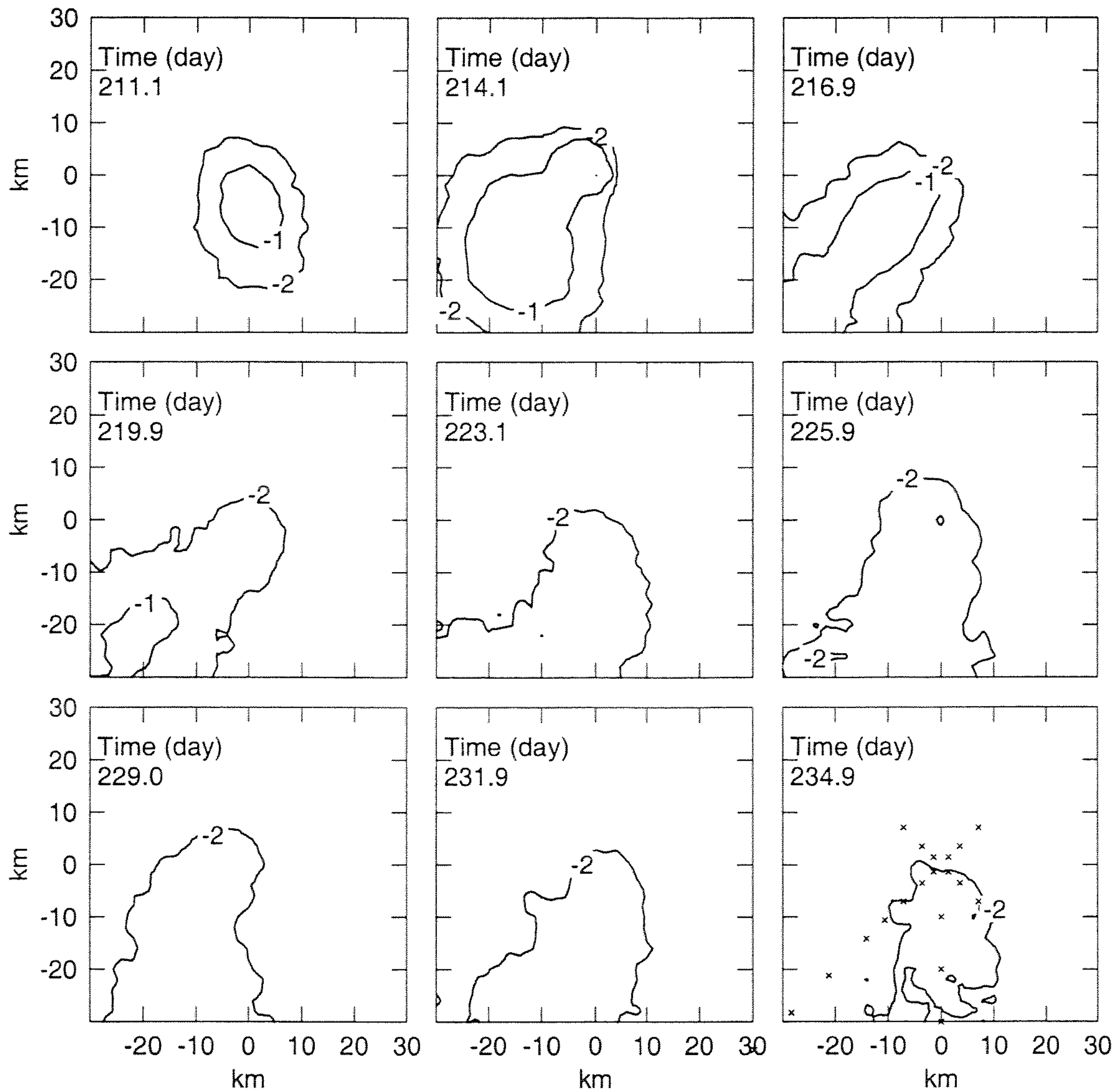

Figure 9. Snapshots of predicted waste concentrations (base 10 logarithm, mg l^{-1}) with time around the discharge location at (0,0) km for the NEP application (Frontal Region). This application was forced with observed summer currents starting on Day 208 and used the higher settling velocity of 0.5 cm s^{-1}. The X's in the last panel indicate the time series sampling positions for near-bottom sampling and biological effects interpretation (Fig. 13).

4.2 Effects of Wastes on Scallop Mortality

Prolonged exposure (on the order of a month) to high concentrations of bentonite and barite can cause mortality to scallops (Cranford and Gordon 1992, Cranford et al. 1999). However, analysis of the number of hours that waste concentrations exceed 10 mg l^{-1} along the primary drift line in these Georges Bank applications indicates that the predicted waste concentrations are not likely to cause scallop mortality, even at the discharge location. Mortalities could, however, result from burial of animals by cuttings under a platform but this is not considered in these model applications.

4.3 Effects of Wastes on Scallop Growth

The results of the twenty-two applications, outlined in Tables 2 and 3, are summarized as follows, grouped according to the physical oceanographic zone on the Bank in which they are located (Fig. 4). Results are presented as total growth days lost for both settling velocities at approximately twenty locations around the release point for the entire simulation period. All data are tabulated, summarized and plotted in Appendix B.

4.3.1 Mixed Zone on Top of the Bank

The two applications at the Georges Bank Frontal Study Site 4 (GBFS4) in the shallow mixed zone on top of the Bank (63 m depth) were forced by current meter data. Net drift of the waste patch was to the south (Table 2). There was no scallop growth lost at the lower settling velocity (Fig. 10). At the higher settling velocity, there was just one location where the lost growth exceeded one day and that was at the discharge location of the application starting on Day 217.

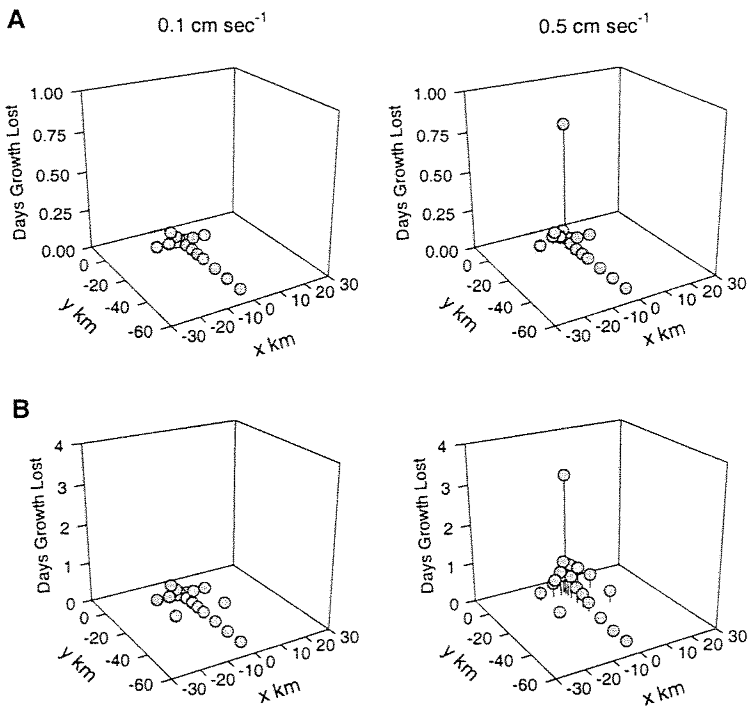

Figure 10. Scallop growth days lost at the lower (left) and higher (right) settling velocities (w_s) at GBFS4 (Mixed Zone). Forced by observed currents, Sections 1-4 of the drilling waste discharge scenario. (A) Days 189-251 and (B) Days 217-279.

4.3.2 Frontal Zone

4.3.2.1 Georges Bank Frontal Study Site 2 (GBFS2)

The five applications at this site (67 m) were forced by both current meter data and the 3-D model. Net drift of the waste patch was generally to the southeast except for the winter when drift was eastward (Tables 2 and 3). There was virtually no scallop growth loss at the lower settling velocity in any of the applications (Figs. 11 and 12). Growth loss was detectable only at the higher settling velocity and ranged on the order of 4-10 days at the discharge location. Concentrations dropped rapidly with distance from the discharge location, but in the model-forced summer application, growth loss in excess of 2 days was still seen as far away as 30 km in the net drift direction (Fig. 12). Growth days lost were less in the winter than in summer (Fig. 12). Growth loss during drilling the last well section was similar to that for Sections 1-4 (Figs 11A and B).

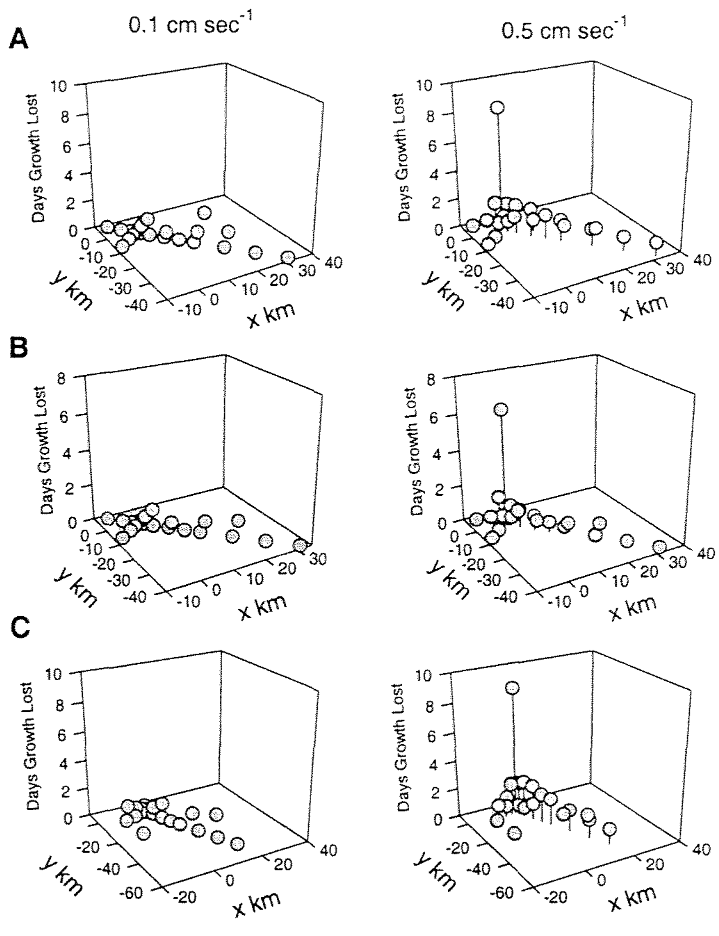

Figure 11. Scallop growth days lost at the lower (left) and higher (right) settling velocities (w_s) at GBFS2 (Frontal Zone). Forced by observed currents during the entire drilling waste discharge scenario. (A) Days 189-251for Sections 1-4, (B) Days 189-239 for Section 5, and (C) Days 217-279 for Sections 1-4.

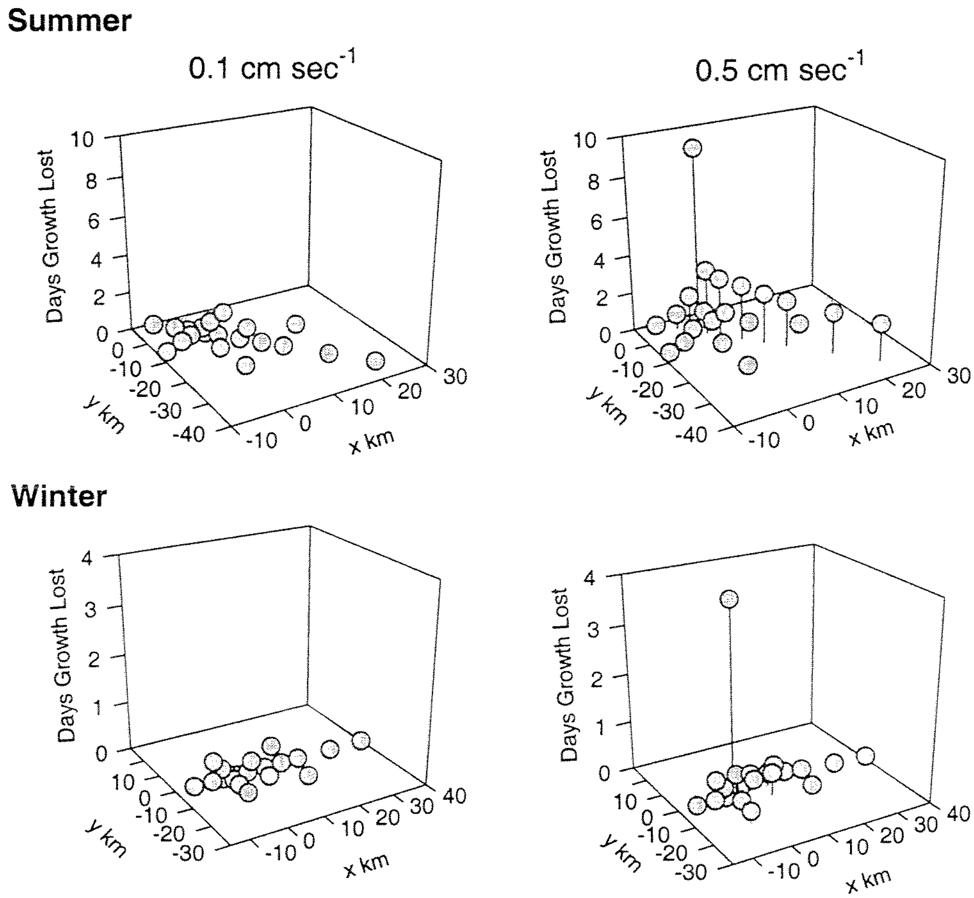

Figure 12. Scallop growth days lost at the lower (left) and higher (right) settling velocities (w_s) at GBFS2 (Node 1127) (Frontal Zone). Forced by the 3-D model during summer and winter for Sections 1-4 of the drilling waste discharge scenario.

4.3.2.2 Northeast Peak (NEP)

The five applications at this site (73 m) were forced by both current meter data and the 3-D model. Net drift of the waste patch was generally to the southwest (Tables 2 and 3). There was virtually no scallop growth loss at the lower settling velocity in any of the applications (Figs. 13 and 14A). Growth loss was detectable at the higher settling velocity and ranged on the order of 3-16 days at the discharge location. Growth loss dropped with distance from the discharge location, but remained as high as 5 days out to 10 km from the discharge location during winter simulations (Fig. 13). Growth loss was lowest in summer (Fig. 13 and 14A). Growth loss was slightly less for Section 5 than for Sections 1-4 (Fig. 13).

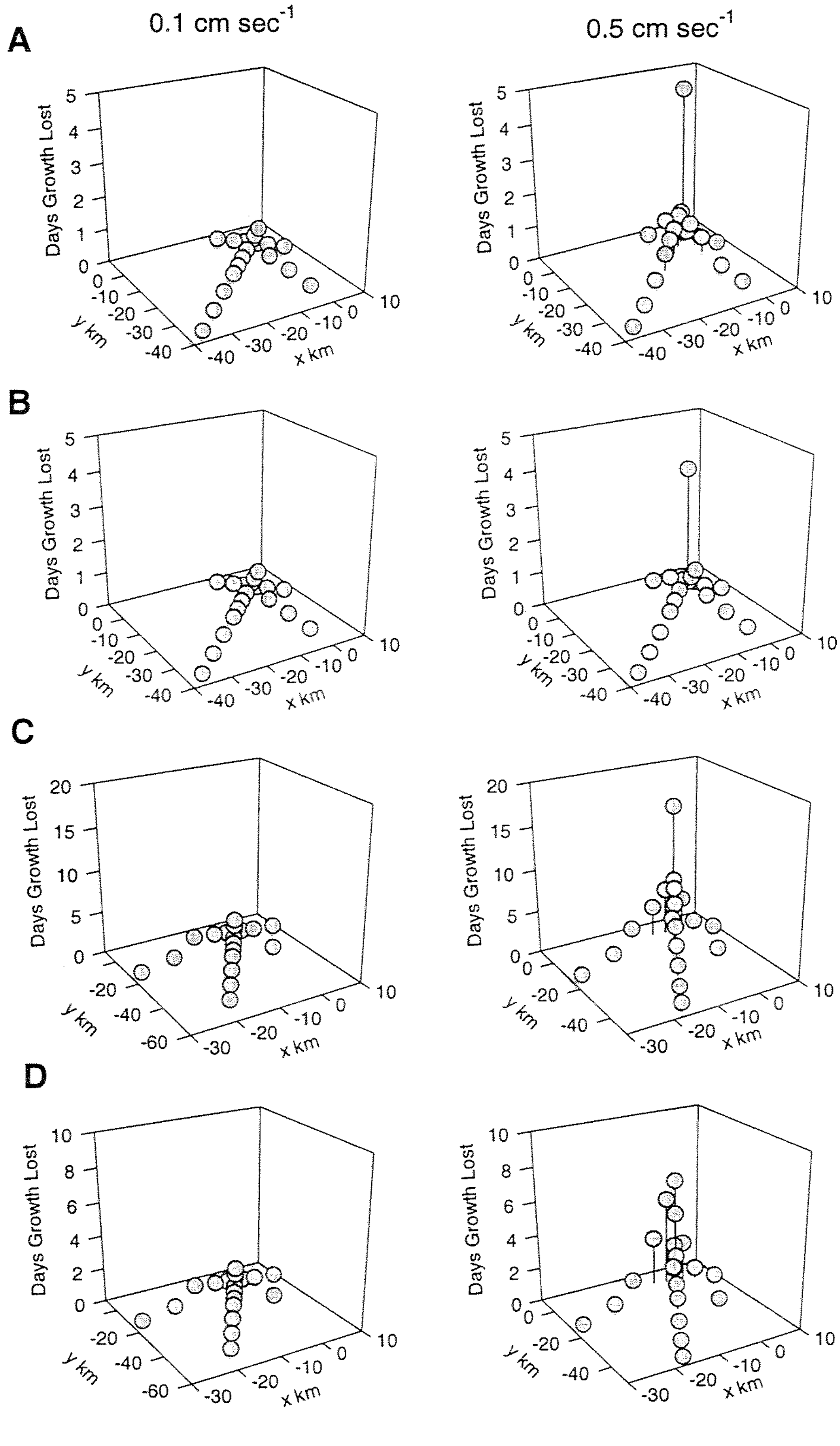

Figure 13. Scallop growth days lost at the lower (left) and higher (right) settling velocities (w_s) at NEP ((Frontal Zone). Forced by observed currents during the entire drilling waste discharge scenario. (A) Days 208-270 for Sections 1-4, (B) Days 208-258 for Section 5, (C) Days 8-70 for Sections 1-4 and (D) Days 8-58 for Section 5.

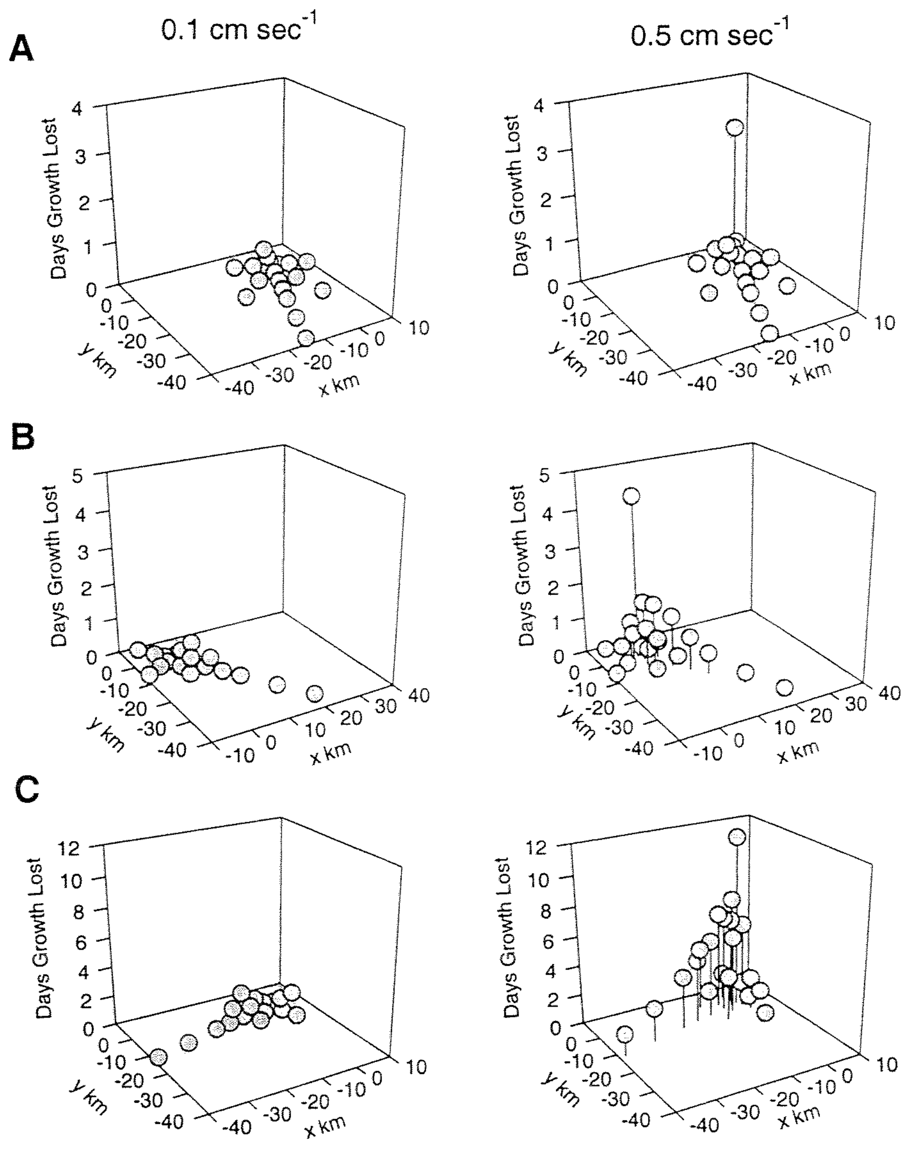

Figure 14. Scallop growth days lost at the lower (left) and higher (right) settling velocities (w_s) during the summer at (A) NEP (Node 344), (B) ENEP (Node 735) and (C) SNEP (Node 315). All sites are in the Frontal Zone. Forced by the 3-D model for Sections 1-4 of the drilling waste discharge scenario.

4.3.2.3 East Northeast Peak (ENEP)

The single application at this site (91 m) was forced by the 3-D model during the summer months (Fig. 14B). Net drift of the waste patch was to the southeast (Table 3). There was no scallop growth loss at the lower settling velocity. Growth loss was detectable at the higher settling velocity and was 4 days at the discharge location. Growth lost dropped rapidly with distance from the discharge location.

4.3.2.4 South Northeast Peak (SNEP)

The single application at this site (91 m) was forced by the 3-D model during the summer months (Fig. 14C). Net drift of the sediment patch was to the west-southwest (Table 3). There was no scallop growth lost at the lower settling velocity. Growth lost was detectable at the higher settling velocity and was 11 days at the discharge location. Growth lost dropped slowly with distance from the discharge location and exceeded 2 days as far as 40 km away along the primary drift line (Fig. 14C).

4.3.2.5 George Bank Frontal Study Site 6 (GBFS6)

The single application at this site (80 m) was forced by the 3-D model during the summer months (Fig. 15). Net drift of the waste patch was to the south southeast (Table 3). There was no scallop growth lost at the lower settling velocity. Growth lost at the higher settling velocity was 6 days at the discharge location and dropped rapidly with distance from the discharge location.

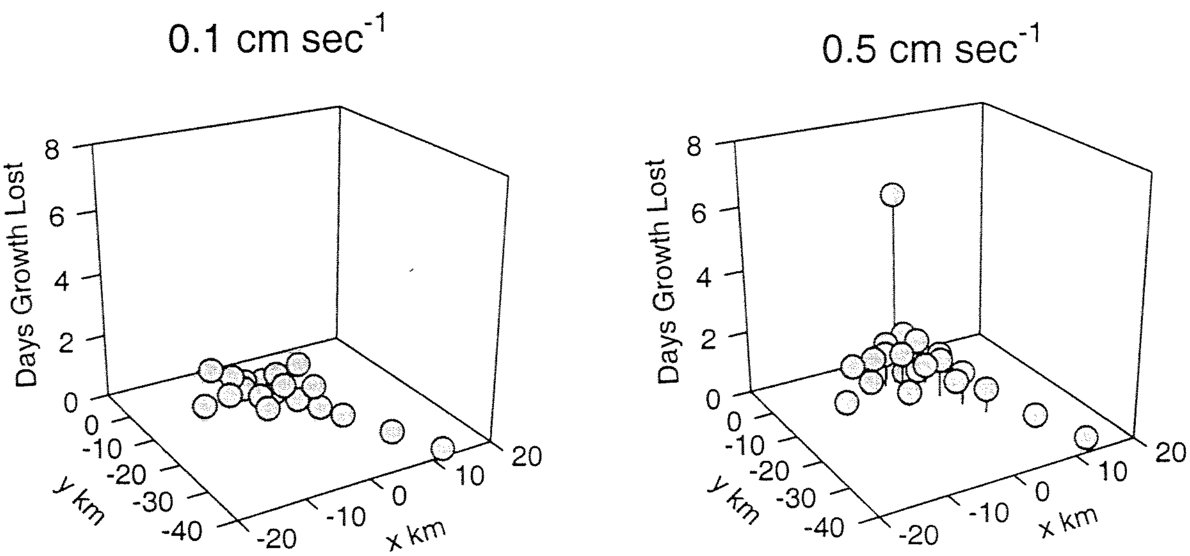

Figure 15. Scallop growth days lost at the lower (left) and higher (right) settling velocities (w_s) at GBFS6 (Node 927) (Frontal Zone). Forced by the 3-D model during the summer for Sections 1-4 of the drilling waste discharge scenario.

4.3.3 Side of the Bank

4.3.3.1 Georges Bank Frontal Study Site 1 (GBFS1)

The five applications at this site (155 m) were forced by both current meter data and the 3-D model. In all applications the net drift of the waste patch was to the northeast (Tables 2 and 3). In contrast to the applications run on top of the Bank and in the frontal zone, there was detectable growth lost at the lower settling velocity which ranged from 1 to 7 days at the discharge location (Figs. 16 and 17). Growth lost was much greater at the higher settling velocity and ranged from 11 to 30 days at the discharge location. Growth lost generally dropped rapidly with distance from the discharge location but, in the case of the model-forced summer application, exceeded 7 days as far as 40 km away along the primary drift line (Fig. 17). Growth lost was greater in the summer than in the winter (Figs. 16 and 17) and was less for Section 5 (Fig. 16B) than for Sections 1-4 (Fig. 16A and C).

4.3.3.2 Growler

The single application at this site (147 m) was forced by the 3-D model during the summer months (Fig. 18). Net drift of the waste patch was to the west of south (Table 3). There was slight loss of scallop growth at the lower settling velocity that was 3 days at the discharge location. Growth lost was greater at the higher settling velocity and was 22 days at the discharge location. Growth lost dropped slowly with distance from the discharge location but still exceeded 15 days as far as 40 km away along the primary drift line.

4.3.3.3 Hunky Dory

The single application at this site (107 m) was forced by the 3-D model during the summer months (Fig. 19). Net drift of the waste patch was to the north (Table 3), different from the near-surface residual circulation. There was no scallop growth lost at the lower settling velocity, even at the discharge location. Growth lost at the higher settling velocity was 18 days at the discharge location, and dropped along the primary drift line but still exceeded 7 days at 40 km.

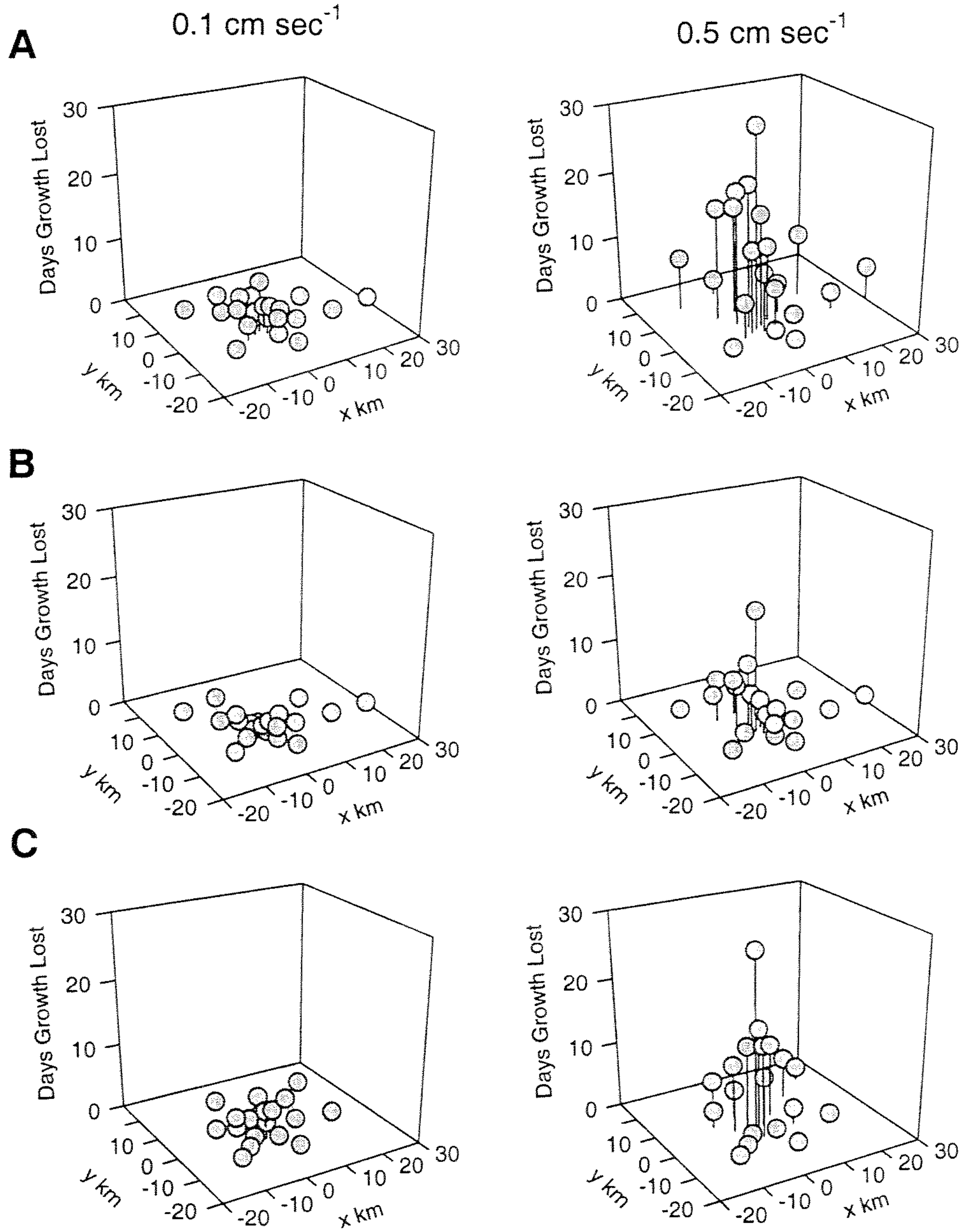

Figure 16. Scallop growth days lost at the lower (left) and higher (right) settling velocities (w_s) at GBFS1 (Side of the Bank). Forced by observed currents during the entire drilling waste discharge scenario. (A) Days 189-251 for Sections 1-4, (B) Days 189-239 for Section 5, and (C) Days 217-279 for Sections 1-4.

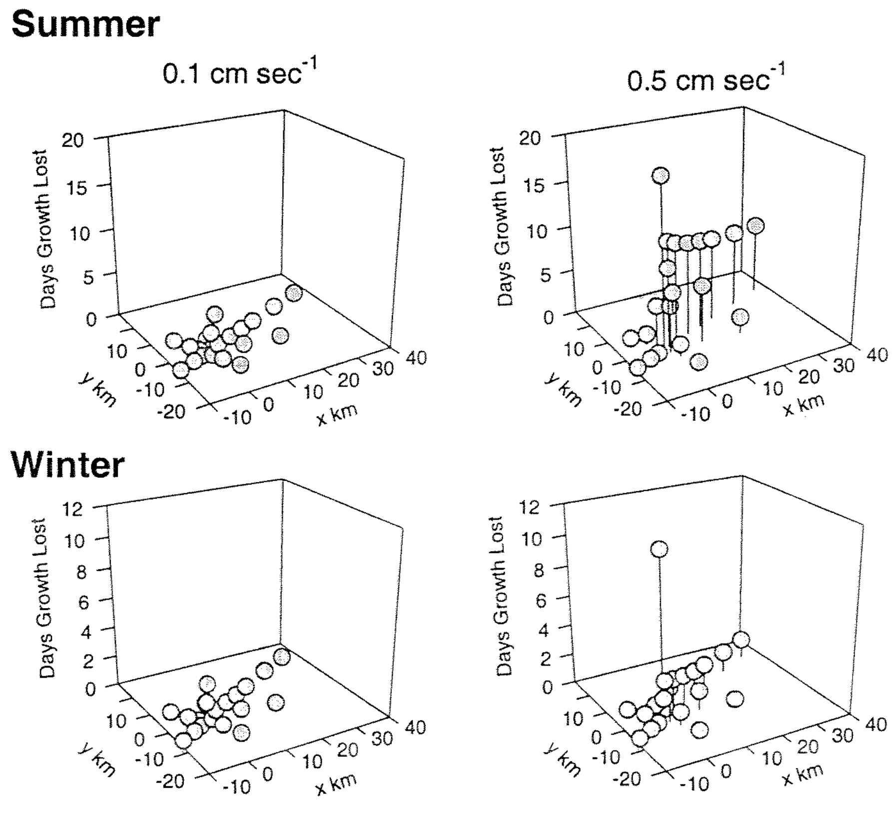

Figure 17. Scallop growth days lost at the lower (left) and higher (right) settling velocities (w_s) at GBFS1 (Node 2029) (Side of the Bank). Forced by the 3-D model during summer and winter for Sections 1-4 of the drilling waste discharge scenario.

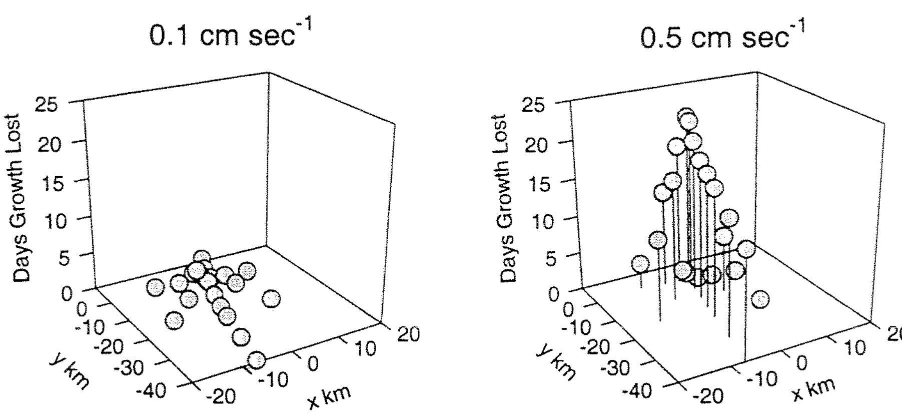

Figure 18. Scallop growth days lost at the lower (left) and higher (right) settling velocities (w_s) at Growler (Node 1537) (Side of the Bank). Forced by the 3-D model for Sections 1-4 of the drilling waste discharge scenario.

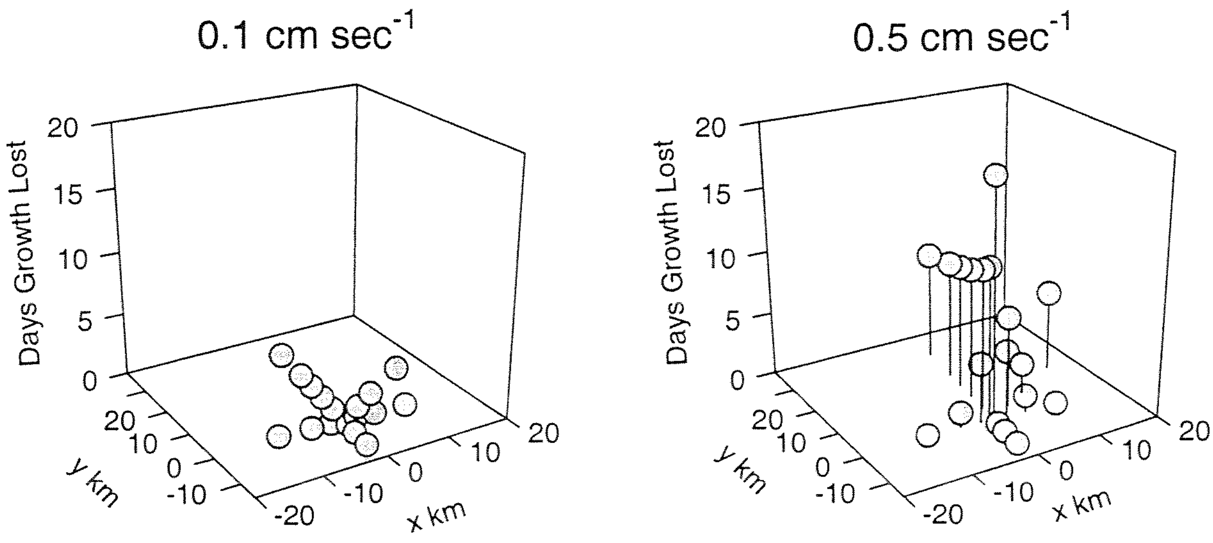

Figure 19. Scallop growth days lost at the lower (left) and higher (right) settling velocities (w_s) at Hunky Dory (Node 1081) (Side of the Bank). Forced by the 3-D model for Sections 1-4 of the drilling waste discharge scenario.

4.3.4 Spatial Extent

As is evident in Figs. 10-19, there is considerable spatial and temporal variability in the predicted biological impacts of the drilling wastes discharged in the scenarios run. This variability is also illustrated by plotting growth days lost along the primary drift line of all applications (Figs. 20 and 21). Only data from the higher settling velocity are shown; growth loss using the lower settling velocity is much lower (Figs. 10-19). As expected, in all cases, the number of potential growth days lost is greatest at the discharge location and decreases with increasing distance. The greatest potential impacts occur at those application sites in deeper water on the side of the Bank, namely GBFS1, Growler and Hunky Dory. In general, the potential impacts at these three locations extend further away from the discharge location than at the application sites in the frontal zone or on top of the Bank. However, these high distant waste concentrations should be interpreted with caution because of the assumption in local *bblt* that the physical oceanographic conditions at the discharge site apply to the entire model domain that is clearly not true. For example, sensitivity simulations with spatially-variable *bblt* (Loder et al. 2000, Xu et al. 2000) indicate a greater tendency for on-bank drift along the Bank's northern edge than in the local *bblt* simulations.

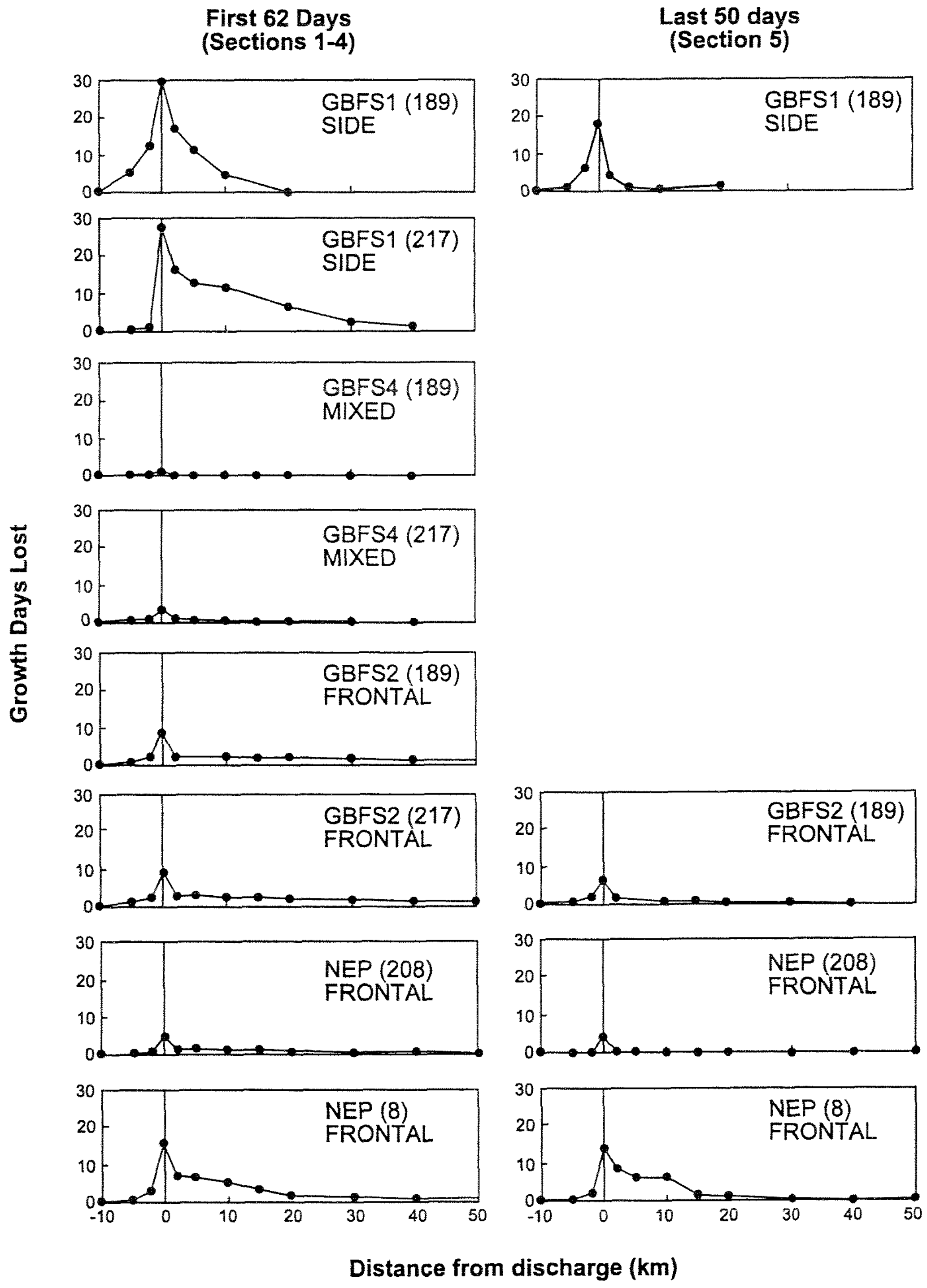

Figure 20. Summary plots of scallop growth lost along the primary drift line in *bblt* runs forced by observations. The starting day is given in parenthesis for each site. Higher settling velocity only (0.5 cm^{-1}). Application sites are categorized according to physical oceanographic zone on Georges Bank.

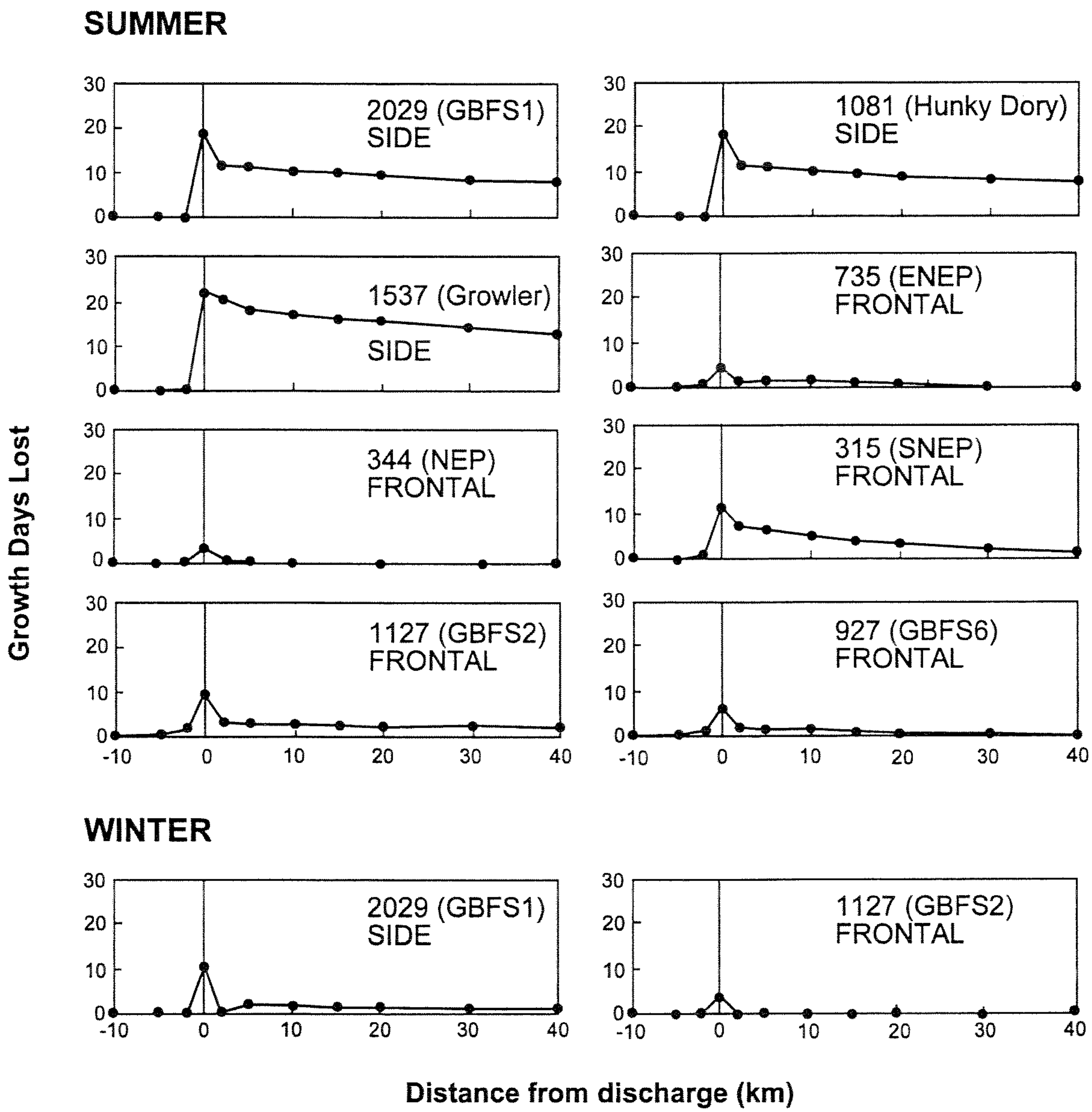

Figure 21. Summary plots of scallop growth lost along the primary drift line in *bblt* runs forced by the 3-D model. Higher settling velocity only (0.5 cm^{-1}). Application sites are categorized according to physical oceanographic zone on Georges Bank.

4.3.5. Synthesis

The biological impacts of all twenty-two applications are summarized by averaging the number of potential growth days lost over different areas relative to the discharge location. These values for applications forced by observed currents are presented in Table 4 and those for applications forced by 3-D model are presented in Table 5. The results were reduced still further by averaging growth loss over the different areas according to physical oceanographic zone on Georges Bank. These calculations combine the results of different physical forcings and seasons since these factors had a relatively minor effect on the predicted near-bottom waste concentrations.

Table 4. Potential growth days lost (G_{lost}) for sea scallops (*Placopecten magellanicus*) calculated from output from the local *bblt* model with observed current forcing. The different application site locations are indicated in Figure 4. G_{lost} for each application was averaged over a radius of 0.5, 2, 5 and 10 km from the discharge site and along the primary drift line (i.e. out to about 40 km). Full data are listed in Appendix B. An asterisk indicates that growth lost was greater than 10% over the simulated period.

Section	Site	Start Day	Zone	w_s (cm s^{-1})	G_{lost} (Days) 0.5 km	2 km	5 km	10 km	Drift Line
1-4	GBFS1	189	Side	0.1	*7.6	4.4	3.5	2.6	2.8
(62 days)				0.5	*29.8	*17.9	*14.1	*11.4	*12.5
	GBFS1	217	Side	0.1	*6.3	3.0	2.1	1.6	1.9
				0.5	*27.3	*13.2	*9.6	*7.7	*10.8
	GBFS2	189	Frontal	0.1	0.1	0.0	0.0	0.0	0.0
				0.5	*8.6	2.8	1.9	1.4	2.3
	GBFS2	217	Frontal	0.1	0.5	0.2	0.1	0.1	0.1
				0.5	*8.8	3.2	2.2	1.7	2.6
	NEP	208	Frontal	0.1	0.0	0.0	0.0	0.0	0.0
				0.5	4.6	1.3	0.9	0.7	1.0
	NEP	8	Frontal	0.1	0.0	0.0	0.0	0.0	0.0
				0.5	*15.7	*7.1	5.2	4.1	1.7
	GBFS4	189	Mixed	0.1	0.0	0.0	0.0	0.0	0.0
				0.5	0.8	0.2	0.1	0.1	0.1
	GBFS4	217	Mixed	0.1	0.0	0.0	0.0	0.0	0.0
				0.5	3.1	1.2	0.9	0.7	0.6
5	GBFS1	189	Side	0.1	1.7	1.0	0.81	0.6	0.7
(50 days)				0.5	*18.4	*8.5	*5.7	4.5	*5.1
	GBFS2	189	Frontal	0.1	0.1	0.0	0.0	0.0	0.0
				0.5	*6.4	2.0	1.3	0.9	1.1
	NEP	208	Frontal	0.1	0.0	0.0	0.0	0.0	0.0
				0.5	3.6	0.9	0.5	0.4	0.6
	NEP	8	Frontal	0.1	0.0	0.0	0.0	0.0	0.0
				0.5	*12.9	*5.8	4.2	3.1	4.2

Table 5. Potential growth days lost (G_{lost}) for sea scallops (*Placopecten magellanicus*) calculated from output from the local *bblt* model with 3-D model current forcing. Predictions are for the first 62 days of the hypothetical discharge scenario (Section 1-4) at different applications sites indicated in Figure 6. G_{lost} for each application was averaged over a radius of 0.5, 2, 5 and 10 km from the discharge site and along the primary drift line (i.e. out to about 40 km). Full data are listed in Appendix B. An asterisk indicates that growth lost was greater than 10% over the simulated period.

Model Node	Zone	Season	w_s (cm s^{-1})	G_{lost} (Days) 0.5 km	2 km	5 km	10 km	Drift line
2029 (GBFS1)	Side	Summer	0.1	1.5	0.3	0.2	0.1	0.2
			0.5	*18.8	*8.0	5.9	4.9	*10.8
2029 (GBFS1)	Side	Winter	0.1	1.3	0.3	0.2	0.2	0.3
			0.5	*10.8	2.9	2.0	1.5	2.6
1537 (Growler)	Side	Summer	0.1	3.0	1.2	0.8	0.6	0. 8
			0.5	*22.1	*12.6	*10.6	*9.0	*18.1
1081 (Hunky Dory)	Side	Summer	0.1	0.0	0.0	0.0	0.0	0.0
			0.5	*18.5	*8.0	5.9	4.9	*10.8
1127 (GBFS2)	Frontal	Summer	0.1	0.0	0.0	0.0	0.0	0.0
			0.5	*9.5	3.2	2.22	1.8	3.5
344 (NEP)	Frontal	Summer	0.1	0.0	0.0	0.0	0.0	0.0
			0.5	3.1	0.8	0.5	0.4	0.5
735 (ENEP)	Frontal	Summer	0.1	0.0	0.0	0.0	0.0	0.0
			0.5	4.5	1.6	1.1	0.9	1.4
315 (SNEP)	Frontal	Summer	0.1	0.0	0.0	0.0	0.0	0.0
			0.5	*11.5	*6.4	4.7	3.6	5.2
927 (GBFS6)	Frontal	Summer	0.1	0.0	0.0	0.0	0.0	0.0
			0.5	6.1	2.0	1.4	1.1	1.7
1127 (GBFS2)	Frontal	Winter	0.1	0.0	0.0	0.0	0.0	0.0
			0.5	3.9	0.9	0.6	0.4	0.6

4.3.5.1 At the Discharge Location (Radius of 0.5 km)

On average, on the side of the Bank, the predicted growth days lost at the discharge location for the two settling velocities range from 3.3 to 21.2 days for the first 62 days of the waste discharge scenario and from 1.7 to 18.4 days for the second 50 days (Table 6). The potential scallop growth loss is substantially less in the frontal zone, ranging from <0.1 to 7.6 days for the first 62 days and from <0.1 to 7.6 days for the second 50 days. The potential growth loss on the top of Bank is negligible, ranging from 0.0 to 2.0 days (first 62 days only). Adding the two time periods, the range of potential scallop growth loss for the full drilling waste discharge scenario ranges from 5.0 to 39.6 days for the side of the Bank and from <0.1 to 15.2 days in the frontal zone when averaged at the discharge location.

Table 6. Number of potential scallop growth days lost at the discharge location (radius of 0.5 km) for all applications averaged by settling velocity and physical oceanographic zone (Fig. 4).

Section	Zone	Mean G_{lost} (Days)	
		0.1 cm s^{-1}	0.5 cm s^{-1}
1-4 (62 days)	Side (>100 m)	3.3	21.2
	Frontal (65-100 m)	<0.1	7.6
	Mixed (<65 m)	<0.1	2.0
5 (50 days)	Side (>100 m)	1.7	18.4
	Frontal (65-100 m)	<0.1	7.6

4.3.5.2 Radius of 2 km from Discharge Location

Potential growth loss is less when averaged over a radius of 2 km from the discharge location (n = 5). On average, on the side of the Bank, it ranges for the two settling velocities from 1.5 to 10.4 days for the first 62 days and from 1.0 to 8.5 days for the second 50 days (Table 7). Again, the potential scallop growth loss is substantially less in the frontal zone, ranging from <0.1 to 2.9 days for the first 62 days and from <0.1 to 2.9 days for the second 50 days. The potential growth loss on the top of Bank is negligible, ranging from 0.0 to 0.7 days (first 62 days only). Adding the two time periods, the range of potential scallop growth loss for the full drilling waste discharge scenario ranges from 2.5 to 18.9 days for the side of the Bank and from <0.1 to 5.8 days in the frontal zone when averaged over a radius of 2 km from the discharge location.

Table 7. Number of potential scallop growth days lost within a radius of 2 km from the discharge location for all applications averaged by settling velocity and physical oceanographic zone (Fig. 4).

Section	Zone	Mean G_{lost} (Days)	
		0.1 cm s^{-1}	0.5 cm s^{-1}
1-4 (62 days)	Side (>100 m)	1.5	10.4
	Frontal (65-100 m)	<0.1	2.9
	Mixed (<65 m)	<0.1	0.7
5 (50 days)	Side (>100 m)	1.0	8.5
	Frontal (65-100 m)	<0.1	2.9

4.3.5.3 Radius of 5 km from Discharge Location

Potential growth loss is less when averaged over a radius of 5 km from the discharge location (n = 13). On average, on the side of the Bank, it ranges for the two settling velocities from 1.5 to 7.9 days for the first 62 days and from 0.8 to 5.7 days for the second 50 days (Table 8). Again, the potential scallop growth loss is substantially less in the frontal zone, ranging from <0.1 to 2.2 days for the first 62 days and from <0.1 to 2.9 days for the second 50 days. The potential growth loss on the top of Bank is negligible, ranging from <0.1 to 0.5 days (first 62 days only). Adding the two time periods, the range of potential scallop growth loss for the full drilling waste discharge scenario ranges from 2.3 to 13.6 days for the side of the Bank and from <0.1 to 5.1 days in the frontal zone when averaged over a radius of 5 km from the discharge location.

4.3.5.4. Radius of 10 km from Discharge Location

Potential growth loss is reduced further when averaged over a radius of 10 km from the discharge location (n = 13). On average, on the side of the Bank, it ranges for the two settling velocities from 0.9 to 6.6 days for the first 62 days and from 0.6 to 4.5 days for the second 50 days (Table 9). Again, the potential scallop growth loss is substantially less in the frontal zone, ranging from <0.1 to 1.6 days for the first 62 days and from <0.1 to 1.5 days for the second 50 days. The potential growth loss on the top of Bank is negligible, ranging from 0.0 to 0.4 days (first 62 days only). Adding the two time periods, the range of potential scallop growth loss for the full drilling waste discharge scenario ranges from 1.5 to 11.1 days for the side of the Bank and from <0.1 to 3.1 days in the frontal zone when averaged over a radius of 10 km from the discharge location.

Table 8. Number of potential scallop growth days lost within a radius of 5 km from the discharge location for all applications averaged by settling velocity and physical oceanographic zone (Fig. 4).

Section	Zone	Mean G_{lost} (Days)	
		0.1 cm s^{-1}	0.5 cm s^{-1}
1-4 (62 days)	Side (>100 m)	1.5	7.9
	Frontal (65-100 m)	<0.1	2.2
	Mixed (<65 m)	<0.1	0.5
5 (50 days)	Side (>100 m)	0.8	5.7
	Frontal (65-100 m)	<0.1	2.9

Table 9. Number of potential scallop growth days lost within a radius of 10 km from the discharge location for all applications averaged by settling velocity and physical oceanographic zone (Fig. 4).

Section	Zone	Mean G_{lost} (Days)	
		0.1 cm s^{-1}	0.5 cm s^{-1}
1-4 (62 days)	Side (>100 m)	0.9	6.6
	Frontal (65-100 m)	<0.1	1.6
	Mixed (<65 m)	<0.1	0.4
5 (50 days)	Side (>100 m)	0.6	4.5
	Frontal (65-100 m)	<0.1	1.5

4.3.5.5 Along the Primary Drift Line

The potential scallop growth loss is somewhat higher than in the r = 0.5-10 km cases when averaged along the 20-50-km primary drift line. On average, on the side of the Bank, it ranges for the two settling velocities from 1.0 to 10.9 days for the first 62 days and from 0.7 to 5.1 days for the second 50 days (Table 10). Again, the potential scallop growth loss is substantially less in the frontal zone, ranging from <0.1 to 2.1 days for the first 62 days and from <0.1 to 2.0 days for the second 50 days. The potential growth loss on the top of Bank is negligible, ranging from 0.0 to 0.4 days (first 62 days only). Adding the two time periods, the range of potential scallop growth loss for the full drilling waste discharge scenario ranges from 1.7 to 16.0 days for the side of the Bank and from <0.1 to 4.1 days in the frontal zone when concentrations are averaged along the primary drift line.

Table 10. Number of potential scallop growth days lost along the primary drift line (20-50 km long) for all applications averaged by settling velocity and physical oceanographic zone (Fig. 4).

Section	Zone	Mean G_{lost} (Days)	
		0.1 cm s^{-1}	0.5 cm s^{-1}
1-4 (62 days)	Side (>100 m)	1.0	10.9
	Frontal (65-100 m)	<0.1	2.1
	Mixed (<65 m)	<0.1	0.4
5 (50 days)	Side (>100 m)	0.7	5.1
	Frontal (65-100 m)	<0.1	2.0

5.0 DISCUSSION

5.1 Confidence in Modelling Results

There is a moderate to high degree of confidence in the reliability of *bblt*'s representation of the important physical processes that control waste dispersion and transportation in the benthic boundary layer in energetic continental shelf environments such as Georges Bank. Fundamental assumptions and structure have been widely reviewed (Hannah et al. 1995, 1996, 1998, Xu et al. 2000). Model output appears to be reasonable and consistent with empirical observations. However, it should be recognized that *bblt* has not been fully validated, but steps in this direction are planned using more complete field data sets from development sites on Sable Island Bank and the Grand Banks.

bblt does not include all of the physical processes that influence the resuspension and vertical mixing of fine sediments in the benthic boundary layer. This means that the concentrations predicted in these applications are probably slightly higher than would occur in the natural environment. On the other hand, there may be transient local near-bottom convergence zones (e.g. sand waves), not represented in the present flow fields, and lower resuspension than estimated here for deep areas where currents are relatively weak (e.g. side of the Bank) which could lead to an underestimation of waste concentrations in some cases.

The present applications use the local version of *bblt* in which the physical forcing conditions are uniform over the entire model domain, which can extend out from the discharge location as far as 50 km (Figs. 20-21). Physical conditions on Georges Bank can change markedly over distances of several kilometres. Therefore, confidence in model output drops with increasing distance from the discharge location. Initial evaluation using the spatially-varying version of *bblt* indicates that, in general, local *bblt* will tend to underestimate dispersion (Xu et al. 2000) and hence overestimate waste concentrations in the side of Bank region where the highest concentrations are predicted, but that the additional influences of spatial variability can result in reduced or increased concentrations depending on site. This effect is generally small compared to those from geographic location and settling velocity, but it could result in greater concentrations over scallop beds than predicted here in the side of Bank applications. Furthermore, small-scale variations in bottom topography can create local dispersive or depositional niches where the actual waste concentrations will differ from those calculated by *bblt*.

Observational data sets for forcing *bblt* on Georges Bank are limited. Therefore, many of the applications had to be forced using the 3-D circulation model. Where comparisons were made, there was excellent agreement between the results of the two forcings with the exception of winter at NEP where observed currents from 14 m above bottom were used.

The drilling waste discharge scenario, while hypothetical, is considered to be realistic. It was developed with the assistance of Texaco Canada Petroleum Ltd. and reviewed by the Georges Bank Steering Committee. The amounts of waste discharged are similar to those reported for the exploration wells drilled on the US sector of George Bank in the early 1980's (Neff 1987).

Laboratory experiments indicate that drilling wastes flocculate rapidly in seawater and therefore have high effective settling velocities. Observations at the CoPan production site on Sable Island Bank indicate that drilling waste flocs are bottom-trapped and can be seen as far as 8 km from the discharge site (Muschenheim and Milligan 1996). The waste concentrations predicted by *bblt* are very sensitive to the effective settling velocities of drilling wastes which are very difficult to define because of flocculation processes. Therefore a range of effective settling velocities (0.1-0.5 cm s^{-1}), thought to bracket those expected to occur in a tidally-energetic environment, was used in these simulations. This range was estimated using observed drilling waste concentration profiles around the CoPan site on Sable Island Bank. However, uncertainties in the vertical distribution of drilling mud in different oceanographic environments remain, and higher effective settling velocities (and hence greater near-bottom waste concentrations), while not considered likely to occur under the tidally-energetic conditions on Georges Bank, cannot be ruled out. Model applications for settling velocities above 0.5 cm s^{-1} indicate very strong sensitivity. If effective settling velocities greater than 0.5 cm s^{-1} were to occur on the Bank, near-bottom concentrations and scallop growth loss could be increased by several fold above the present model predictions.

On the other hand, the size of drilling waste flocs is very dependent on turbulence levels. *bblt* assumes that flocs do not break up (i.e. constant w_s) while tidally-induced shear on Georges Bank is likely to exceed levels that could break them up and thereby reduce both settling velocity (Milligan and Hill 1998) and near-bottom waste concentrations.

The biological effects are estimated using the results of extensive laboratory experiments with adult scallops. These were conducted under environmentally representative conditions in a series of flow-through raceway tanks (Cranford and Gordon 1992, Cranford et al. 1999). Because of the greater toxicity of barite, most of the effects seen in these simulations are due to the presence of barite in the drilling waste, especially at the lower concentrations. The zero growth threshold for barite (0.1 mg l^{-1}) had to be estimated but should be reasonable. However, there is some uncertainty whether flocculation, which was limited in the laboratory experiments, influences the toxicity of both bentonite and barite. Considering that the larger water-based mud cuttings had a much lower impact on scallops than bentonite and barite (Cranford et al. 1999), natural aggregation processes may reduce the effects of fine particulate wastes on scallop feeding behaviour. This is suggested by observations that sea scallops exposed to aggregated bentonite in the laboratory did not reduce feeding rate (White 1997), as was observed for scallops feeding on disaggregated bentonite (Cranford and Gordon 1992). However, field observations of sea scallops feeding on flocculated suspensions (Cranford et al. 1998a) showed that natural flocs are fragile and are easily disrupted by the animal's feeding processes. Once the flocs are disaggregated, scallops would be exposed to a similar size spectrum of particles as was presented in the laboratory experiments, and similar results are anticipated.

Overall, the greatest uncertainty in the modelling is the assigned value of the effective settling velocity of the discharge drilling waste. Hence a range, thought to bracket the values expected in a tidally-energetic continental shelf environment such as Georges Bank, was used in these simulations. Considering the net effect of other uncertainties, it is likely that the predicted waste concentrations are slightly higher than would occur in the natural environment. Therefore, the estimated effects on scallop growth are considered to be conservative (i.e. over-estimated), especially those obtained with the higher settling velocity.

5.2 Effects of Wastes on Scallop Growth

The interpretation of the results from these *bblt* applications on Georges Bank depends upon several factors which include the location of the discharge site and the distribution of scallop stocks. The location of the nine application sites in relation to the scallop populations on Georges Bank, averaged over 1993-1997, is shown in Fig. 22. The distribution of scallops is patchy and varies somewhat from year to year. In general, the greatest densities of scallops are found in the frontal zone. The application sites in or closest to the greatest scallop densities are GBFS2, GBFS6 and ENEP. The sites in regions of low scallop densities are GBFS1, NEP and Growler. The GBFS4, Hunky Dory and SNEP sites are in regions of moderate scallop populations. Maximum densities of juvenile scallops are recorded in the northern area of the frontal zone near GBFS2 and GBFS6 (Thouzeau et al. 1991b).

Discharge locations that are closest to high scallop densities will naturally tend to have a greater chance for impacts, the details of which are heavily dependent upon waste properties (e.g. settling velocity) and local physical oceanographic conditions.

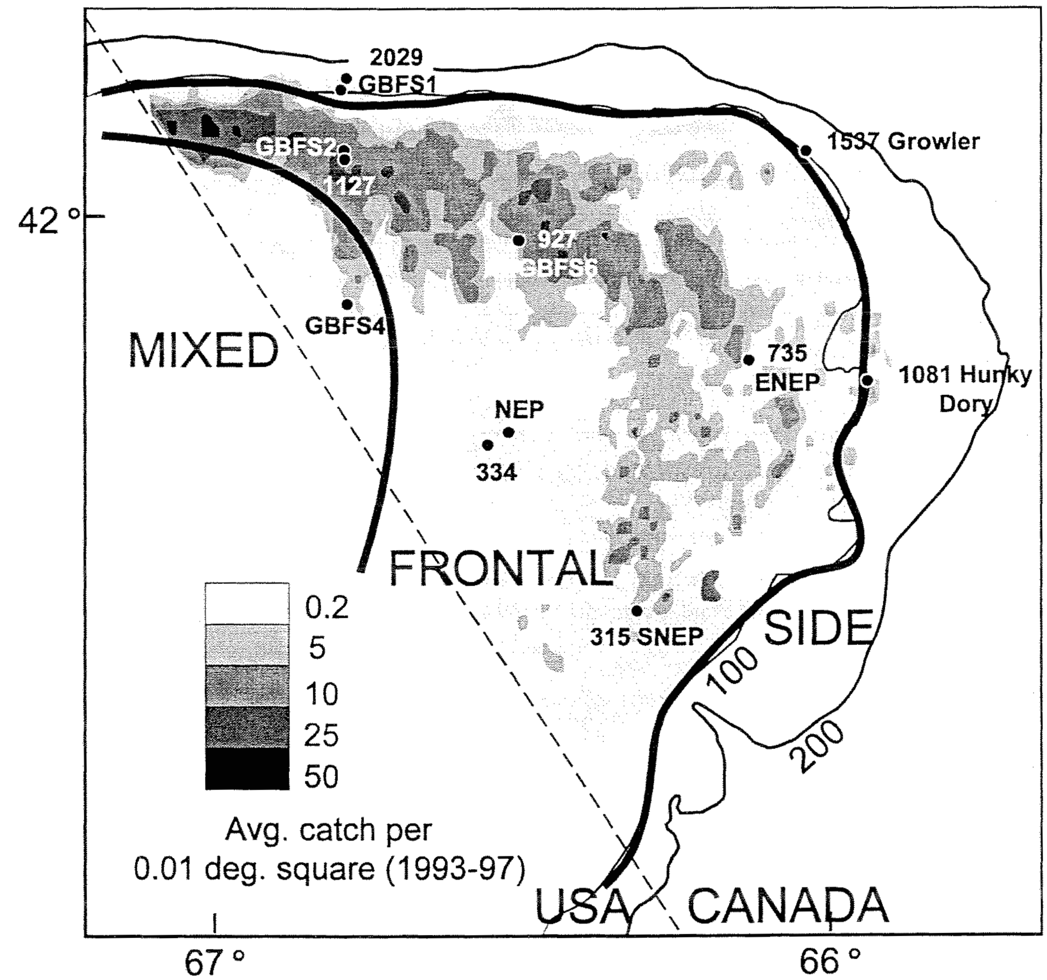

Figure 22. Location of the *bblt* application sites on Georges Bank in relation to the distribution scallop stocks. The heavy solid lines indicate the approximate location of the boundaries between different oceanographic zones (Mixed, Frontal and Side).

The potential impacts of the near-bottom drilling waste concentrations predicted by the *bblt* applications on scallop growth are summarized as follows according to physical oceanographic zone on Georges Bank.

5.2.1 Side of the Bank (>100 m)

The three application sites on the side of the Bank have the highest drilling waste concentrations (Loder et al. 2000) and therefore the greatest potential scallop growth losses (Tables 6-10). Average growth days lost range between 1.5 and 39.6 for the full waste discharge scenario depending on settling velocity and the area over which data are averaged. The GBFS1 site is in an area of low scallop abundance (Fig. 22) and the net drift of the near-bottom discharge patch is predicted by local *bblt* to be north-east (Tables 2-3), generally away from the scallop beds. This suggests that, even though the waste concentrations are predicted to be high when using the higher settling velocity, the discharge at this location is unlikely to have a measurable effect on scallops. However, the sensitivity simulations with spatially-variable *bblt* (Loder et al. 2000; Xu et al. 2000) indicating some on-bank drift, point to the possibility of greater concentrations over scallop beds than estimated here. Growler is also located in an area of low scallop abundance (Fig. 22). Net drift (Table 3) at this site is onto the Bank so some distant effects are possible but would probably be minor. Hunky Dory is located in an area of moderate scallop density (Fig. 22) and wastes discharged at this site have a much greater potential of coming into contact with scallop stocks and affecting growth.

5.2.2 Frontal Zone (65-100 m)

The near-bottom waste concentrations predicted by *bblt* for the complete waste discharge scenario would reduce potential scallop growth in the frontal zone on the order of <0.1 to 15.2 days depending on settling velocity and the area over which data are averaged (Tables 6-10). With the exception of NEP, all sites in this zone are in or near high scallop densities (Fig. 22) and therefore the potential of drilling wastes to come into contact with scallop stocks is high when the higher settling velocity is used. Growth loss would be greatest at the discharge location where waste concentrations are highest (Tables 4-5 and Figs. 32-33).

5.2.3. Mixed Zone on Top of the Bank (<65 m)

Due to high energy levels, predicted near-bottom waste concentrations at GBFS4 are very low and the potential growth loss is less than one day, even at the higher settling velocity (Tables 6-10). This zone does not have many scallops, presumably due to unfavourable habitat (i.e. active bedforms). Even if scallops were present, it is highly unlikely that the drilling waste discharge scenario used in these applications would have any measurable effects on scallop growth in this zone because of rapid dispersion.

5.3 Potential Implications of Growth Loss for Scallop Populations

Interpretation of the predicted growth impacts at the population level requires knowledge of the life history, growth trends, and reproductive dynamics of sea scallops on Georges Bank. The growth rate of scallops depends on seasonal cycles of food availability, water temperature and gametogenesis (development of gametes for spawning).

McGarvey et al. (1993) have demonstrated a correlation between egg production and recruitment for scallops on the Northeast Peak which implies that this stock is self-sustaining. Scallops on Georges Bank display a semi-annual reproductive cycle, with spawning occurring in May-June and September-October. The autumn spawn is larger then the spring spawn and, while only mature gametes are released during the spring, the scallops are reproductively spent after the fall spawn. Gametogenesis is immediately reinitiated after spawning in the fall. Somatic weight tends to decrease during gametogenesis as accumulated energy reserves are utilized to support gonad growth, but increases outside the reproductive period and when food is abundant. Sea scallops appear to invest surplus energy mainly into the production of gametes such that reproductive effort (fecundity) increases only when conditions are favourable. As a result of this conservative strategy of controlled growth and opportunistic reproduction, interannual variations in environmental conditions greatly alter the timing (semi-annual or annual) and nature (synchronised or protracted) of spawning events on Georges Bank (DiBacco et al. 1995).

Any reductions in somatic tissue growth caused by drilling muds could affect reproductive success as the accumulation of carbohydrate and lipid energy reserves in the muscle and digestive gland is believed essential for the initiation of gametogenesis and the later maturation of gonad (Robinson et al. 1981). Although much of the observed growth loss resulting from bentonite and barite exposure was due to retarded gonad development, both wastes were shown to be capable of reducing somatic tissue growth (Cranford and Gordon 1992, Cranford et al. 1999). However, it is likely that drilling wastes would have more effect on scallop populations, and therefore the fishery, through changes in gonadal growth rather than somatic tissue growth (i.e. adductor muscle). Reduction in gonad growth could reduce fecundity, an impact that would not become readily apparent in the fishery until recruitment was impaired in future years.

Nutritional stress during gametogenesis, resulting from the presence of drilling wastes in the diet, can cause reduced gonad growth rates (Cranford and Gordon 1992) that results in the production of fewer gametes and/or smaller ova having a reduced energy content. More severe nutrient or chemical stress resulting from barite exposure can result in the resorption of gametes (Cranford et al. 1999). Considering that gametogenesis is almost continuous on Georges Bank, exposure to drilling wastes could have some impact on fecundity and egg viability regardless of the time of drilling. However, the spring and summer are of greatest concern as the majority of annual gonad production occurs between March and August. The loss of 10 consecutive days of growth during this period could reduce fecundity by 5 to 10%. Because of the large variability in natural mortalities of early life stages, it is unlikely that a 10% reduction in fecundity would be detectable in future stocks unless it occurred over a very large area in a region of abundant scallop stocks. Considering the naturally erratic nature of spring spawning, any impacts on reproductive growth between March and June could limit spawning to the fall. Presently, little is known of the relative importance of spring and fall spawns to future year class strength.

The viability of eggs in adults exposed to drilling wastes may be of greater concern than impacts on fecundity as the potential consequences to larval survival could have a large impact on future year class strength. It is unlikely, however, that the scallops would release non-viable eggs, but rather would resorb and utilize the high nutritive content of some gametes to allow others to reach the critical size for spawning (DiBacco et al.1995). Scallop populations from regions characterized by nutritive stress were observed to produce viable gametes even though reproductive effort was low (MacDonald and Thompson 1986).

Large spatial differences in the reproductive condition and growth of scallop stocks have been observed on Georges Bank (DiBacco et al. 1995, Thouzeau et al. 1991b). Scallops are distributed primarily in water depths less than 85 m owing to reduced food availability in deeper waters. The lower condition of scallops in deeper waters along the edge of the bank may increase their susceptibility to the lethal and sublethal effects of drilling wastes owing to enhanced nutritive stress. Any additional stress on populations experiencing marginal food supplies can reduce energy reserves to a point where successful spawning is prevented.

The biological effects predicted in these applications apply only to adult scallops (3-5 years old). The sensitivity of early life-stages of scallops to water-based mud has recently been studied as part of a project funded by the Georges Bank Review Panel. That study found scallop veliger larvae to be less sensitive to water-based drilling mud than adults (Cranford et al. 1998b). Exposure duration also differs greatly for larvae and adult scallops. Although veligers entrained in a discharge patch can be exposed to high contaminant concentrations, exposure time is generally shorter than the time required for ambient waste concentrations to cause acute and chronic effects owing to rapid dilution with surrounding seawater. The sedentary nature of adult scallops greatly increases the potential for chronic effects from particulate wastes that tend to accumulate in the benthic boundary layer through sedimentation/resuspension processes. The extent to which scallops may be able to emigrate from an impacted area is not known. Although contaminated sediments might interfere with the settlement of larvae on the seabed, the consequences of this to scallop stock recruitment is presently unknown.

5.4 Other Potential Applications of *bblt*

These applications have demonstrated the usefulness of local *bblt* to address the question of the potential impacts of water-based muds discharged from a single exploration well on the growth of adult scallops on Georges Bank. *bblt* can also be applied to many other potential applications.

5.4.1. Spatially-varying Version

It would be useful to repeat these applications using the spatially-varying version of *bblt* that will have a more realistic representation of the physical environment over the entire model domain (Xu et al. 2000). The testing so far suggests that the predicted waste concentrations would be generally less with this version, but there may be greater drift from the side region onto the bank plateau than predicted by local *bblt*.

5.4.2. Other Regions and Drilling Wastes

bblt can also be applied to other energetic continental shelf regions. Numerous applications have already been made at the CoPan site on Sable Island Bank (Hannah et al. 1995). Additional applications are also planned for Hibernia on the Grand Banks. It can also be applied to look at the effects of other drilling wastes if information on effective settling velocity and toxicity is available. For example, *bblt* simulations of drilling waste dispersion and transport on the Scotian Shelf have already been used to explore the potential effects of oil-based muds discharged during the drilling of development wells on Sable Island Bank scallop populations as part of the Sable Offshore Energy Project environmental impact assessment (MacLaren Plansearch 1997).

5.4.3 Mitigation Measures

The drilling waste discharge scenario used in these applications illustrates the potential effects on adult scallop growth under just one set of possible operating conditions for drilling an exploration well. Changing the amounts or properties of the drilling mud and the conditions of discharge can influence the predicted impacts on scallop growth substantially. For example, any of the following changes in operating conditions should decrease the predicted effects of water-based mud on scallop growth and *bblt* could be used to explore their relative influence in reducing impacts.

- Reduce the amount of water-based mud allowed to be discharged (or ban discharge altogether).
- Reduce the amount of water-based mud discharged directly at the seafloor (Sections 1 and 2).
- Reduce the amount of barite in the water-based mud (which in turn will reduce both the toxicity and the effective settling velocity);
- Reduce the mud density (which will reduce settling velocity).
- Substantially dilute water-based mud prior to discharge to reduce flocculation (which will reduce settling velocity) and minimize convective descent.
- Limit discharge to times of the year when scallop growth is low (November to February).
- Select a discharge depth that maximizes exposure to current flow, entrainment and mixing.
- Discharge during periods of strong currents such as spring tides.

5.4.4 Effects on Other Species

The near-bottom waste concentrations predicted by *bblt* can be used to explore the potential effects on other benthic species if exposure-response data were available. Prime candidates would be filter-feeding molluscs (primarily surf clams and ocean quahogs) that dominate the benthic megafauna on Georges Bank (Thouzeau et al. 1991a), herring (eggs), lobster and groundfish. Data on the effects of water-based mud on lobster *(Homarus americanus)* larvae indicate sensitivity to drilling fluids (Neff 1987). The acute lethal concentration is between 100-200 mg l^{-1} (Cranford et al. 1998b, Derby and Capuzzo 1984) and sublethal effects on growth, development, respiration and feeding rates have been observed at concentrations as low as 10 mg l^{-1} (Derby and Capuzzo 1984). Haddock (*Melanogrammus aeglefinus*) late-stage embryos and yolk-sac larvae showed a similar sensitivity to water-based mud as lobster larvae in acute toxicity tests (Cranford et al. 1998b), but no data are available on potential sublethal effects. Fish eggs and early embryonic stages are generally less sensitive than later developmental stages as the egg chorion layer appears to act as an effective barrier against entry of toxicants (reviewed in Cranford et al. 1998b).

5.4.5 Effects of Development Drilling

If hydrocarbon resources are ever found on Georges Bank and a decision is made to exploit them, the effects of wastes discharged from development wells on scallop resources could be explored with *bblt*. These effects are potentially greater since multiple (and larger diameter) wells are generally drilled at the same location and more waste is discharged over a longer time period. The effects will depend on the kind of drilling mud used. It is likely that water-based mud would be used under some conditions. In the past, oil-based mud has been widely used for development drilling but it is the most toxic of the drilling wastes tested so far (Fig. 4). The Canada Nova Scotia Offshore Petroleum Board, the principal regulator, has decided that as of January 2000, oil-based mud cuttings can not be discharged unless the oil content is less than 1% by weight. This effectively precludes the use of oil-based mud unless the cuttings can be reinjected or brought ashore for disposal. It is likely that some kind of alternative-based mud would be used for development drilling, as is currently being used on Sable Island Bank and the Grand Banks. The effects of these on scallops are not known, but are currently being investigated using the same methods as Cranford et al. (1999). They also contain bentonite and barite and may contain synthetic oil. Tainting would be an issue with developmental drilling if organic mud components were employed.

5.4.6 Cumulative Effects

bblt could also be used to explore the potential cumulative impacts of multiple hydrocarbon wells, both exploration and development.

6.0 SUMMARY

- Recent studies of drilling waste properties, dispersion and effects on sea scallops (*Placopecten magellanicus*) in laboratory experiments, combined with our understanding of the physical environment and the distribution of scallops on Georges Bank, provide a substantial knowledge base for estimating the potential impacts of drilling wastes released from potential hydrocarbon exploration wells.

- The chronic lethal and sublethal responses of scallops to bentonite and barite, the major water-based mud constituents, were used with the outputs of an industry-standard plume descent model and a new benthic boundary layer transport model, called *bblt*, to predict the spatial and temporal effects of these wastes on scallop growth around hypothetical exploratory well sites on the Canadian sector of Georges Bank.

- *bblt* is a numerical model that has been developed by DFO to simulate the dispersion and transport of suspended sediment (i.e. drilling waste) in the benthic boundary layer (the bottom of the water column affected by the seafloor).

- The discharge scenario used assumed a single exploration well drilled over a three-month period with water-based mud comprised of an equal (and unvarying) mixture of bentonite and barite. It was assumed that mud was discharged at the seafloor for the first two well sections and from the platform (at a depth of 10 m) for deeper sections. In the latter case, the fraction of the discharge reaching the benthic boundary layer was estimated using the plume descent model.

- *bblt* model was forced by either current meter data (when available) or a 3-D circulation model, and produced estimates of waste concentrations as a function of space and time around the discharge location. For the purpose of these applications, predicted concentrations in the bottom 10 cm of the water column were used. This is the layer where scallops obtain most of their food particles. Biological impacts were estimated by calculating the effects of predicted waste concentrations on scallop growth, using effects thresholds estimated from laboratory experiments, and expressing the results as days of growth lost.

- Twenty-two applications were run at different locations and times of the year. One application site was located in the well-mixed zone on top of the Bank (water depth < 65 m), five were located in the frontal zone (65-100 m), and three were located in the permanently stratified zone of the side of the Bank (> 100 m).

- Near-bottom waste concentrations predicted by *bblt* are very sensitive to the effective settling velocities of drilling wastes. These are difficult to determine with certainty because of flocculation processes, the changing dynamics of the benthic boundary layer, and sampling difficulties. Available information indicates that bentonite and barite will flocculate when released together in seawater and that their effective settling velocities should range between 0.1 and 0.5 cm s^{-1}. Simulations were run at both of these settling velocities for all applications in order to bracket the expected range. At the lower velocity, waste particles are distributed more widely over the water column and disperse more rapidly, while at the higher velocity they become more concentrated in the benthic boundary layer where dispersion is reduced. Lost growth was generally an order of magnitude less at the lower settling velocity.

- Effects on sea scallop growth of a single exploration well utilizing water-based mud depend very much upon its location in relation to the different physical oceanographic zones on Georges Bank. As expected, potential growth lost is greatest at the discharge location and decreases with increasing distance and time. Predicted effects decrease more slowly with distance along the primary drift line, which is determined by the residual circulation.

- The greatest potential effects of near-bottom drilling waste concentrations on scallop growth are at the application sites on the side of Bank (>100 m). The predicted effect would be a loss on the order of 2 to 40 growth days depending upon settling velocity and the area over which data are averaged[2]. Generally speaking, this zone has low to moderate scallop densities but aggregations are found at various sites and high numbers occur nearby that could be influenced by a waste patch, especially if the net drift is onto the Bank. Therefore, it is possible to lose several days to several weeks of growth in this zone depending upon the settling velocity and the location of the discharge site relative to scallop stocks. This could have potential effects at the population level.

- Potential effects at the application sites in the frontal zone are lower. The predicted effect would be a loss on the order of <0.1 to 15 growth days depending upon settling velocity and the area over which data are averaged. This zone contains the majority of the scallop stocks on the Bank, but it is unlikely that the predicted growth losses could be detected at the population level, except perhaps at or close to the discharge location at the higher settling velocity.

- Potential effects in the shallow, well-mixed zone on top of the Bank appear to be negligible. Even at the higher settling velocity, due to the highly dynamic physical environment, wastes dispersed rapidly and growth lost was generally less than 1 day. Also, this zone does not have commercial scallop stocks.

- Available evidence suggests that any growth loss would affect gonad development (i.e. reproductive potential) more than somatic tissue (i.e. muscle) or egg viability. Under the worst case scenario of discharge on the side of the Bank using the high settling velocity, the loss of two week's reproductive growth could potentially reduce the annual reproductive output of scallops by 5-10% within an area on the order of 100 km^2. It is difficult to predict how this would alter recruitment to the scallop fishery because of natural variability but, if the discharge occurred in a region of medium to high scallop stocks during the growing season, effects at the population might be detectable.

- Most of the assumptions in *bblt* are conservative so that dispersion is underestimated and waste concentrations are therefore most likely overestimated. Although *bblt* has not been completely validated, output is in general agreement with field observations at offshore drill sites, and there is a moderate-to-high level of confidence in the predicted waste mud concentrations. Confidence is highest for the applications in the well-mixed and frontal zones on the top of the Bank. However, confidence drops with increasing distance from the discharge location since the version of *bblt* used assumes a uniform physical environment over the entire model domain, which is not true on parts of Georges Bank, especially on the side.

- The potential biological effects of discharged drilling wastes observed in these applications could be potentially mitigated in several ways including by modifying (or eliminating) the discharge of water-based mud, reducing the amount of mud discharged at the seafloor, reducing the amount of barite used in the drilling mud, reducing flocculation

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[2] As noted in Section 3.5, the exact number of growth days lost may be underestimated in the present study by a few days, but this is not expected to change the overall conclusions.

potential before discharge, and drilling during the November-February period when scallop growth is low.

- The predictions of the effects of drilling wastes on scallop growth presented in this report are specific to the discharge scenario used. This was selected to represent reasonable conditions for a single exploration well on Georges Bank. Should exploration drilling ever take place on Georges Bank, drilling wastes discharge conditions could be quite different depending upon changes in drilling technology and regulations. The models developed can be used to look at the potential effects of a wide range of other wastes, settling velocities and discharge conditions. The effects on other benthic organisms could be estimated using the same models if the necessary exposure-response data were available. The models could also be used to examine the potential impacts of production wells, both single and multiple. Therefore, they have considerable potential in conducting environmental impact assessments, investigating mitigative measures and designing environmental effects monitoring programs.

- *bblt* is a valuable quantitative tool for investigating the drift and dispersion of particulate drilling wastes in the benthic boundary layer of continental shelf environments. However, further observational validation is required to reduce uncertainties, particularly for areas that are less tidally-energetic than Georges Bank.

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APPENDIX A: Drilling Waste Discharge Scenario

DAY	Activity	Discharge Depth	Discharge Volume (m^3)			Density (g cm^{-3})			Dry Weight (MT)	
			Total	Cuttings	Mud	Total	Cuttings	Mud	Cuttings	Mud
Section 1										
1	Drilling	Seafloor	270	118	14	1.0750	2.6	2.6	306	46
2	Drilling	Seafloor	270	117	13	1.2000	2.6	2.6	305	44
3	Casing	Seafloor	2.4	-	0.2	1.2000	-	2.6	-	0.4
4	Cementing	Seafloor	15	-	0.8	1.2000	-	2.6	-	2.2
5	Cementing	Seafloor	15	-	0.8	1.2000	-	2.6	-	2.2
Section 1 Total			**572.4**	**235**	**28.8**				**611**	**94.8**
Section 2										
6	Drilling	Seafloor	187	105	8	1.0750	2.6	2.6	272	24
7	Drilling	Seafloor	186	104	8	1.0750	2.6	2.6	271	23
8	Drilling	Seafloor	186	104	7	1.0750	2.6	2.6	271	23
9	Casing	Seafloor	3.4	-	0.2	1.2000	-	2.6	-	0.5
10	Casing	Seafloor	3.4	-	0.2	1.2000	-	2.6	-	0.5
11	Cementing	Seafloor	43	-	2.5	1.2000	-	2.6	-	6.4
12	Cementing	Seafloor	43	-	2.5	1.2000	-	2.6	-	6.4
Section 2 Total			**651.8**	**313**	**28.4**				**814**	**83.8**
Section 3										
13	Drilling	10 m	135	26	3	1.0750	2.6	3.4	68	9
14	Drilling	10 m	135	26	3	1.0750	2.6	3.4	68	9
15	Drilling	10 m	135	26	3	1.0750	2.6	3.4	68	9
16	Drilling	10 m	135	26	2	1.0750	2.6	3.4	67	9
17	Drilling	10 m	135	26	2	1.0750	2.6	3.4	67	8
18	Drilling	10 m	85	17	2	1.0750	2.6	3.4	43	6
19	Drilling	10 m	85	17	2	1.0750	2.6	3.4	43	6
20	Drilling	10 m	85	16	2	1.0750	2.6	3.4	42	6
21	Drilling	10 m	84	16	2	1.0750	2.6	3.4	42	6
22	Drilling	10 m	84	16	2	1.0750	2.6	3.4	42	5
23	Drilling	10 m	84	16	1	1.0750	2.6	3.4	42	5
24	Drilling	10 m	84	16	1	1.0750	2.6	3.4	42	5
25	Drilling	10 m	84	16	1	1.2000	2.6	3.4	42	5
26	Casing	None	-	-	-	-	-	-	-	-
27	Casing	None	-	-	-	-	-	-	-	-
28	Casing	None	-	-	-	-	-	-	-	-
29	Casing	None	-	-	-	-	-	-	-	-
30	Cementing	None	-	-	-	-	-	-	-	-
31	Cementing	None	-	-	-	-	-	-	-	-
32	Cementing	None	-	-	-	-	-	-	-	-
Section 3 Total			**1350**	**260**	**26**				**676**	**88**

Drilling Waste Discharge Scenario (Cont.)

Day	Activity	Discharge Depth	Discharge Volume (m^3)			Density (g cm^{-3})			Dry Weight (MT)	
			Total	Cuttings	Mud	Total	Cuttings	Mud	Cuttings	Mud
Section 4										
33	Drilling	10 m	44	8	0.8	1.0750	2.6	3.8	21	3
34	Drilling	10 m	38	7	0.6	1.0750	2.6	3.8	18	3
35	Drilling	10 m	38	7	0.6	1.0750	2.6	3.8	18	3
36	Drilling	10 m	38	7	0.6	1.0750	2.6	3.8	18	3
37	Drilling	10 m	38	7	0.6	1.0750	2.6	3.8	18	2
38	Drilling	10 m	38	7	0.6	1.0750	2.6	3.8	18	2
39	Drilling	10 m	38	7	0.6	1.0750	2.6	3.8	18	2
40	Drilling	10 m	38	6	0.6	1.0750	2.6	3.8	18	2
41	Drilling	10 m	38	6	0.6	1.0750	2.6	3.8	18	2
42	Drilling	10 m	38	6	0.6	1.0750	2.6	3.8	16	2
43	Drilling	10 m	38	6	0.6	1.0750	2.6	3.8	16	2
44	Drilling	10 m	38	6	0.6	1.0750	2.6	3.8	16	2
45	Drilling	10 m	38	6	0.6	1.0750	2.6	3.8	16	2
46	Drilling	10 m	38	6	0.6	1.0750	2.6	3.8	16	2
47	Drilling	10 m	38	6	0.5	1.0750	2.6	3.8	16	2
48	Drilling	10 m	38	6	0.5	1.0750	2.6	3.8	16	2
49	Drilling	10 m	38	6	0.5	1.0750	2.6	3.8	15	2
50	Drilling	10 m	38	6	0.5	1.0750	2.6	3.8	15	2
51	Drilling	10 m	38	6	0.5	1.0750	2.6	3.8	15	2
52	Drilling	10 m	38	6	0.5	1.0750	2.6	3.8	15	2
53	Drilling	10 m	38	6	0.5	1.0750	2.6	3.8	15	2
54	Drilling	10 m	38	6	0.5	1.0750	2.6	3.8	15	2
55	Drilling	10 m	38	6	0.5	1.0750	2.6	3.8	15	2
56	Drilling	10 m	38	6	0.5	1.2000	2.6	3.8	15	2
57	Casing	None	-	-	-	-	-	-	-	-
58	Casing	None	-	-	-	-	-	-	-	-
59	Casing	None	-	-	-	-	-	-	-	-
60	Cementing	None	-	-	-	-	-	-	-	-
61	Cementing	None	-	-	-	-	-	-	-	-
62	Cementing	None	-	-	-	-	-	-	-	-
63	Dump	10 m	150	0	6	1.2000	2.6	3.8	0	22.8
Section 4 Total			**1068**	**152**	**19.6**				**397**	**74.8**
Section 5										
64	Drilling	10 m	28	2	3	1.2300	2.6	4	5	12
65	Drilling	10 m	27	2	2	1.2300	2.6	4	5	8
66	Drilling	10 m	26	2	2	1.2300	2.6	4	5	8
67	Drilling	10 m	26	2	2	1.2300	2.6	4	5	8
68	Drilling	10 m	26	2	2	1.2300	2.6	4	5	8
69	Drilling	10 m	26	2	2	1.2300	2.6	4	5	8

Drilling Waste Discharge Scenario (Cont.)

Day	Activity	Discharge Depth	Discharge Volume (m^3)			Density ($g\ cm^{-3}$)			Dry Weight (MT)	
			Total	Cuttings	Mud	Total	Cuttings	Mud	Cuttings	Mud
70	Drilling	10 m	26	2	2	1.2300	2.6	4	5	8
71	Drilling	10 m	25	2	2	1.2300	2.6	4	5	8
72	Drilling	10 m	25	2	2	1.2300	2.6	4	5	8
73	Drilling	10 m	25	2	2	1.2300	2.6	4	5	8
74	Drilling	10 m	25	1	1	1.2300	2.6	4	3	4
75	Drilling	10 m	25	1	1	1.2300	2.6	4	3	4
76	Drilling	10 m	10	1	1	1.2300	2.6	4	3	4
77	Drilling	10 m	10	0.4	0.4	1.2300	2.6	4	3	4
78	Drilling	10 m	10	0.4	0.4	1.2300	2.6	4	3	4
79	Drilling	10 m	10	0.4	0.4	1.2300	2.6	4	3	4
80	Drilling	10 m	10	0.4	0.4	1.2300	2.6	4	3	4
81	Casing	None	-	-	-	-	-	-	-	-
82	Casing	None	-	-	-	-	-	-	-	-
83	Casing	None	-	-	-	-	-	-	-	-
84	Casing	None	-	-	-	-	-	-	-	-
85	Casing	None	-	-	-	-	-	-	-	-
86	Cementing	None	-	-	-	-	-	-	-	-
87	Cementing	None	-	-	-	-	-	-	-	-
88	Cementing	None	-	-	-	-	-	-	-	-
89	Cementing	None	-	-	-	-	-	-	-	-
90	Cementing	None	-	-	-	-	-	-	-	-
91	Cementing	None	-	-	-	-	-	-	-	-
92	Cementing	None	-	-	-	-	-	-	-	-
93	Dump	10 m	90	0	3.6	1.23	2.6	4	0	14.4
Section 5 Total			**450**	**24.6**	**29.2**				**71**	**126.4**
Well Total			**4092.2**	**984.6**	**132**				**2569**	**467.8**

APPENDIX B

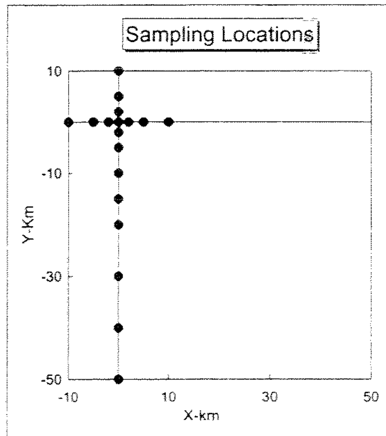
Summary Tables and Figures of Potential Growth Effects for all Applications

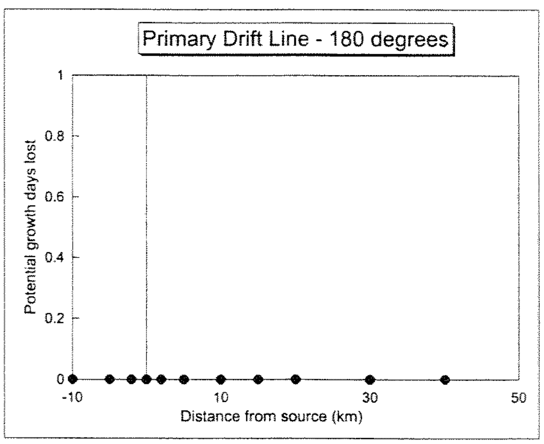
Organized by physical oceanographic zone on Georges Bank (Mixed, Frontal or Side)

Table A2.1. Summary data and plots of potential scallop growth days lost during well Sections 1 to 4 at GBFS4 using observed currents for Days 189 to 251 and a settling velocity of 0.1 cm/s.

Zone: MIXED

Site	x km	y km	distance (km)	Growth Loss (%)	Growth Days Lost
1	0.00	0.00	0.00	0.0	0.0
2	0.00	-2.00	2.00	0.0	0.0
3	2.00	0.00	2.00	0.0	0.0
4	0.00	2.00	2.00	0.0	0.0
5	-2.00	0.00	2.00	0.0	0.0
6	0.00	-5.00	5.00	0.0	0.0
7	5.00	0.00	5.00	0.0	0.0
8	0.00	5.00	5.00	0.0	0.0
9	-5.00	0.00	5.00	0.0	0.0
10	0.00	-10.00	10.00	0.0	0.0
11	10.00	-0.00	10.00	0.0	0.0
12	0.00	10.00	10.00	0.0	0.0
13	-10.00	0.00	10.00	0.0	0.0
14	-0.00	-15.00	15.00	0.0	0.0
15	-0.00	-20.00	20.00	0.0	0.0
16	-0.00	-30.00	30.00	0.0	0.0
17	-0.00	-40.00	40.00	0.0	0.0
18	-0.00	-50.00	50.00	0.0	0.0
mean for drift axis stations				0.0	0.0
mean for		10 km radius		0.0	0.0
		5 km radius		0.0	0.0
		2 km radius		0.0	0.0





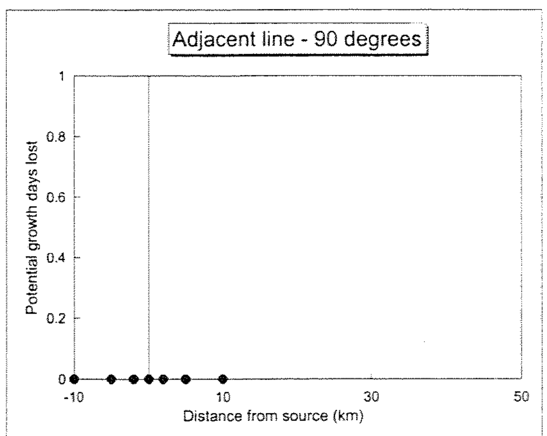
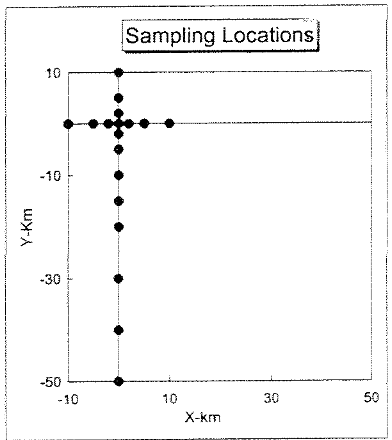
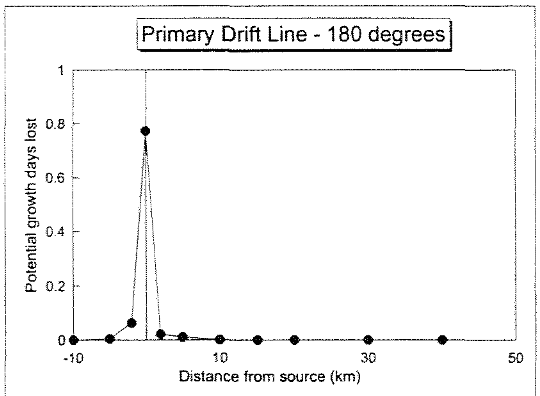


Table A2.2. Summary data and plots of potential scallop growth days lost during well Sections 1 to 4 at GBFS4 using observed currents for Days 189 to 251 and a settling velocity of 0.5 cm/s.

Zone: MIXED

Site	x km	y km	distance (km)	Growth Loss (%)	Growth Days Lost
1	0.00	0.00	0.00	1.2	0.8
2	0.00	-2.00	2.00	0.0	0.0
3	2.00	0.00	2.00	0.0	0.0
4	0.00	2.00	2.00	0.1	0.1
5	-2.00	0.00	2.00	0.0	0.0
6	0.00	-5.00	5.00	0.0	0.0
7	5.00	0.00	5.00	0.0	0.0
8	0.00	5.00	5.00	0.0	0.0
9	-5.00	0.00	5.00	0.1	0.0
10	0.00	-10.00	10.00	0.0	0.0
11	10.00	-0.00	10.00	0.0	0.0
12	0.00	10.00	10.00	0.0	0.0
13	-10.00	0.00	10.00	0.0	0.0
14	-0.00	-15.00	15.00	0.0	0.0
15	-0.00	-20.00	20.00	0.0	0.0
16	-0.00	-30.00	30.00	0.0	0.0
17	-0.00	-40.00	40.00	0.0	0.0
18	-0.00	-50.00	50.00	0.0	0.0
mean for drift axis stations				0.1	0.1
mean for		10 km radius		0.1	0.1
		5 km radius		0.2	0.1
		2 km radius		0.3	0.2





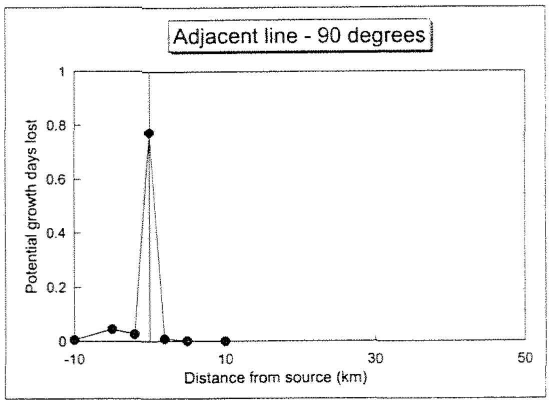
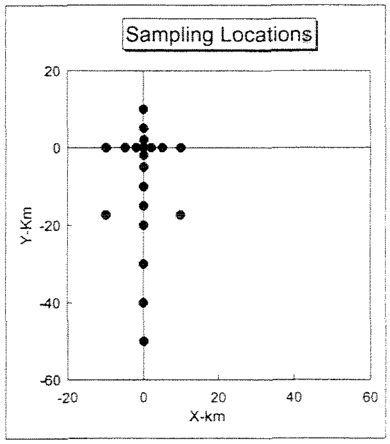
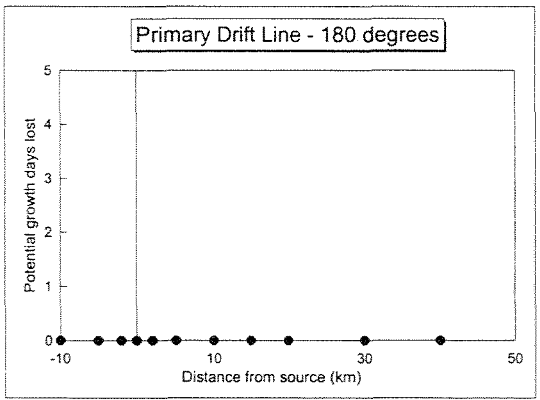


Table A2.3. Summary data and plots of potential scallop growth days lost during well Sections 1 to 4 at GBFS4 using observed currents for Days 217 to 279 and a settling velocity of 0.1 cm/s.

Zone: MIXED

Site	x km	y km	distance (km)	Growth Loss (%)	Growth Days Lost
1	0.00	0.00	0.00	0.0	0.0
2	0.00	-2.00	2.00	0.0	0.0
3	2.00	0.00	2.00	0.0	0.0
4	0.00	2.00	2.00	0.0	0.0
5	-2.00	0.00	2.00	0.0	0.0
6	0.00	-5.00	5.00	0.0	0.0
7	5.00	0.00	5.00	0.0	0.0
8	0.00	5.00	5.00	0.0	0.0
9	-5.00	0.00	5.00	0.0	0.0
10	0.00	-10.00	10.00	0.0	0.0
11	10.00	-0.00	10.00	0.0	0.0
12	0.00	10.00	10.00	0.0	0.0
13	-10.00	0.00	10.00	0.0	0.0
14	-0.00	-15.00	15.00	0.0	0.0
15	-0.00	-20.00	20.00	0.0	0.0
16	-0.00	-30.00	30.00	0.0	0.0
17	-0.00	-40.00	40.00	0.0	0.0
18	-0.00	-50.00	50.00	0.0	0.0
19	-10.00	-17.32	20.00	0.0	0.0
20	10.00	-17.32	20.00	0.0	0.0
mean for drift axis stations				0.0	0.0
mean for	10 km radius			0.0	0.0
	5 km radius			0.0	0.0
	2 km radius			0.0	0.0





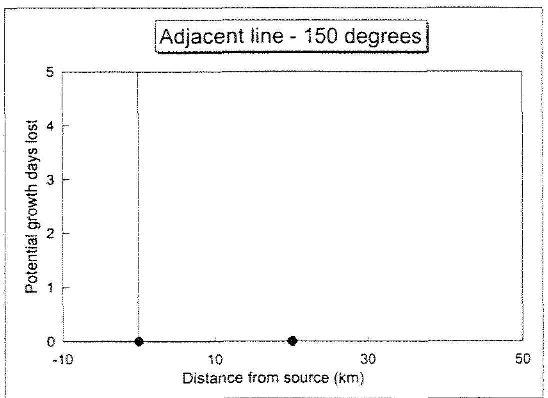
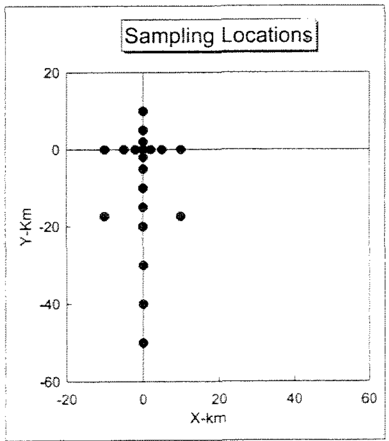
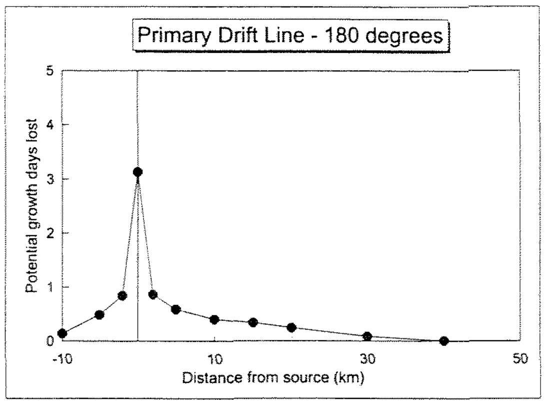


Table A2.4. Summary data and plots of potential scallop growth days lost during well Sections 1 to 4 at GBFS4 using observed currents for Days 217 to 279 and a settling velocity of 0.5 cm/s.

Zone: MIXED

Site	x km	y km	distance (km)	Growth Loss (%)	Growth Days Lost
1	0.00	0.00	0.00	5.0	3.1
2	0.00	-2.00	2.00	1.4	0.9
3	2.00	0.00	2.00	1.2	0.8
4	0.00	2.00	2.00	1.4	0.8
5	-2.00	0.00	2.00	0.9	0.5
6	0.00	-5.00	5.00	1.0	0.6
7	5.00	0.00	5.00	1.0	0.6
8	0.00	5.00	5.00	0.8	0.5
9	-5.00	0.00	5.00	0.6	0.4
10	0.00	-10.00	10.00	0.6	0.4
11	10.00	-0.00	10.00	0.6	0.4
12	0.00	10.00	10.00	0.2	0.1
13	-10.00	0.00	10.00	0.3	0.2
14	-0.00	-15.00	15.00	0.5	0.3
15	-0.00	-20.00	20.00	0.4	0.2
16	-0.00	-30.00	30.00	0.1	0.1
17	-0.00	-40.00	40.00	0.0	0.0
18	-0.00	-50.00	50.00	0.0	0.0
19	-10.00	-17.32	20.00	0.2	0.1
20	10.00	-17.32	20.00	0.5	0.3
mean for drift axis stations				1.0	0.6
mean for		10 km radius		1.2	0.7
		5 km radius		1.5	0.9
		2 km radius		2.0	1.2





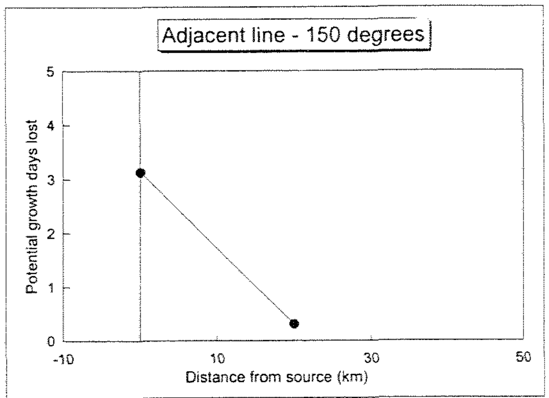
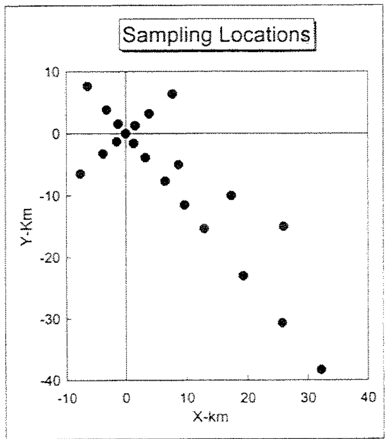
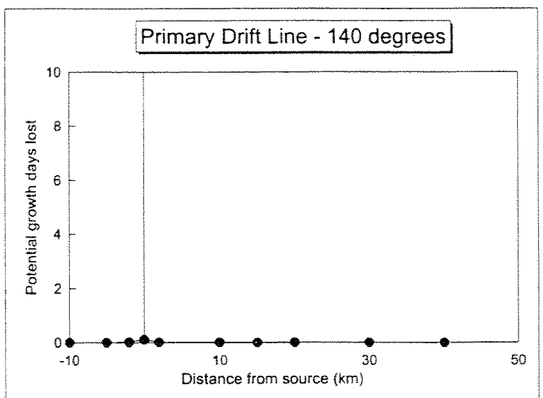


Table A2.5. Summary data and plots of potential scallop growth days lost during well Sections 1 to 4 at GBFS2 using observed currents for Days 189 to 251 and a settling velocity of 0.1 cm/s.

Zone: FRONTAL

Site	x km	y km	distance (km)	Growth Loss (%)	Growth Days Lost
1	0.00	0.00	0.00	0.2	0.1
2	1.29	-1.53	2.00	0.0	0.0
3	1.53	1.29	2.00	0.0	0.0
4	-1.29	1.53	2.00	0.0	0.0
5	-1.53	-1.29	2.00	0.0	0.0
6	3.21	-3.83	5.00	0.0	0.0
7	3.83	3.21	5.00	0.0	0.0
8	-3.21	3.83	5.00	0.0	0.0
9	-3.83	-3.21	5.00	0.0	0.0
10	6.43	-7.66	10.00	0.0	0.0
11	7.66	6.43	10.00	0.0	0.0
12	-6.43	7.66	10.00	0.0	0.0
13	-7.66	-6.43	10.00	0.0	0.0
14	9.64	-11.49	15.00	0.0	0.0
15	12.86	-15.32	20.00	0.0	0.0
16	19.28	-22.98	30.00	0.0	0.0
17	25.71	-30.64	40.00	0.0	0.0
18	32.14	-38.30	50.00	0.0	0.0
19	8.66	-5.00	10.00	0.0	0.0
20	17.32	-10.00	20.00	0.1	0.0
21	25.98	-15.00	30.00	0.0	0.0
mean for drift axis stations				0.0	0.0
mean for		10 km radius		0.0	0.0
		5 km radius		0.0	0.0
		2 km radius		0.1	0.0





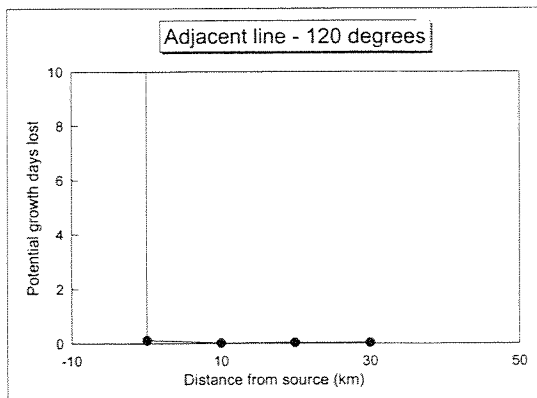
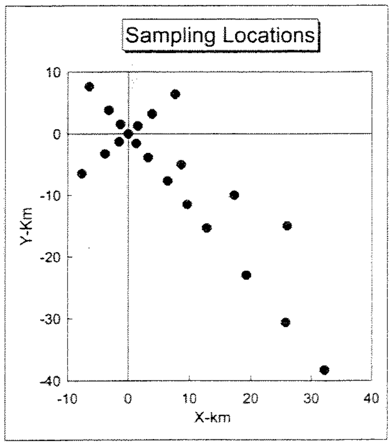
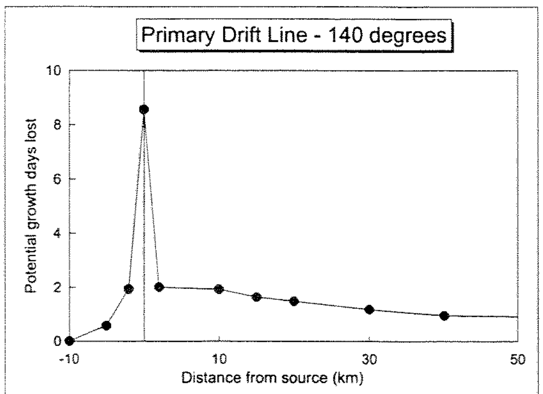


Table A2.6. Summary data and plots of potential scallop growth days lost during well Sections 1 to 4 at GBFS2 using observed currents for Days 189 to 251 and a settling velocity of 0.5 cm/s.

Zone: FRONTAL

Site	x km	y km	distance (km)	Growth Loss (%)	Growth Days Lost
1	0.00	0.00	0.00	13.8	8.6
2	1.29	-1.53	2.00	3.2	2.0
3	1.53	1.29	2.00	1.3	0.8
4	-1.29	1.53	2.00	3.1	1.9
5	-1.53	-1.29	2.00	1.2	0.7
6	3.21	-3.83	5.00	3.2	2.0
7	3.83	3.21	5.00	0.3	0.2
8	-3.21	3.83	5.00	0.9	0.6
9	-3.83	-3.21	5.00	0.0	0.0
10	6.43	-7.66	10.00	3.1	1.9
11	7.66	6.43	10.00	0.0	0.0
12	-6.43	7.66	10.00	0.0	0.0
13	-7.66	-6.43	10.00	0.0	0.0
14	9.64	-11.49	15.00	2.7	1.6
15	12.86	-15.32	20.00	2.4	1.5
16	19.28	-22.98	30.00	1.9	1.2
17	25.71	-30.64	40.00	1.5	1.0
18	32.14	-38.30	50.00	1.5	0.9
19	8.66	-5.00	10.00	1.3	0.8
20	17.32	-10.00	20.00	0.6	0.4
21	25.98	-15.00	30.00	0.2	0.1
mean for drift axis stations				3.8	2.3
mean for		10 km radius		2.3	1.4
		5 km radius		3.0	1.9
		2 km radius		4.5	2.8





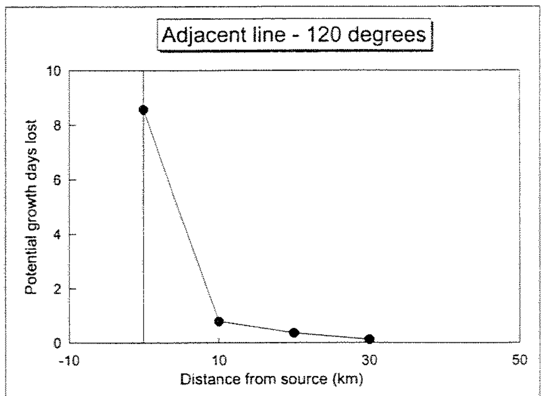
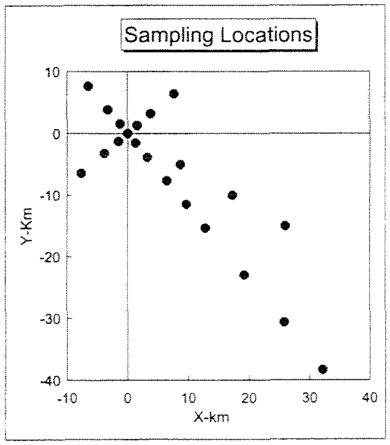
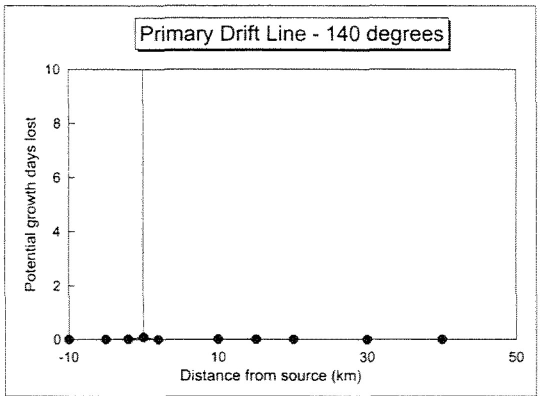


Table A2.7. Summary data and plots of potential scallop growth days lost during well Section 5 at GBFS2 using observed currents for Days 189 to 239 and a settling velocity of 0.1 cm/s.

Zone: FRONTAL

Site	x km	y km	distance (km)	Growth Loss (%)	Growth Days Lost
1	0.00	0.00	0.00	0.2	0.1
2	1.29	-1.53	2.00	0.0	0.0
3	1.53	1.29	2.00	0.0	0.0
4	-1.29	1.53	2.00	0.0	0.0
5	-1.53	-1.29	2.00	0.0	0.0
6	3.21	-3.83	5.00	0.0	0.0
7	3.83	3.21	5.00	0.0	0.0
8	-3.21	3.83	5.00	0.0	0.0
9	-3.83	-3.21	5.00	0.0	0.0
10	6.43	-7.66	10.00	0.0	0.0
11	7.66	6.43	10.00	0.0	0.0
12	-6.43	7.66	10.00	0.0	0.0
13	-7.66	-6.43	10.00	0.0	0.0
14	9.64	-11.49	15.00	0.0	0.0
15	12.86	-15.32	20.00	0.0	0.0
16	19.28	-22.98	30.00	0.0	0.0
17	25.71	-30.64	40.00	0.0	0.0
18	32.14	-38.30	50.00	0.0	0.0
19	8.66	-5.00	10.00	0.0	0.0
20	17.32	-10.00	20.00	0.0	0.0
21	25.98	-15.00	30.00	0.0	0.0
mean for drift axis stations				0.0	0.0
mean for		10 km radius		0.0	0.0
		5 km radius		0.0	0.0
		2 km radius		0.0	0.0





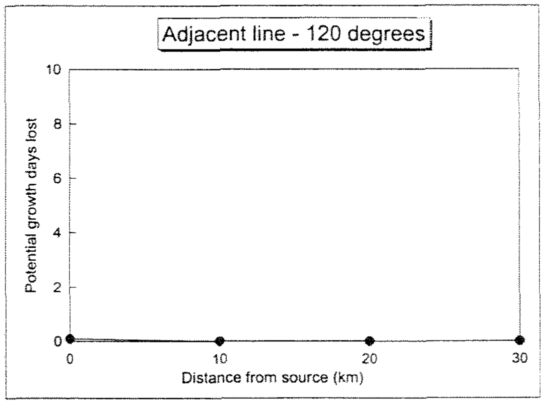
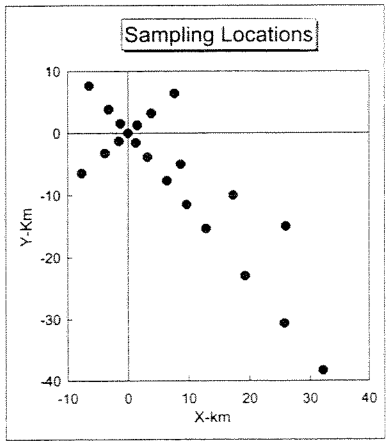
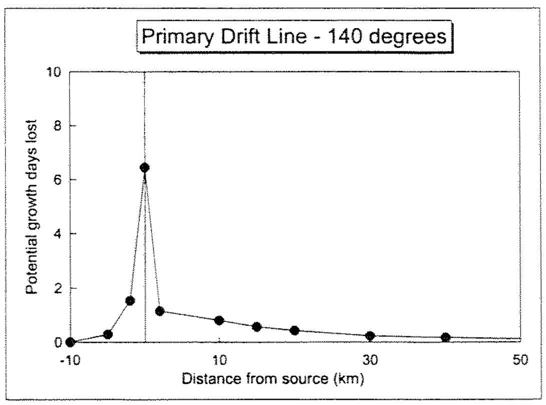


Table A2.8. Summary data and plots of potential scallop growth days lost during well Section 5 at GBFS2 using observed currents for Days 189 to 239 and a settling velocity of 0.5cm/s.

Zone: FRONTAL

Site	x km	y km	distance (km)	Growth Loss (%)	Growth Days Lost
1	0.00	0.00	0.00	12.9	6.4
2	1.29	-1.53	2.00	2.3	1.1
3	1.53	1.29	2.00	0.4	0.2
4	-1.29	1.53	2.00	3.1	1.5
5	-1.53	-1.29	2.00	1.3	0.6
6	3.21	-3.83	5.00	2.0	1.0
7	3.83	3.21	5.00	0.0	0.0
8	-3.21	3.83	5.00	0.6	0.3
9	-3.83	-3.21	5.00	0.1	0.1
10	6.43	-7.66	10.00	1.6	0.8
11	7.66	6.43	10.00	0.0	0.0
12	-6.43	7.66	10.00	0.0	0.0
13	-7.66	-6.43	10.00	0.0	0.0
14	9.64	-11.49	15.00	1.1	0.6
15	12.86	-15.32	20.00	0.9	0.4
16	19.28	-22.98	30.00	0.5	0.2
17	25.71	-30.64	40.00	0.4	0.2
18	32.14	-38.30	50.00	0.2	0.1
19	8.66	-5.00	10.00	0.4	0.2
20	17.32	-10.00	20.00	0.1	0.1
21	25.98	-15.00	30.00	0.0	0.0
mean for drift axis stations				2.2	1.1
mean for		10 km radius		1.9	0.9
		5 km radius		2.5	1.3
		2 km radius		4.0	2.0





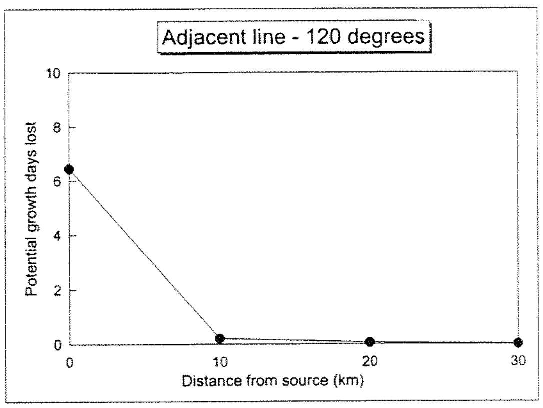
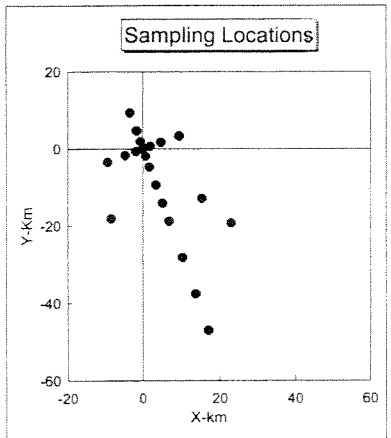
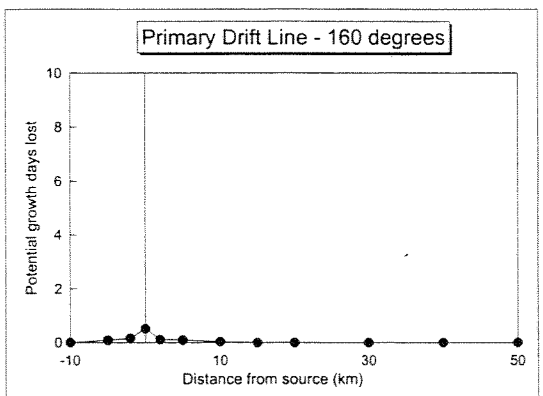


Table A2.9. Summary data and plots of potential scallop growth days lost during well Sections 1 to 4 at GBFS2 using observed currents for Days 217 to 279 and a settling velocity of 0.1 cm/s.

Zone: FRONTAL

Site	x km	y km	distance (km)	Growth Loss (%)	Growth Days Lost
1	0.00	0.00	0.00	0.84	0.5
2	0.68	-1.88	2.00	0.19	0.1
3	1.88	0.68	2.00	0.16	0.1
4	-0.68	1.88	2.00	0.25	0.2
5	-1.88	-0.68	2.00	0.15	0.1
6	1.71	-4.70	5.00	0.16	0.1
7	4.70	1.71	5.00	0.10	0.1
8	-1.71	4.70	5.00	0.15	0.1
9	-4.70	-1.71	5.00	0.02	0.0
10	3.42	-9.40	10.00	0.06	0.0
11	9.40	3.42	10.00	0.00	0.0
12	-3.42	9.40	10.00	0.00	0.0
13	-9.40	-3.42	10.00	0.00	0.0
14	5.13	-14.10	15.00	0.00	0.0
15	6.84	-18.79	20.00	0.00	0.0
16	10.26	-28.19	30.00	0.00	0.0
17	13.68	-37.59	40.00	0.00	0.0
18	17.10	-46.98	50.00	0.00	0.0
19	15.32	-12.86	20.00	0.09	0.1
20	22.98	-19.28	30.00	0.04	0.0
21	-8.45	-18.13	20.00	0.00	0.0
mean for drift axis stations				0.14	0.1
mean for		10 km radius		0.16	0.1
		5 km radius		0.22	0.1
		2 km radius		0.32	0.2





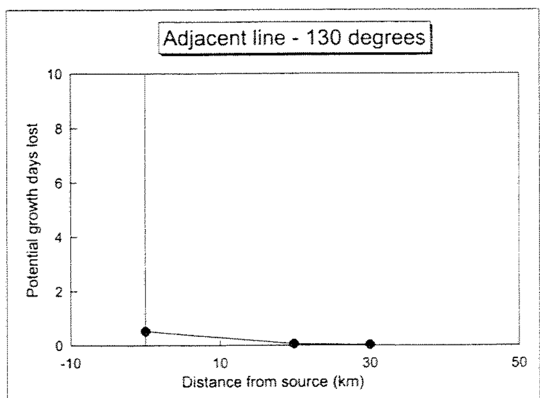
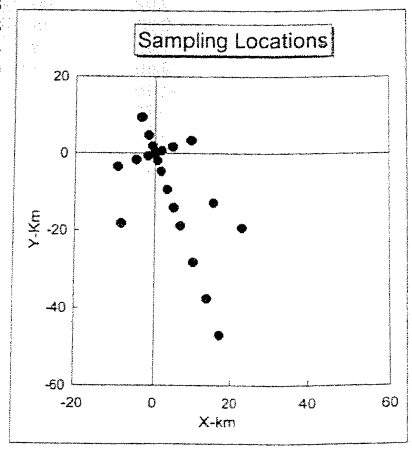
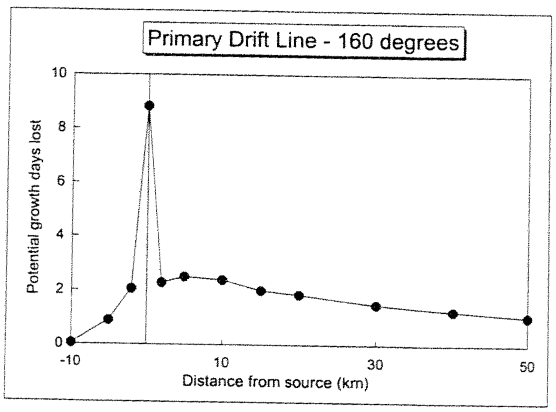


Table A2.10. Summary data and plots of potential scallop growth days lost during well Sections 1 to 4 at GBFS2 using observed currents for Days 217 to 279 and a settling velocity of 0.5 cm/s.

Zone: FRONTAL

Site	x km	y km	distance (km)	Growth Loss (%)	Growth Days Lost
1	0.00	0.00	0.00	14.2	8.8
2	0.68	-1.88	2.00	3.7	2.3
3	1.88	0.68	2.00	0.7	0.4
4	-0.68	1.88	2.00	3.3	2.0
5	-1.88	-0.68	2.00	3.5	2.2
6	1.71	-4.70	5.00	4.0	2.5
7	4.70	1.71	5.00	0.1	0.0
8	-1.71	4.70	5.00	1.4	0.9
9	-4.70	-1.71	5.00	1.2	0.7
10	3.42	-9.40	10.00	3.8	2.4
11	9.40	3.42	10.00	0.0	0.0
12	-3.42	9.40	10.00	0.1	0.0
13	-9.40	-3.42	10.00	0.0	0.0
14	5.13	-14.10	15.00	3.2	2.0
15	6.84	-18.79	20.00	3.0	1.9
16	10.26	-28.19	30.00	2.4	1.5
17	13.68	-37.59	40.00	2.0	1.3
18	17.10	-46.98	50.00	1.7	1.1
19	15.32	-12.86	20.00	0.0	0.0
20	22.98	-19.28	30.00	0.0	0.0
21	-8.45	-18.13	20.00	0.0	0.0
mean for drift axis stations				4.2	2.6
mean for	10 km radius			2.8	1.7
	5 km radius			3.6	2.2
	2 km radius			5.1	3.1





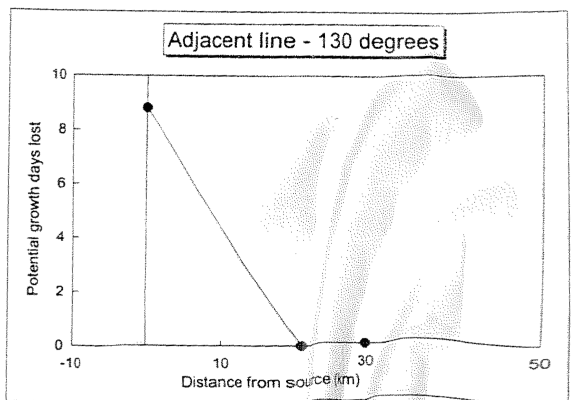
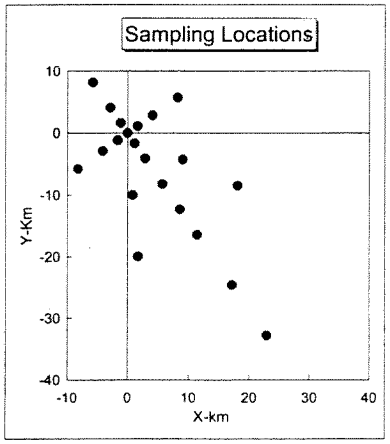
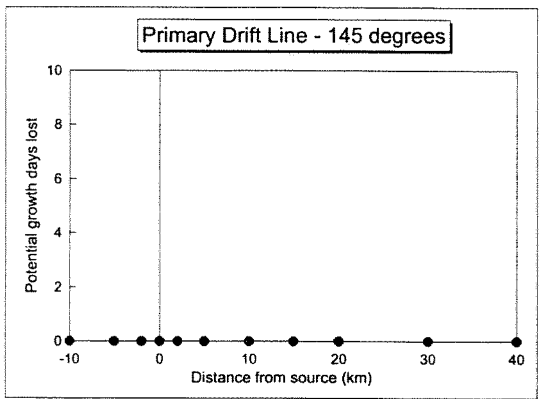


Table A2.11. Summary data and plots of potential scallop growth days lost during well Sections 1 to 4 at Node 1127 (GBFS2) during summer using 3-D model currents and a settling velocity of 0.1cm/s.

Zone: FRONTAL

Site	x km	y km	distance (km)	Growth Loss (%)	Growth Days Lost
1	0.00	0.00	0.00	0.0	0.0
2	1.15	-1.64	2.00	0.0	0.0
3	1.64	1.15	2.00	0.0	0.0
4	-1.15	1.64	2.00	0.0	0.0
5	-1.64	-1.15	2.00	0.0	0.0
6	2.87	-4.10	5.00	0.0	0.0
7	4.10	2.87	5.00	0.0	0.0
8	-2.87	4.10	5.00	0.0	0.0
9	-4.10	-2.87	5.00	0.0	0.0
10	5.74	-8.19	10.00	0.0	0.0
11	8.19	5.74	10.00	0.0	0.0
12	-5.74	8.19	10.00	0.0	0.0
13	-8.19	-5.74	10.00	0.0	0.0
14	8.60	-12.29	15.00	0.0	0.0
15	11.47	-16.38	20.00	0.0	0.0
16	17.21	-24.57	30.00	0.0	0.0
17	22.94	-32.77	40.00	0.0	0.0
18	0.87	-9.96	10.00	0.0	0.0
19	1.74	-19.92	20.00	0.0	0.0
20	9.06	-4.23	10.00	0.0	0.0
21	18.13	-8.45	20.00	0.0	0.0
mean for drift axis stations				0.0	0.0
mean for		10 km radius		0.0	0.0
		5 km radius		0.0	0.0
		2 km radius		0.0	0.0





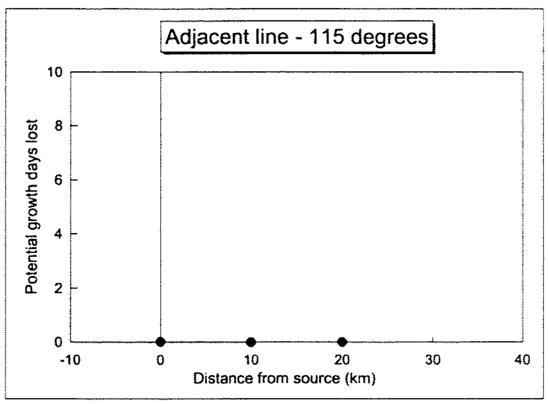
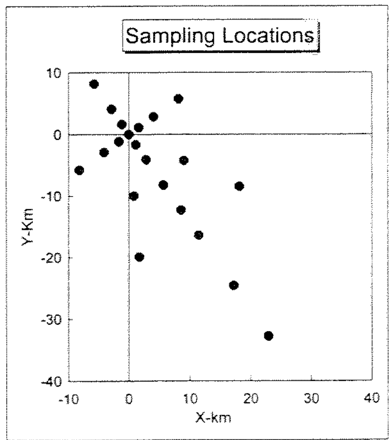
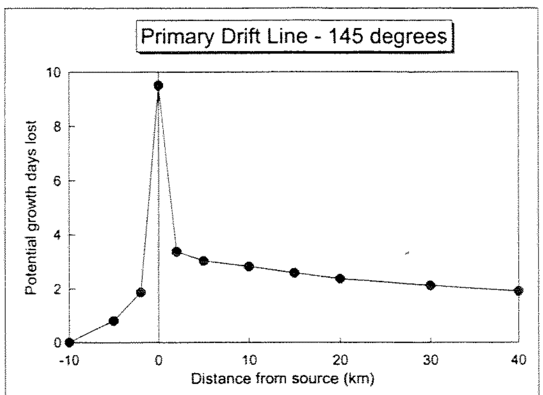


Table A2.12. Summary data and plots of potential scallop growth days lost during well Sections 1 to 4 at Node 1127 (GBFS2) during summer using 3-D model currents and a settling velocity of 0.5 cm/s.

Zone: FRONTAL

Site	x km	y km	distance (km)	Growth Loss (%)	Growth Days Lost
1	0.00	0.00	0.00	15.3	9.5
2	1.15	-1.64	2.00	5.5	3.4
3	1.64	1.15	2.00	1.5	0.9
4	-1.15	1.64	2.00	3.0	1.9
5	-1.64	-1.15	2.00	0.6	0.4
6	2.87	-4.10	5.00	4.9	3.0
7	4.10	2.87	5.00	0.1	0.1
8	-2.87	4.10	5.00	1.3	0.8
9	-4.10	-2.87	5.00	0.0	0.0
10	5.74	-8.19	10.00	4.6	2.8
11	8.19	5.74	10.00	0.0	0.0
12	-5.74	8.19	10.00	0.0	0.0
13	-8.19	-5.74	10.00	0.0	0.0
14	8.60	-12.29	15.00	4.2	2.6
15	11.47	-16.38	20.00	3.8	2.4
16	17.21	-24.57	30.00	3.4	2.1
17	22.94	-32.77	40.00	3.1	1.9
18	0.87	-9.96	10.00	0.4	0.3
19	1.74	-19.92	20.00	0.0	0.0
20	9.06	-4.23	10.00	0.5	0.3
21	18.13	-8.45	20.00	0.0	0.0
mean for drift axis stations				5.6	3.5
mean for		10 km radius		2.8	1.8
		5 km radius		3.6	2.2
		2 km radius		5.2	3.2





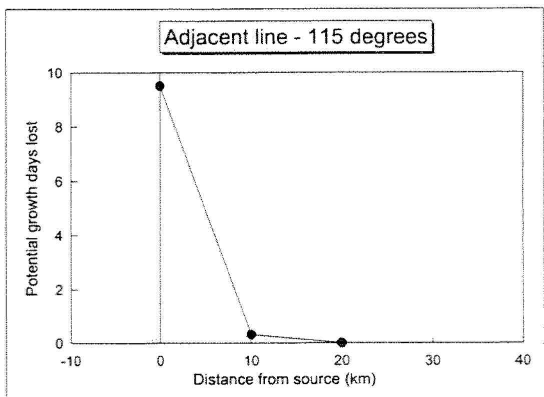
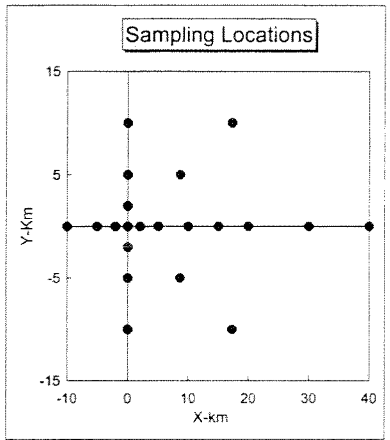
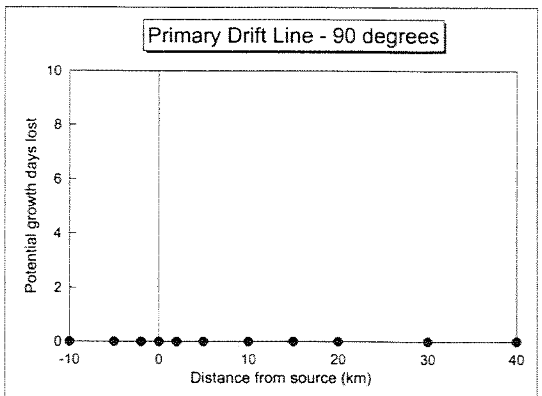


Table A2.13. Summary data and plots of potential scallop growth days lost during well Sections 1 to 4 at Node 1127 (GBFS2) during winter using 3-D model currents and a settling velocity of 0.1 cm/s.

Zone: FRONTAL

Site	x km	y km	distance (km)	Growth Loss (%)	Growth Days Lost
1	0.00	0.00	0.00	0.0	0.0
2	2.00	0.00	2.00	0.0	0.0
3	0.00	2.00	2.00	0.0	0.0
4	-2.00	0.00	2.00	0.0	0.0
5	0.00	-2.00	2.00	0.0	0.0
6	5.00	0.00	5.00	0.0	0.0
7	0.00	5.00	5.00	0.0	0.0
8	-5.00	0.00	5.00	0.0	0.0
9	0.00	-5.00	5.00	0.0	0.0
10	10.00	0.00	10.00	0.0	0.0
11	0.00	10.00	10.00	0.0	0.0
12	-10.00	0.00	10.00	0.0	0.0
13	0.00	-10.00	10.00	0.0	0.0
14	15.00	0.00	15.00	0.0	0.0
15	20.00	0.00	20.00	0.0	0.0
16	30.00	0.00	30.00	0.0	0.0
17	40.00	0.00	40.00	0.0	0.0
18	8.66	5.00	10.00	0.0	0.0
19	17.32	10.00	20.00	0.0	0.0
20	8.66	-5.00	10.00	0.0	0.0
21	17.32	-10.00	20.00	0.0	0.0
mean for drift axis stations				0.0	0.0
mean for		10 km radius		0.0	0.0
		5 km radius		0.0	0.0
		2 km radius		0.0	0.0





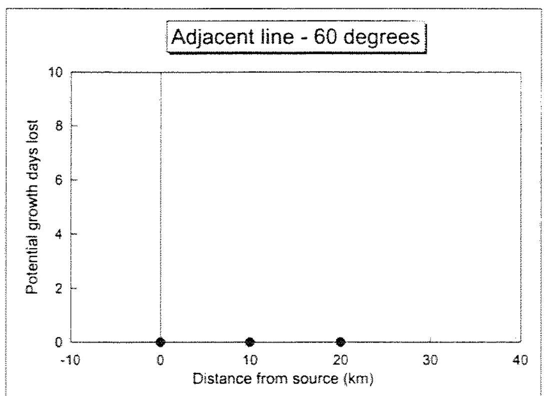
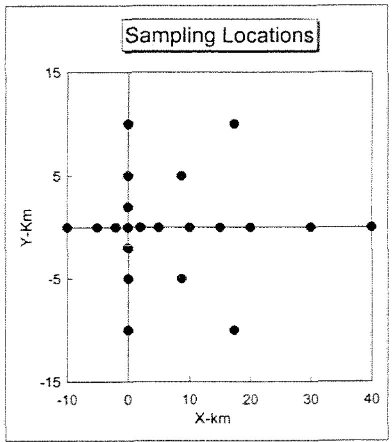
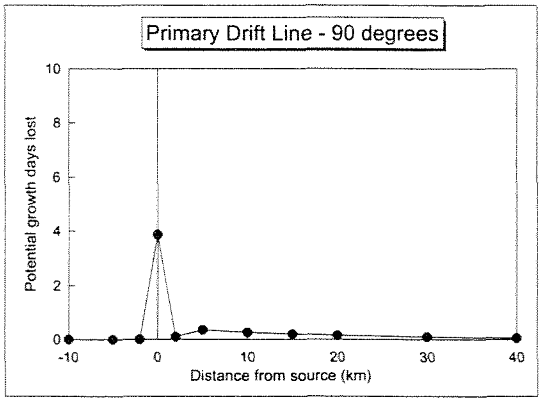


Table A2.14. Summary data and plots of potential scallop growth days lost during well Sections 1 to 4 at Node 1127 (GBFS2) during winter using 3-D model currents and a settling velocity of 0.5 cm/s.

Zone: FRONTAL

Site	x km	y km	distance (km)	Growth Loss (%)	Growth Days Lost
1	0.00	0.00	0.00	6.3	3.9
2	2.00	0.00	2.00	0.2	0.1
3	0.00	2.00	2.00	0.1	0.1
4	-2.00	0.00	2.00	0.0	0.0
5	0.00	-2.00	2.00	0.8	0.5
6	5.00	0.00	5.00	0.6	0.4
7	0.00	5.00	5.00	0.0	0.0
8	-5.00	0.00	5.00	0.0	0.0
9	0.00	-5.00	5.00	0.1	0.1
10	10.00	0.00	10.00	0.4	0.3
11	0.00	10.00	10.00	0.0	0.0
12	-10.00	0.00	10.00	0.0	0.0
13	0.00	-10.00	10.00	0.0	0.0
14	15.00	0.00	15.00	0.3	0.2
15	20.00	0.00	20.00	0.3	0.2
16	30.00	0.00	30.00	0.2	0.1
17	40.00	0.00	40.00	0.1	0.1
18	8.66	5.00	10.00	0.0	0.0
19	17.32	10.00	20.00	0.0	0.0
20	8.66	-5.00	10.00	0.7	0.5
21	17.32	-10.00	20.00	0.3	0.2
mean for drift axis stations				1.0	0.6
mean for		10 km radius		0.6	0.4
		5 km radius		0.9	0.6
		2 km radius		1.5	0.9





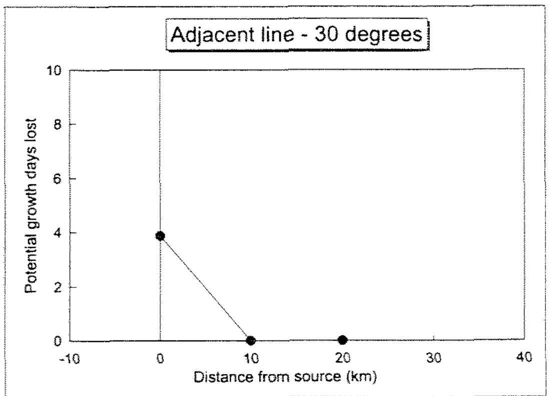
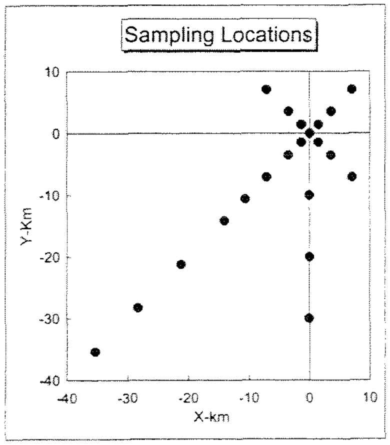
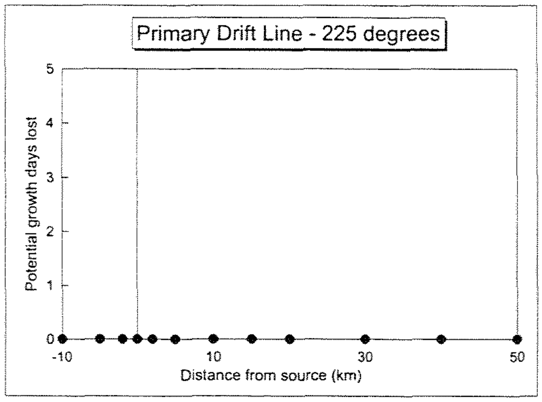


Table A2.15. Summary data and plots of potential scallop growth days lost during well Sections 1 to 4 at NEP using observed currents for Days 208 to 270 and a settling velocity of 0.1 cm/s.

Zone: FRONTAL

Site	x km	y km	distance (km)	Growth Loss (%)	Growth Days Lost
1	0.00	0.00	0.00	0.0	0.0
2	-1.41	-1.41	2.00	0.0	0.0
3	1.41	-1.41	2.00	0.0	0.0
4	1.41	1.41	2.00	0.0	0.0
5	-1.41	1.41	2.00	0.0	0.0
6	-3.54	-3.54	5.00	0.0	0.0
7	3.54	-3.54	5.00	0.0	0.0
8	3.54	3.54	5.00	0.0	0.0
9	-3.54	3.54	5.00	0.0	0.0
10	-7.07	-7.07	10.00	0.0	0.0
11	7.07	-7.07	10.00	0.0	0.0
12	7.07	7.07	10.00	0.0	0.0
13	-7.07	7.07	10.00	0.0	0.0
14	-10.61	-10.61	15.00	0.0	0.0
15	-14.14	-14.14	20.00	0.0	0.0
16	-21.21	-21.21	30.00	0.0	0.0
17	-28.28	-28.28	40.00	0.0	0.0
18	-35.36	-35.36	50.00	0.0	0.0
19	0.00	-10.00	10.00	0.0	0.0
20	-0.00	-20.00	20.00	0.0	0.0
21	-0.00	-30.00	30.00	0.0	0.0
mean for drift axis stations				0.0	0.0
mean for	10 km radius			0.0	0.0
	5 km radius			0.0	0.0
	2 km radius			0.0	0.0





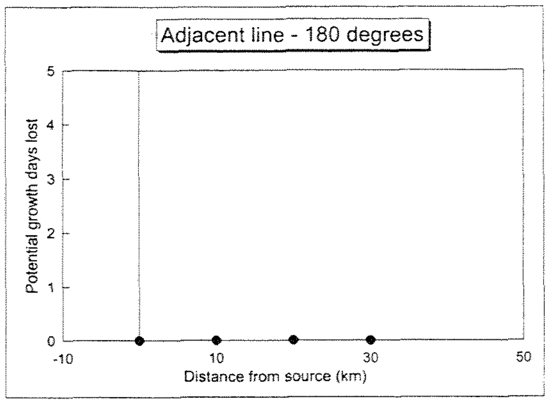
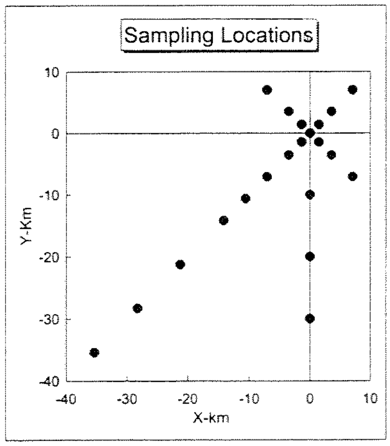
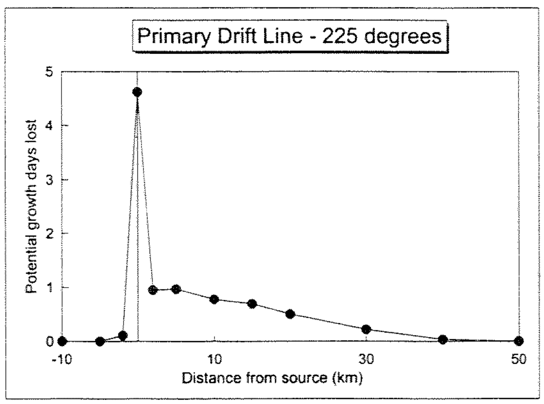


Table A2.16. Summary data and plots of potential scallop growth days lost during well Sections 1 to 4 at NEP using observed currents for Days 208 to 270 and a settling velocity of 0.5 cm/s.

Zone: FRONTAL

Site	x km	y km	distance (km)	Growth Loss (%)	Growth Days Lost
1	0.00	0.00	0.00	7.4	4.6
2	-1.41	-1.41	2.00	1.5	1.0
3	1.41	-1.41	2.00	0.6	0.4
4	1.41	1.41	2.00	0.2	0.1
5	-1.41	1.41	2.00	0.9	0.5
6	-3.54	-3.54	5.00	1.6	1.0
7	3.54	-3.54	5.00	0.2	0.1
8	3.54	3.54	5.00	0.0	0.0
9	-3.54	3.54	5.00	0.8	0.5
10	-7.07	-7.07	10.00	1.3	0.8
11	7.07	-7.07	10.00	0.0	0.0
12	7.07	7.07	10.00	0.0	0.0
13	-7.07	7.07	10.00	0.0	0.0
14	-10.61	-10.61	15.00	1.1	0.7
15	-14.14	-14.14	20.00	0.8	0.5
16	-21.21	-21.21	30.00	0.4	0.2
17	-28.28	-28.28	40.00	0.1	0.0
18	-35.36	-35.36	50.00	0.0	0.0
19	0.00	-10.00	10.00	0.8	0.5
20	-0.00	-20.00	20.00	0.0	0.0
21	-0.00	-30.00	30.00	0.0	0.0
mean for drift axis stations				1.6	1.0
mean for		10 km radius		1.1	0.7
		5 km radius		1.5	0.9
		2 km radius		2.1	1.3





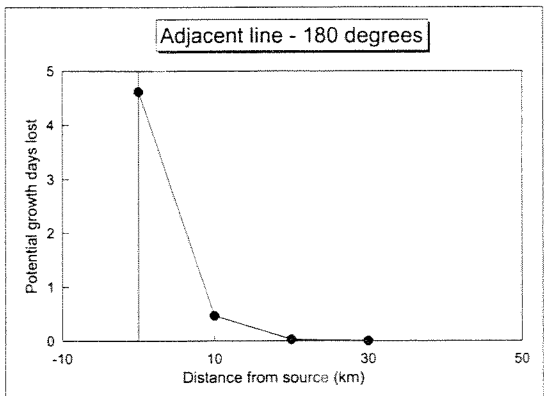
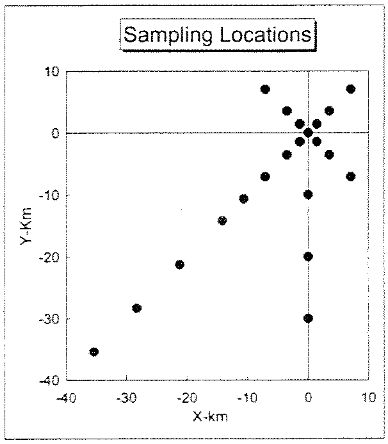
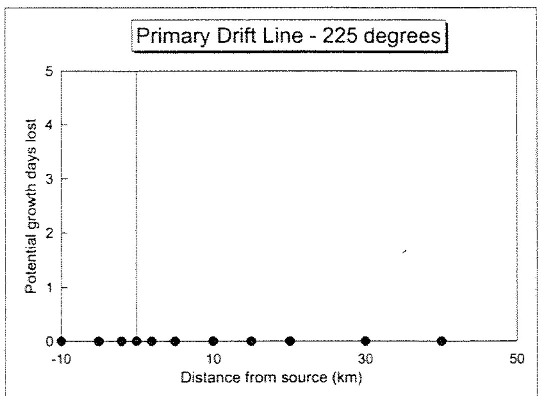


Table A2.17. Summary data and plots of potential scallop growth days lost during well Section 5 at NEP using observed currents for Days 208 to 258 and a settling velocity of 0.1 cm/s.

Zone: FRONTAL

Site	x km	y km	distance (km)	Growth Loss (%)	Growth Days Lost
1	0.00	0.00	0.00	0.00	0.00
2	-1.41	-1.41	2.00	0.00	0.00
3	1.41	-1.41	2.00	0.00	0.00
4	1.41	1.41	2.00	0.00	0.00
5	-1.41	1.41	2.00	0.00	0.00
6	-3.54	-3.54	5.00	0.00	0.00
7	3.54	-3.54	5.00	0.00	0.00
8	3.54	3.54	5.00	0.00	0.00
9	-3.54	3.54	5.00	0.00	0.00
10	-7.07	-7.07	10.00	0.00	0.00
11	7.07	-7.07	10.00	0.00	0.00
12	7.07	7.07	10.00	0.00	0.00
13	-7.07	7.07	10.00	0.00	0.00
14	-10.61	-10.61	15.00	0.00	0.00
15	-14.14	-14.14	20.00	0.00	0.00
16	-21.21	-21.21	30.00	0.00	0.00
17	-28.28	-28.28	40.00	0.00	0.00
18	-35.36	-35.36	50.00	0.00	0.00
19	0.00	-10.00	10.00	0.00	0.00
20	-0.00	-20.00	20.00	0.00	0.00
21	-0.00	-30.00	30.00	0.00	0.00
mean for drift axis stations				0.00	0.00
mean for		10 km radius		0.00	0.00
		5 km radius		0.00	0.00
		2 km radius		0.00	0.00





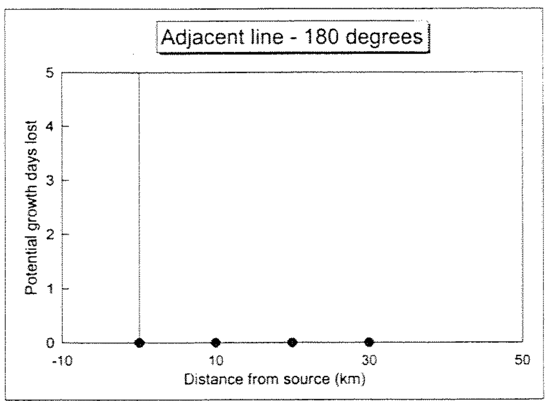
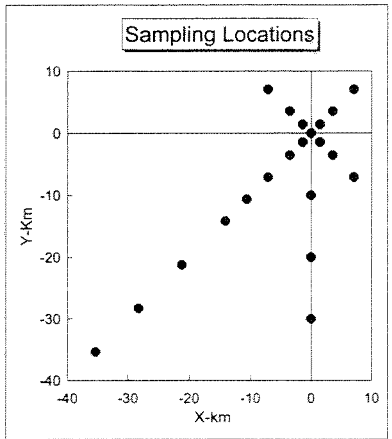
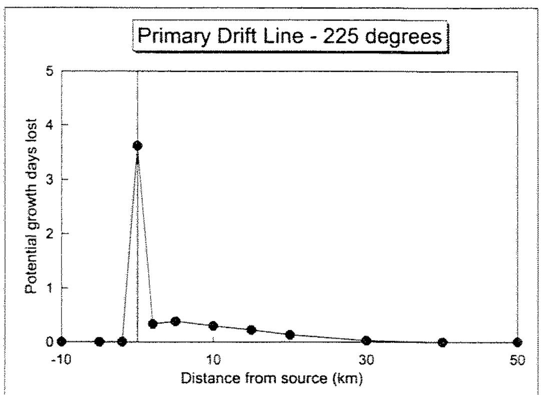


Table A2.18. Summary data and plots of potential scallop growth days lost during well Section 5 at NEP using observed currents for Days 208 to 258 and a settling velocity of 0.5 cm/s.

Zone: FRONTAL

Site	x km	y km	distance (km)	Growth Loss (%)	Growth Days Lost
1	0.00	0.00	0.00	7.2	3.6
2	-1.41	-1.41	2.00	0.7	0.3
3	1.41	-1.41	2.00	0.2	0.1
4	1.41	1.41	2.00	0.0	0.0
5	-1.41	1.41	2.00	0.5	0.2
6	-3.54	-3.54	5.00	0.8	0.4
7	3.54	-3.54	5.00	0.1	0.0
8	3.54	3.54	5.00	0.0	0.0
9	-3.54	3.54	5.00	0.3	0.2
10	-7.07	-7.07	10.00	0.6	0.3
11	7.07	-7.07	10.00	0.0	0.0
12	7.07	7.07	10.00	0.0	0.0
13	-7.07	7.07	10.00	0.0	0.0
14	-10.61	-10.61	15.00	0.4	0.2
15	-14.14	-14.14	20.00	0.3	0.1
16	-21.21	-21.21	30.00	0.1	0.0
17	-28.28	-28.28	40.00	0.0	0.0
18	-35.36	-35.36	50.00	0.0	0.0
19	0.00	-10.00	10.00	0.1	0.1
20	-0.00	-20.00	20.00	0.0	0.0
21	-0.00	-30.00	30.00	0.0	0.0
mean for drift axis stations				1.1	0.6
mean for		10 km radius		0.8	0.4
		5 km radius		1.1	0.5
		2 km radius		1.7	0.9





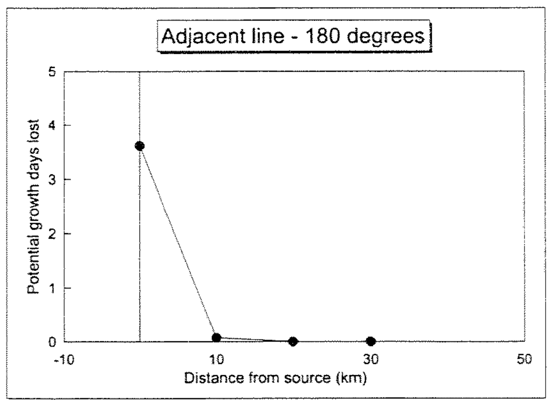
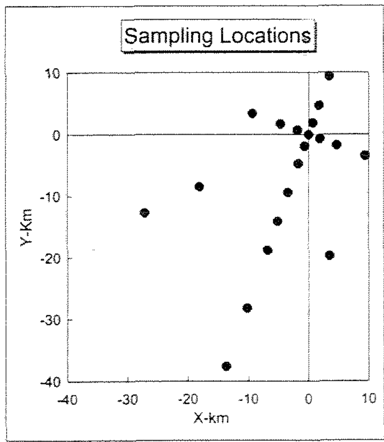
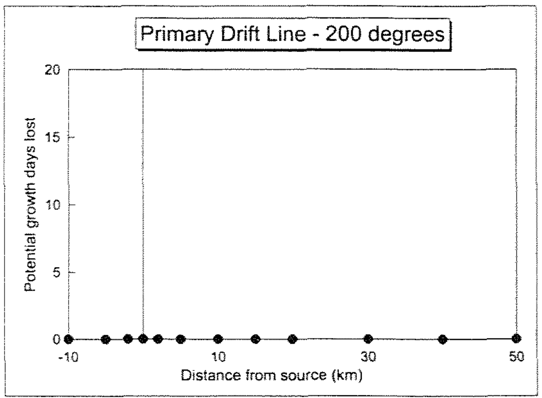


Table A2.19. Summary data and plots of potential scallop growth days lost during well Sections 1 to 4 at NEP using observed currents for Days 8 to 70 and a settling velocity of 0.1 cm/s.

Zone: FRONTAL

Site	x km	y km	distance (km)	Growth Loss (%)	Growth Days Lost
1	0.00	0.00	0.00	0.0	0.0
2	-0.68	-1.88	2.00	0.0	0.0
3	1.88	-0.68	2.00	0.0	0.0
4	0.68	1.88	2.00	0.0	0.0
5	-1.88	0.68	2.00	0.0	0.0
6	-1.71	-4.70	5.00	0.0	0.0
7	4.70	-1.71	5.00	0.0	0.0
8	1.71	4.70	5.00	0.0	0.0
9	-4.70	1.71	5.00	0.0	0.0
10	-3.42	-9.40	10.00	0.0	0.0
11	9.40	-3.42	10.00	0.0	0.0
12	3.42	9.40	10.00	0.0	0.0
13	-9.40	3.42	10.00	0.0	0.0
14	-5.13	-14.10	15.00	0.0	0.0
15	-6.84	-18.79	20.00	0.0	0.0
16	-10.26	-28.19	30.00	0.0	0.0
17	-13.68	-37.59	40.00	0.0	0.0
18	-17.10	-46.98	50.00	0.0	0.0
19	-18.13	-8.45	20.00	0.0	0.0
20	-27.19	-12.68	30.00	0.0	0.0
21	3.47	-19.70	20.00	0.0	0.0
mean for drift axis stations				0.0	0.0
mean for		10 km radius		0.0	0.0
		5 km radius		0.0	0.0
		2 km radius		0.0	0.0





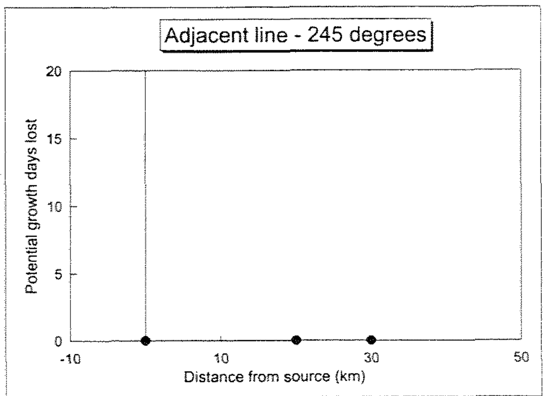
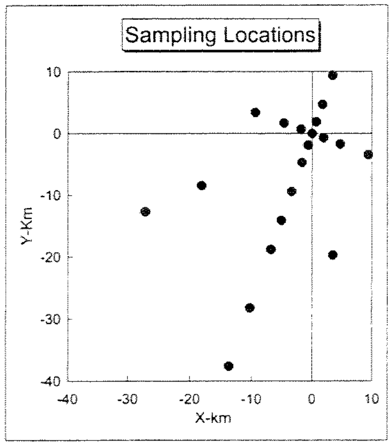
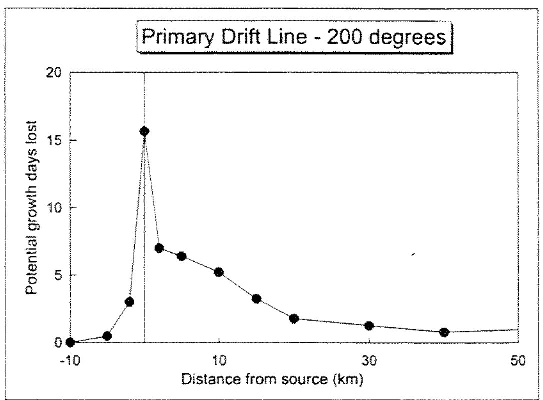


Table A2.20. Summary data and plots of potential scallop growth days lost during well Sections 1 to 4 at NEP using observed currents for Days 8 to 70 and a settling velocity of 0.5 cm/s.

Zone: FRONTAL

Site	x km	y km	distance (km)	Growth Loss (%)	Growth Days Lost
1	0.00	0.00	0.00	25.3	15.7
2	-0.68	-1.88	2.00	11.3	7.0
3	1.88	-0.68	2.00	6.7	4.2
4	0.68	1.88	2.00	4.8	3.0
5	-1.88	0.68	2.00	9.0	5.6
6	-1.71	-4.70	5.00	10.3	6.4
7	4.70	-1.71	5.00	1.8	1.1
8	1.71	4.70	5.00	0.8	0.5
9	-4.70	1.71	5.00	5.7	3.6
10	-3.42	-9.40	10.00	8.4	5.2
11	9.40	-3.42	10.00	0.0	0.0
12	3.42	9.40	10.00	0.0	0.0
13	-9.40	3.42	10.00	1.7	1.1
14	-5.13	-14.10	15.00	5.3	3.3
15	-6.84	-18.79	20.00	2.9	1.8
16	-10.26	-28.19	30.00	2.0	1.3
17	-13.68	-37.59	40.00	1.3	0.8
18	-17.10	-46.98	50.00	1.6	1.0
19	-18.13	-8.45	20.00	1.3	0.8
20	-27.19	-12.68	30.00	0.2	0.1
21	3.47	-19.70	20.00	0.4	0.3
mean for drift axis stations				7.6	4.7
mean for		10 km radius		6.6	4.1
		5 km radius		8.4	5.2
		2 km radius		11.4	7.1





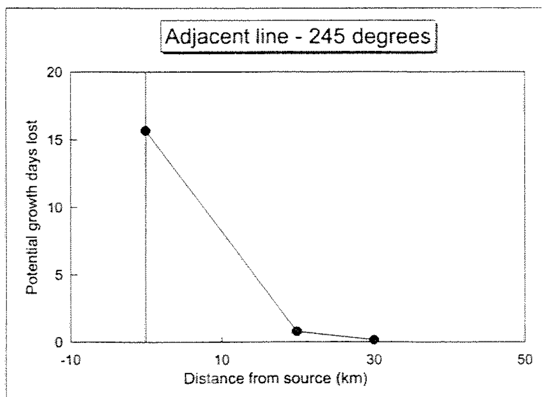
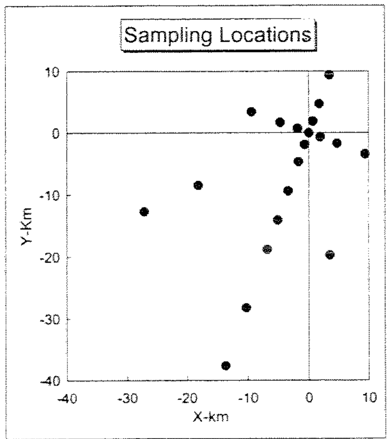
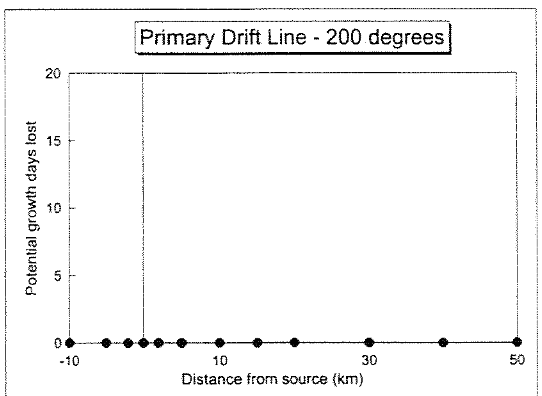


Table A2.21. Summary data and plots of potential scallop growth days lost during well Section 5 at NEP using observed currents for Days 8 to 58 and a settling velocity of 0.1 cm/s.

Zone: FRONTAL

Site	x km	y km	distance (km)	Growth Loss (%)	Growth Days Lost
1	0.00	0.00	0.00	0.0	0.0
2	-0.68	-1.88	2.00	0.0	0.0
3	1.88	-0.68	2.00	0.0	0.0
4	0.68	1.88	2.00	0.0	0.0
5	-1.88	0.68	2.00	0.0	0.0
6	-1.71	-4.70	5.00	0.0	0.0
7	4.70	-1.71	5.00	0.0	0.0
8	1.71	4.70	5.00	0.0	0.0
9	-4.70	1.71	5.00	0.0	0.0
10	-3.42	-9.40	10.00	0.0	0.0
11	9.40	-3.42	10.00	0.0	0.0
12	3.42	9.40	10.00	0.0	0.0
13	-9.40	3.42	10.00	0.0	0.0
14	-5.13	-14.10	15.00	0.0	0.0
15	-6.84	-18.79	20.00	0.0	0.0
16	-10.26	-28.19	30.00	0.0	0.0
17	-13.68	-37.59	40.00	0.0	0.0
18	-17.10	-46.98	50.00	0.0	0.0
19	-18.13	-8.45	20.00	0.0	0.0
20	-27.19	-12.68	30.00	0.0	0.0
21	3.47	-19.70	20.00	0.0	0.0
mean for drift axis stations				0.0	0.0
mean for		10 km radius		0.0	0.0
		5 km radius		0.0	0.0
		2 km radius		0.0	0.0





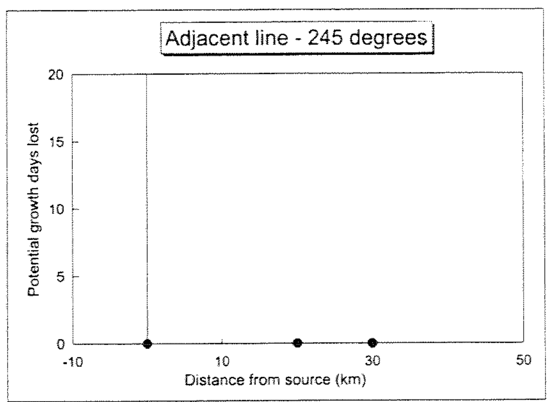
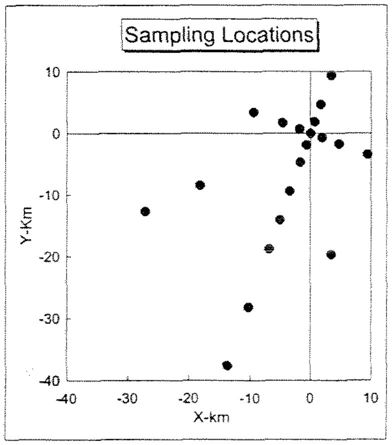
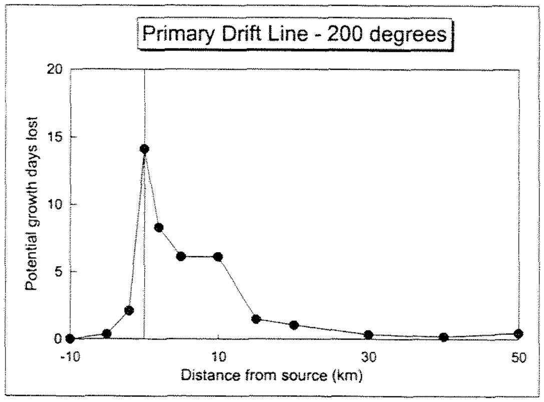


Table A2.22. Summary data and plots of potential scallop growth days lost during well Section 5 at NEP using observed currents for Days 8 to 58 and a settling velocity of 0.5 cm/s.

Zone: FRONTAL

Site	x km	y km	distance (km)	Growth Loss (%)	Growth Days Lost
1	0.00	0.00	0.00	25.8	12.9
2	-0.68	-1.88	2.00	12.9	6.4
3	1.88	-0.68	2.00	4.7	2.4
4	0.68	1.88	2.00	4.2	2.1
5	-1.88	0.68	2.00	10.5	5.2
6	-1.71	-4.70	5.00	9.3	4.6
7	4.70	-1.71	5.00	1.3	0.7
8	1.71	4.70	5.00	0.7	0.3
9	-4.70	1.71	5.00	5.7	2.9
10	-3.42	-9.40	10.00	4.8	2.4
11	9.40	-3.42	10.00	0.0	0.0
12	3.42	9.40	10.00	0.0	0.0
13	-9.40	3.42	10.00	0.7	0.3
14	-5.13	-14.10	15.00	2.2	1.1
15	-6.84	-18.79	20.00	1.3	0.6
16	-10.26	-28.19	30.00	0.4	0.2
17	-13.68	-37.59	40.00	0.1	0.1
18	-17.10	-46.98	50.00	0.4	0.2
19	-18.13	-8.45	20.00	0.5	0.3
20	-27.19	-12.68	30.00	0.0	0.0
21	3.47	-19.70	20.00	0.0	0.0
mean for drift axis stations				8.5	4.2
mean for		10 km radius		6.2	3.1
		5 km radius		8.3	4.2
		2 km radius		11.6	5.8





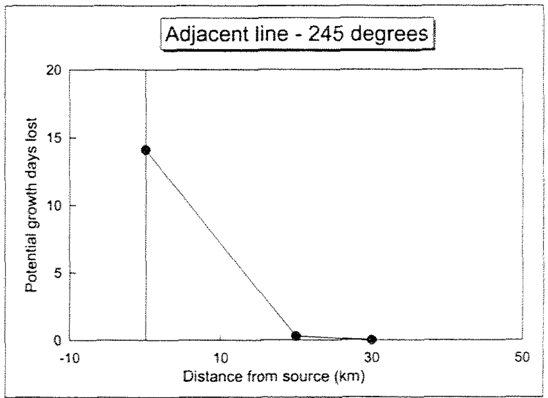
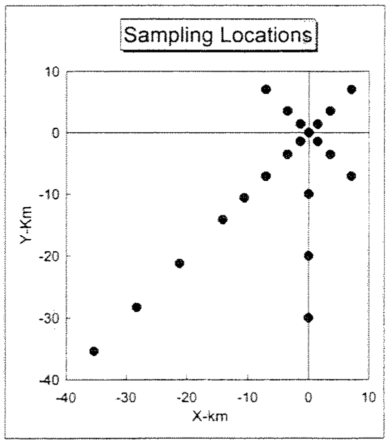
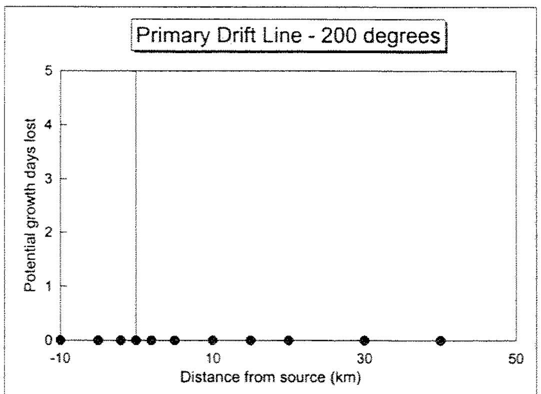


Table A2.23. Summary data and plots of potential scallop growth days lost during well Sections 1 to 4 at Node 344 (NEP) during summer using 3-D model currents and a settling velocity of 0.1 cm/s.

Zone: FRONTAL

Site	x km	y km	distance (km)	Growth Loss (%)	Growth Days Lost
1	0.00	0.00	0.00	0.0	0.0
2	-0.68	-1.88	2.00	0.0	0.0
3	1.88	-0.68	2.00	0.0	0.0
4	0.68	1.88	2.00	0.0	0.0
5	-1.88	0.68	2.00	0.0	0.0
6	-1.71	-4.70	5.00	0.0	0.0
7	4.70	-1.71	5.00	0.0	0.0
8	1.71	4.70	5.00	0.0	0.0
9	-4.70	1.71	5.00	0.0	0.0
10	-3.42	-9.40	10.00	0.0	0.0
11	9.40	-3.42	10.00	0.0	0.0
12	3.42	9.40	10.00	0.0	0.0
13	-9.40	3.42	10.00	0.0	0.0
14	-5.13	-14.10	15.00	0.0	0.0
15	-6.84	-18.79	20.00	0.0	0.0
16	-10.26	-28.19	30.00	0.0	0.0
17	-13.68	-37.59	40.00	0.0	0.0
18	-7.66	-6.43	10.00	0.0	0.0
19	-15.32	-12.86	20.00	0.0	0.0
20	1.74	-9.85	10.00	0.0	0.0
21	3.47	-19.70	20.00	0.0	0.0
mean for drift axis stations				0.0	0.0
mean for		10 km radius		0.0	0.0
		5 km radius		0.0	0.0
		2 km radius		0.0	0.0





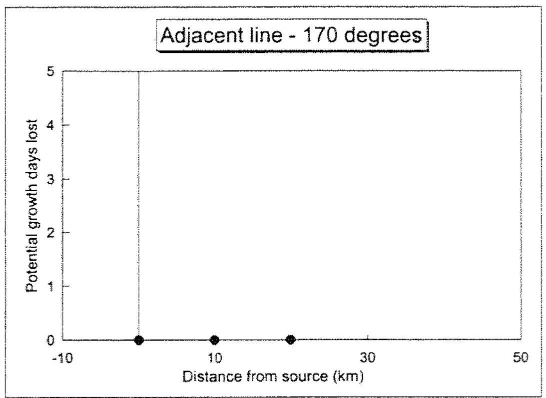
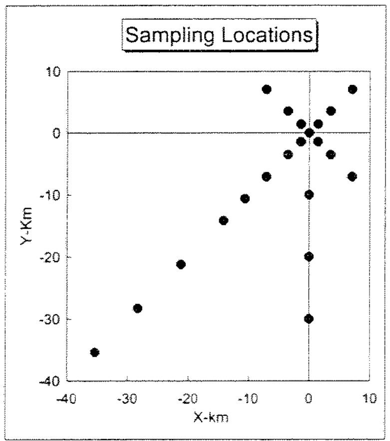
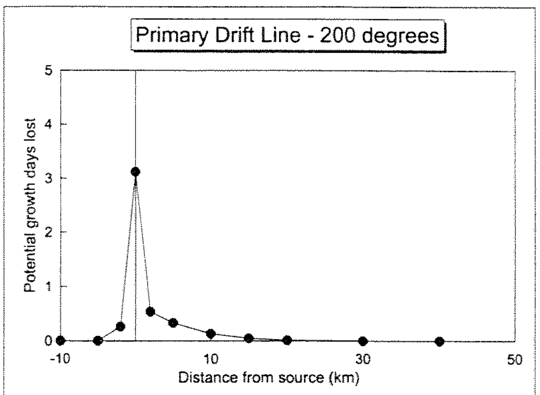


Table A2.24. Summary data and plots of potential scallop growth days lost during well Sections 1 to 4 at Node 344 (NEP) during summer using 3-D model currents and a settling velocity of 0.5 cm/s.

Zone: FRONTAL

Site	x km	y km	distance (km)	Growth Loss (%)	Growth Days Lost
1	0.00	0.00	0.00	5.0	3.1
2	-0.68	-1.88	2.00	0.9	0.5
3	1.88	-0.68	2.00	0.0	0.0
4	0.68	1.88	2.00	0.4	0.3
5	-1.88	0.68	2.00	0.3	0.2
6	-1.71	-4.70	5.00	0.5	0.3
7	4.70	-1.71	5.00	0.0	0.0
8	1.71	4.70	5.00	0.0	0.0
9	-4.70	1.71	5.00	0.5	0.3
10	-3.42	-9.40	10.00	0.2	0.1
11	9.40	-3.42	10.00	0.0	0.0
12	3.42	9.40	10.00	0.0	0.0
13	-9.40	3.42	10.00	0.0	0.0
14	-5.13	-14.10	15.00	0.1	0.1
15	-6.84	-18.79	20.00	0.0	0.0
16	-10.26	-28.19	30.00	0.0	0.0
17	-13.68	-37.59	40.00	0.0	0.0
18	-7.66	-6.43	10.00	0.4	0.2
19	-15.32	-12.86	20.00	0.0	0.0
20	1.74	-9.85	10.00	0.1	0.0
21	3.47	-19.70	20.00	0.0	0.0
mean for drift axis stations				0.8	0.5
mean for		10 km radius		0.6	0.4
		5 km radius		0.9	0.5
		2 km radius		1.3	0.8





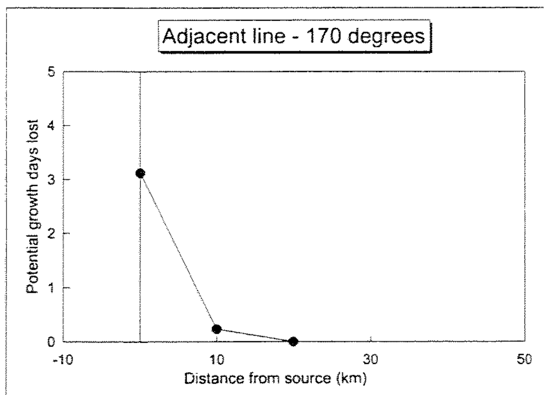
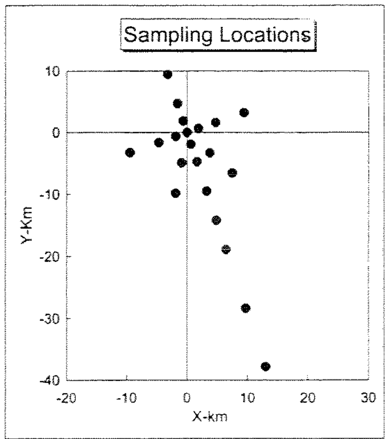
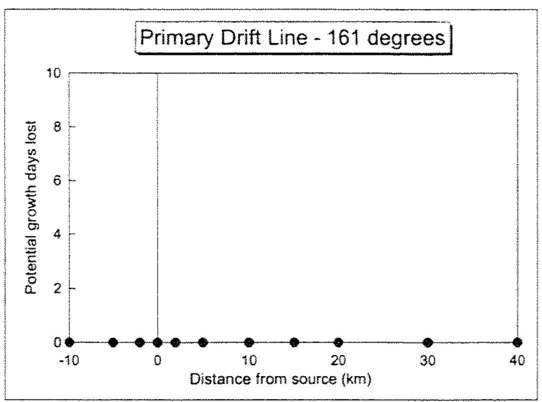


Table A2.25. Summary data and plots of potential scallop growth days lost during well Sections 1 to 4 at Node 927 (GBFS6) during summer using 3-D model currents and a settling velocity of 0.1 cm/s.

Zone: FRONTAL

Site	x km	y km	distance (km)	Growth Loss (%)	Growth Days Lost
1	0.00	0.00	0.00	0.0	0.0
2	0.65	-1.89	2.00	0.0	0.0
3	1.89	0.65	2.00	0.0	0.0
4	-0.65	1.89	2.00	0.0	0.0
5	-1.89	-0.65	2.00	0.0	0.0
6	1.63	-4.73	5.00	0.0	0.0
7	4.73	1.63	5.00	0.0	0.0
8	-1.63	4.73	5.00	0.0	0.0
9	-4.73	-1.63	5.00	0.0	0.0
10	3.26	-9.46	10.00	0.0	0.0
11	9.46	3.26	10.00	0.0	0.0
12	-3.26	9.46	10.00	0.0	0.0
13	-9.46	-3.26	10.00	0.0	0.0
14	4.88	-14.18	15.00	0.0	0.0
15	6.51	-18.91	20.00	0.0	0.0
16	9.77	-28.37	30.00	0.0	0.0
17	13.02	-37.82	40.00	0.0	0.0
18	-0.95	-4.91	5.00	0.0	0.0
19	-1.91	-9.82	10.00	0.0	0.0
20	3.77	-3.28	5.00	0.0	0.0
21	7.55	-6.56	10.00	0.0	0.0
mean for drift axis stations				0.0	0.0
mean for		10 km radius		0.0	0.0
		5 km radius		0.0	0.0
		2 km radius		0.0	0.0





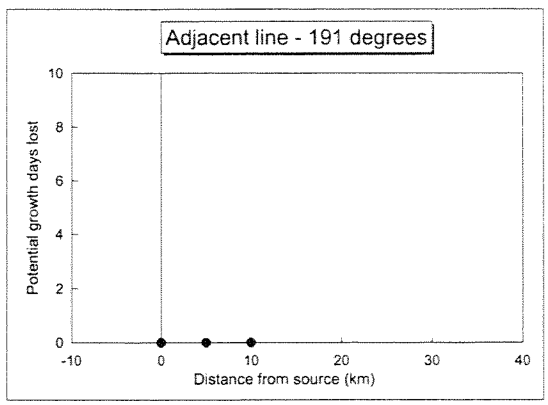
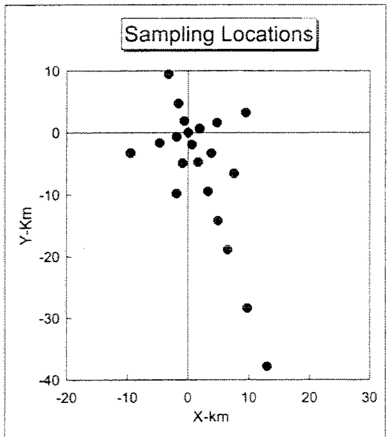
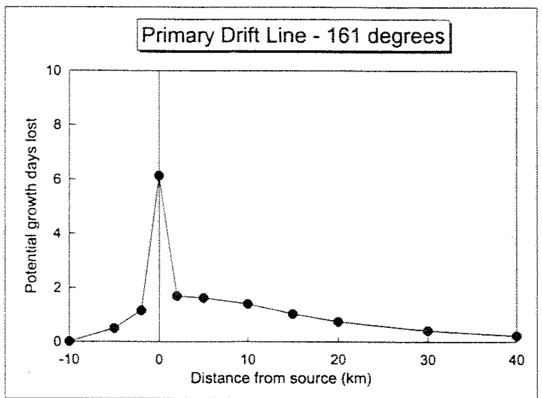


Table A2.26. Summary data and plots of potential scallop growth days lost during well Sections 1 to 4 at Node 927 (GBFS6) during summer using 3-D model currents and a settling velocity of 0.5 cm/s.

Zone: FRONTAL

Site	x km	y km	distance (km)	Growth Loss (%)	Growth Days Lost
1	0.00	0.00	0.00	9.9	6.1
2	0.65	-1.89	2.00	2.7	1.7
3	1.89	0.65	2.00	0.3	0.2
4	-0.65	1.89	2.00	1.9	1.2
5	-1.89	-0.65	2.00	1.7	1.1
6	1.63	-4.73	5.00	2.6	1.6
7	4.73	1.63	5.00	0.0	0.0
8	-1.63	4.73	5.00	0.8	0.5
9	-4.73	-1.63	5.00	0.5	0.3
10	3.26	-9.46	10.00	2.3	1.4
11	9.46	3.26	10.00	0.0	0.0
12	-3.26	9.46	10.00	0.0	0.0
13	-9.46	-3.26	10.00	0.0	0.0
14	4.88	-14.18	15.00	1.7	1.0
15	6.51	-18.91	20.00	1.2	0.7
16	9.77	-28.37	30.00	0.7	0.4
17	13.02	-37.82	40.00	0.3	0.2
18	-0.95	-4.91	5.00	2.1	1.3
19	-1.91	-9.82	10.00	0.7	0.4
20	3.77	-3.28	5.00	0.9	0.6
21	7.55	-6.56	10.00	0.1	0.0
mean for drift axis stations				2.7	1.7
mean for		10 km radius		1.7	1.1
		5 km radius		2.3	1.4
		2 km radius		3.3	2.0





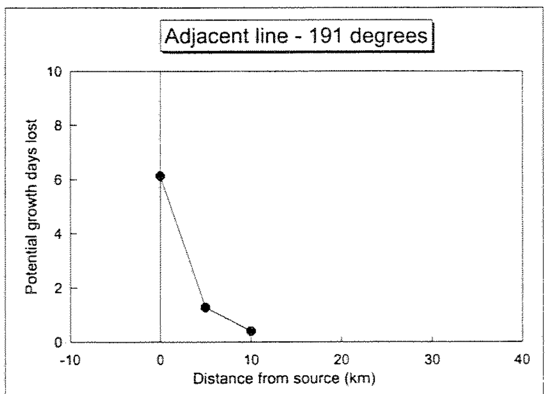
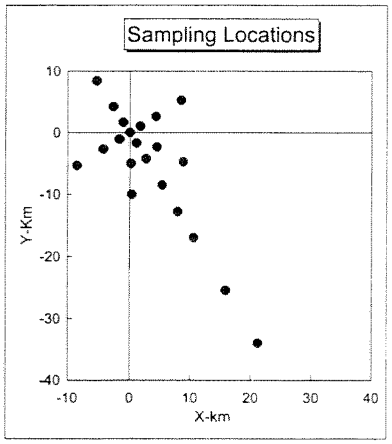
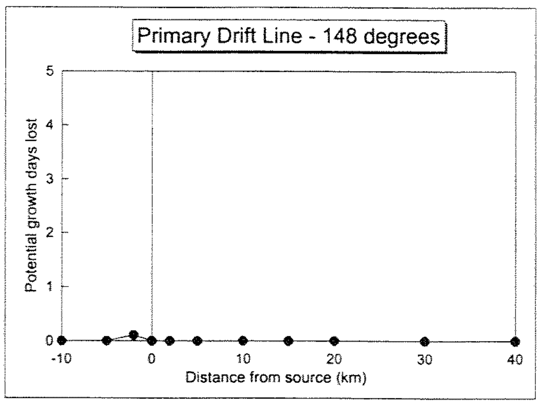


Table A2.27. Summary data and plots of potential scallop growth days lost during well Sections 1 to 4 at Node 735 (ENEP) during summer using 3-D model currents and a settling velocity of 0.1 cm/s.

Zone: FRONTAL

Site	x km	y km	distance (km)	Growth Loss (%)	Growth Days Lost
1	0.00	0.00	0.00	0.0	0.0
2	1.06	-1.70	2.00	0.0	0.0
3	1.70	1.06	2.00	0.0	0.0
4	-1.06	1.70	2.00	0.0	0.0
5	-1.70	-1.06	2.00	0.0	0.0
6	2.65	-4.24	5.00	0.0	0.0
7	4.24	2.65	5.00	0.0	0.0
8	-2.65	4.24	5.00	0.0	0.0
9	-4.24	-2.65	5.00	0.0	0.0
10	5.30	-8.48	10.00	0.0	0.0
11	8.48	5.30	10.00	0.0	0.0
12	-5.30	8.48	10.00	0.0	0.0
13	-8.48	-5.30	10.00	0.0	0.0
14	7.95	-12.72	15.00	0.0	0.0
15	10.60	-16.96	20.00	0.0	0.0
16	15.90	-25.44	30.00	0.0	0.0
17	21.20	-33.92	40.00	0.0	0.0
18	0.17	-5.00	5.00	0.0	0.0
19	0.35	-9.99	10.00	0.0	0.0
20	4.41	-2.35	5.00	0.0	0.0
21	8.83	-4.69	10.00	0.0	0.0
mean for drift axis stations				0.0	0.0
mean for		10 km radius		0.0	0.0
		5 km radius		0.0	0.0
		2 km radius		0.0	0.0





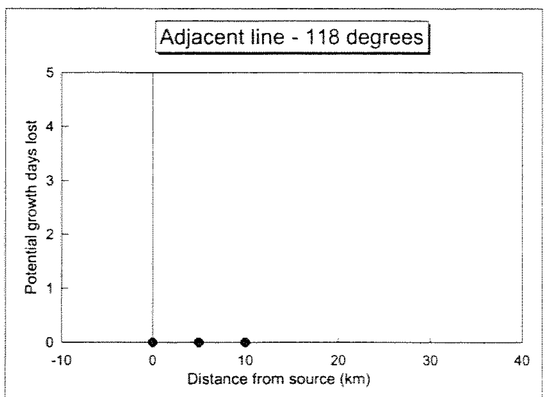
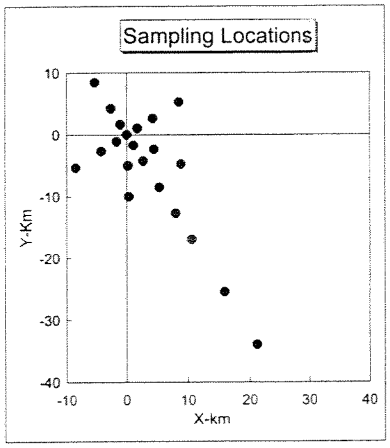
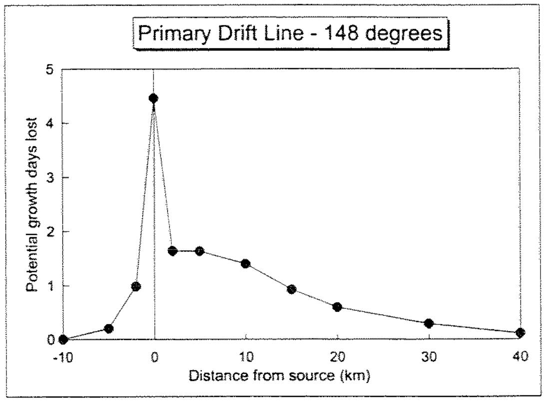


Table A2.28. Summary data and plots of potential scallop growth days lost during well Sections 1 to 4 at Nnode 735 (ENEP) during summer using 3-D model currents and a settling velocity of 0.5 cm/s.

Zone: FRONTAL

Site	x km	y km	distance (km)	Growth Loss (%)	Growth Days Lost
1	0.00	0.00	0.00	7.2	4.5
2	1.06	-1.70	2.00	2.6	1.6
3	1.70	1.06	2.00	0.3	0.2
4	-1.06	1.70	2.00	1.6	1.0
5	-1.70	-1.06	2.00	1.3	0.8
6	2.65	-4.24	5.00	2.6	1.6
7	4.24	2.65	5.00	0.0	0.0
8	-2.65	4.24	5.00	0.3	0.2
9	-4.24	-2.65	5.00	0.1	0.1
10	5.30	-8.48	10.00	2.3	1.4
11	8.48	5.30	10.00	0.0	0.0
12	-5.30	8.48	10.00	0.0	0.0
13	-8.48	-5.30	10.00	0.0	0.0
14	7.95	-12.72	15.00	1.5	0.9
15	10.60	-16.96	20.00	1.0	0.6
16	15.90	-25.44	30.00	0.5	0.3
17	21.20	-33.92	40.00	0.2	0.1
18	0.17	-5.00	5.00	1.7	1.1
19	0.35	-9.99	10.00	0.2	0.1
20	4.41	-2.35	5.00	0.8	0.5
21	8.83	-4.69	10.00	0.0	0.0
mean for drift axis stations				2.2	1.4
mean for		10 km radius		1.4	0.9
		5 km radius		1.8	1.1
		2 km radius		2.6	1.6





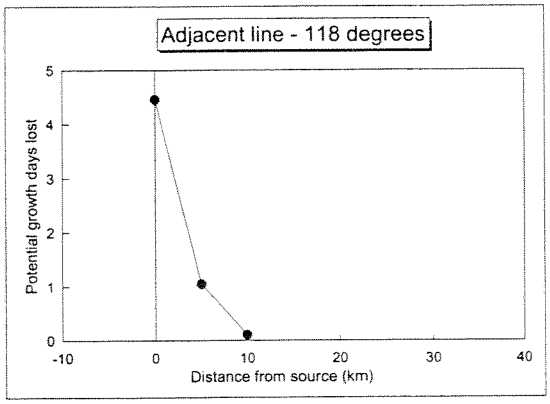
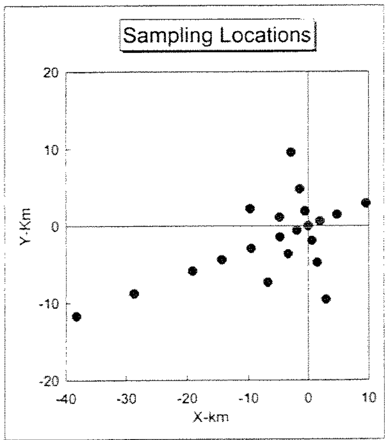
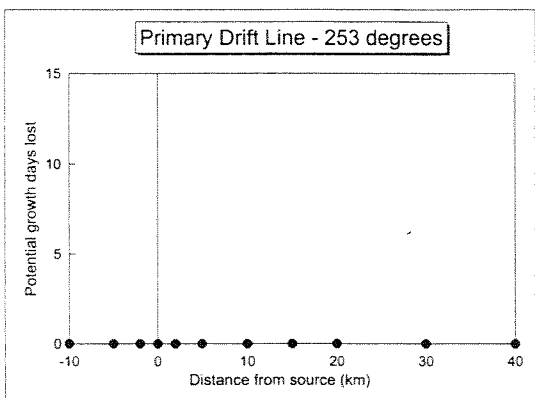


Table A2.29. Summary data and plots of potential scallop growth days lost during well Sections 1 to 4 at Node 315 (SNEP) during summer using 3-D model currents and a settling velocity of 0.1 cm/s.

Zone: FRONTAL

Site	x km	y km	distance (km)	Growth Loss (%)	Growth Days Lost
1	0.00	0.00	0.00	0.0	0.0
2	-1.91	-0.58	2.00	0.0	0.0
3	0.58	-1.91	2.00	0.0	0.0
4	1.91	0.58	2.00	0.0	0.0
5	-0.58	1.91	2.00	0.0	0.0
6	-4.78	-1.46	5.00	0.0	0.0
7	1.46	-4.78	5.00	0.0	0.0
8	4.78	1.46	5.00	0.0	0.0
9	-1.46	4.78	5.00	0.0	0.0
10	-9.56	-2.92	10.00	0.0	0.0
11	2.92	-9.56	10.00	0.0	0.0
12	9.56	2.92	10.00	0.0	0.0
13	-2.92	9.56	10.00	0.0	0.0
14	-14.34	-4.39	15.00	0.0	0.0
15	-19.13	-5.85	20.00	0.0	0.0
16	-28.69	-8.77	30.00	0.0	0.0
17	-38.25	-11.69	40.00	0.0	0.0
18	-3.41	-3.66	5.00	0.0	0.0
19	-6.82	-7.31	10.00	0.0	0.0
20	-4.87	1.12	5.00	0.0	0.0
21	-9.74	2.25	10.00	0.0	0.0
mean for drift axis stations				0.0	0.0
mean for		10 km radius		0.0	0.0
		5 km radius		0.0	0.0
		2 km radius		0.0	0.0





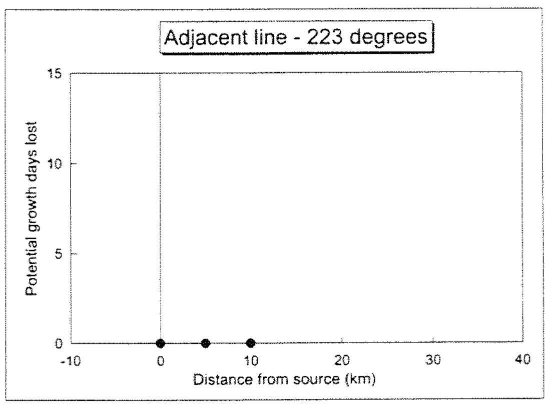
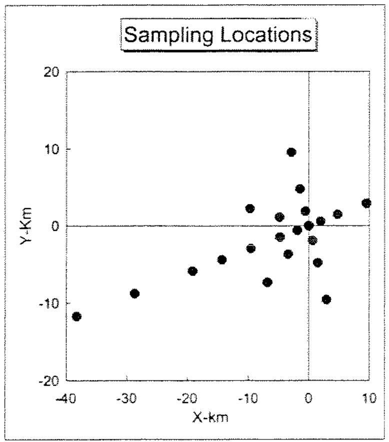
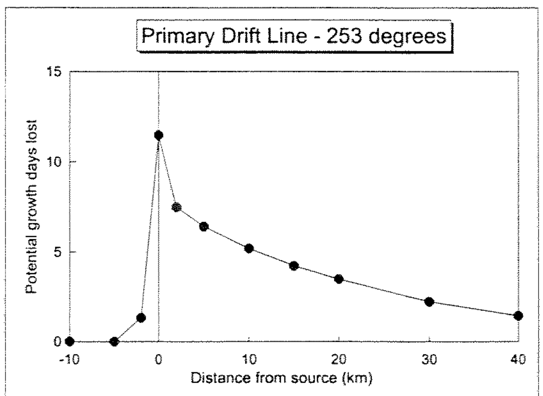


Table A2.30. Summary data and plots of potential scallop growth days lost during well Sections 1 to 4 at Node 315 (SNEP) during summer using 3-D model currents and a settling velocity of 0.5 cm/s.

Zone: FRONTAL

Site	x km	y km	distance (km)	Growth Loss (%)	Growth Days Lost
1	0.00	0.00	0.00	18.5	11.5
2	-1.91	-0.58	2.00	12.1	7.5
3	0.58	-1.91	2.00	9.3	5.8
4	1.91	0.58	2.00	2.1	1.3
5	-0.58	1.91	2.00	9.3	5.8
6	-4.78	-1.46	5.00	10.3	6.4
7	1.46	-4.78	5.00	3.5	2.2
8	4.78	1.46	5.00	0.0	0.0
9	-1.46	4.78	5.00	2.8	1.7
10	-9.56	-2.92	10.00	8.4	5.2
11	2.92	-9.56	10.00	0.0	0.0
12	9.56	2.92	10.00	0.0	0.0
13	-2.92	9.56	10.00	0.0	0.0
14	-14.34	-4.39	15.00	6.8	4.2
15	-19.13	-5.85	20.00	5.6	3.5
16	-28.69	-8.77	30.00	3.6	2.2
17	-38.25	-11.69	40.00	2.3	1.4
18	-3.41	-3.66	5.00	8.3	5.2
19	-6.82	-7.31	10.00	4.7	2.9
20	-4.87	1.12	5.00	10.5	6.5
21	-9.74	2.25	10.00	6.7	4.2
mean for drift axis stations				8.5	5.2
mean for		10 km radius		5.9	3.6
		5 km radius		7.6	4.7
		2 km radius		10.3	6.4





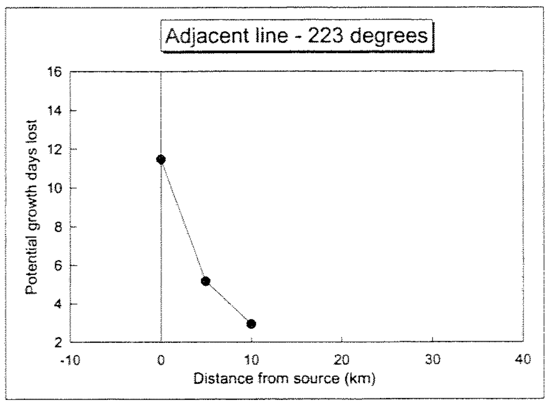
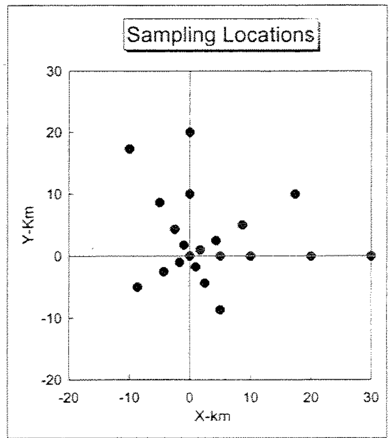
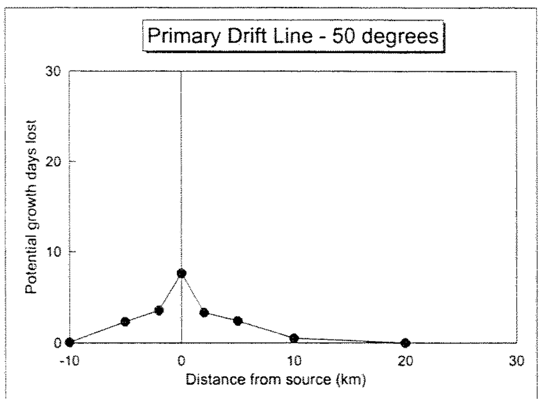


Table A2.31. Summary data and plots of potential scallop growth days lost during well Sections 1 to 4 at GBFS1 using observed currents for Days 189 to251 and a settling velocity of 0.1 cm/s.

Zone: Side of Bank

Site	x km	y km	distance (km)	Growth Loss (%)	Growth Days Lost
1	0.00	0.00	0.00	12.3	7.6
2	-1.00	1.73	2.00	8.3	5.1
3	-1.73	-1.00	2.00	5.7	3.6
4	1.00	-1.73	2.00	3.9	2.4
5	1.73	1.00	2.00	5.4	3.3
6	-2.50	4.33	5.00	7.3	4.5
7	-4.33	-2.50	5.00	3.7	2.3
8	2.50	-4.33	5.00	0.7	0.4
9	4.33	2.50	5.00	3.9	2.4
10	-5.00	8.66	10.00	2.1	1.3
11	-8.66	-5.00	10.00	0.1	0.0
12	5.00	-8.66	10.00	0.0	0.0
13	8.66	5.00	10.00	0.8	0.5
14	-10.00	17.32	20.00	0.0	0.0
15	17.32	10.00	20.00	0.0	0.0
16	5.00	0.00	5.00	1.9	1.2
17	10.00	0.00	10.00	0.4	0.2
18	20.00	0.00	20.00	0.3	0.2
19	30.00	0.00	30.00	1.1	0.7
20	0.00	10.00	10.00	0.7	0.5
21	0.00	20.00	20.00	0.0	0.0
mean for drift axis stations				4.5	2.8
mean for		10 km radius		4.2	2.6
		5 km radius		5.7	3.5
		2 km radius		7.1	4.4





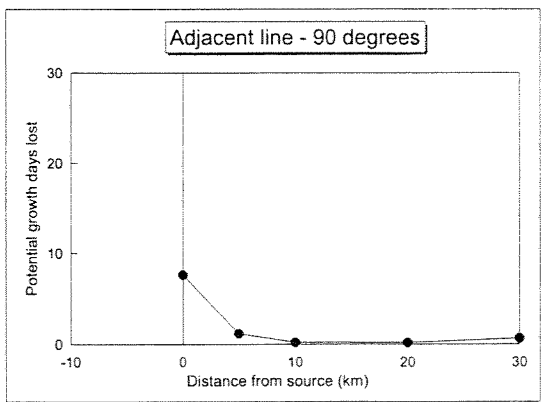
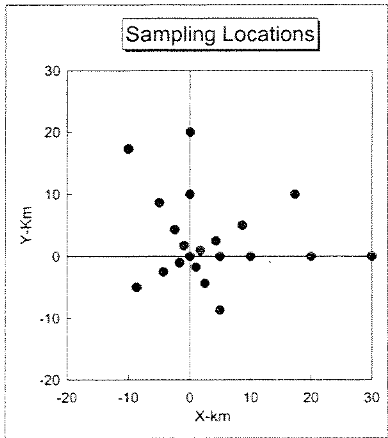
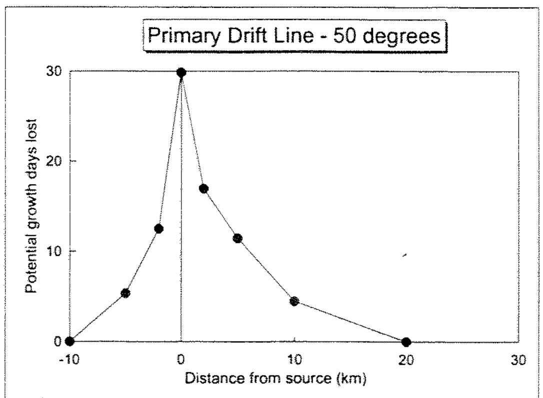


Table A2.32. Summary data and plots of potential scallop growth days lost during well Sections 1 to 4 at GBFS1 using observed currents for Days 189 to251 and a settling velocity of 0.5 cm/s.

Zone: Side of Bank

Site	x km	y km	distance (km)	Growth Loss (%)	Growth Days Lost
1	0.00	0.00	0.00	48.1	29.8
2	-1.00	1.73	2.00	34.6	21.5
3	-1.73	-1.00	2.00	20.2	12.5
4	1.00	-1.73	2.00	14.3	8.9
5	1.73	1.00	2.00	27.3	17.0
6	-2.50	4.33	5.00	32.3	20.0
7	-4.33	-2.50	5.00	8.6	5.4
8	2.50	-4.33	5.00	1.0	0.6
9	4.33	2.50	5.00	18.5	11.4
10	-5.00	8.66	10.00	27.3	16.9
11	-8.66	-5.00	10.00	0.0	0.0
12	5.00	-8.66	10.00	0.0	0.0
13	8.66	5.00	10.00	7.2	4.5
14	-10.00	17.32	20.00	12.8	8.0
15	17.32	10.00	20.00	15.5	9.6
16	5.00	0.00	5.00	8.9	5.5
17	10.00	0.00	10.00	0.9	0.6
18	20.00	0.00	20.00	4.2	2.6
19	30.00	0.00	30.00	8.2	5.1
20	0.00	10.00	10.00	26.2	16.2
21	0.00	20.00	20.00	3.7	2.3
mean for drift axis stations				20.2	12.5
mean for		10 km radius		18.4	11.4
		5 km radius		22.8	14.1
		2 km radius		28.9	17.9





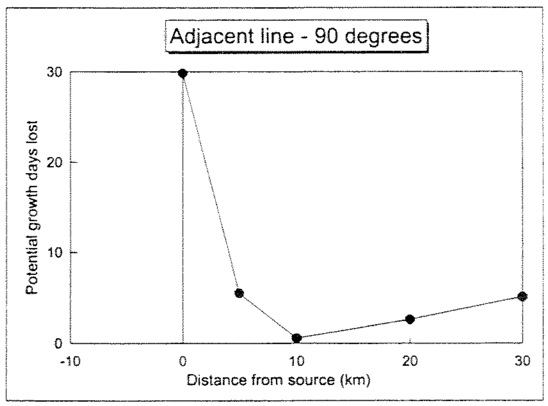
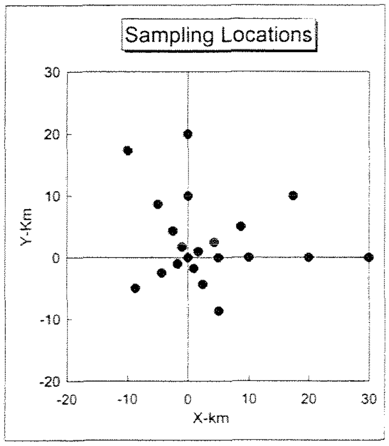
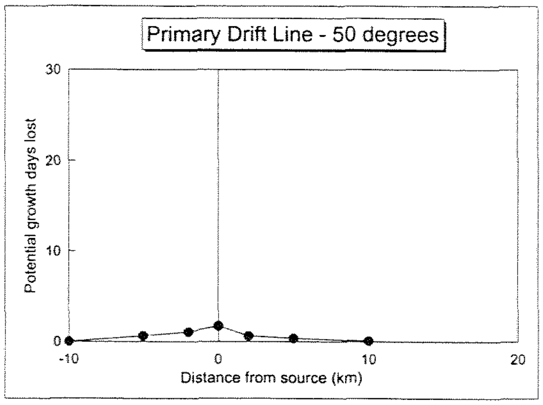


Table A2.33. Summary data and plots of potential scallop growth days lost during well Section 5 at GBFS1 using observed currents for Days 189 to239 and a settling velocity of 0.1 cm/s.

Zone: Side of Bank

Site	x km	y km	distance (km)	Growth Loss (%)	Growth Days Lost
1	0.00	0.00	0.00	3.5	1.7
2	-1.00	1.73	2.00	2.2	1.1
3	-1.73	-1.00	2.00	2.1	1.1
4	1.00	-1.73	2.00	1.3	0.6
5	1.73	1.00	2.00	1.2	0.6
6	-2.50	4.33	5.00	2.1	1.1
7	-4.33	-2.50	5.00	1.3	0.6
8	2.50	-4.33	5.00	0.1	0.0
9	4.33	2.50	5.00	0.7	0.4
10	-5.00	8.66	10.00	0.4	0.2
11	-8.66	-5.00	10.00	0.0	0.0
12	5.00	-8.66	10.00	0.0	0.0
13	8.66	5.00	10.00	0.2	0.1
14	-10.00	17.32	20.00	0.0	0.0
15	17.32	10.00	20.00	0.0	0.0
16	5.00	0.00	5.00	0.2	0.1
17	10.00	0.00	10.00	0.0	0.0
18	20.00	0.00	20.00	0.0	0.0
19	30.00	0.00	30.00	0.1	0.1
20	0.00	10.00	10.00	0.0	0.0
21	0.00	20.00	20.00	0.0	0.0
mean for drift axis stations				1.4	0.7
mean for		10 km radius		1.2	0.6
		5 km radius		1.6	0.8
		2 km radius		2.1	1.0





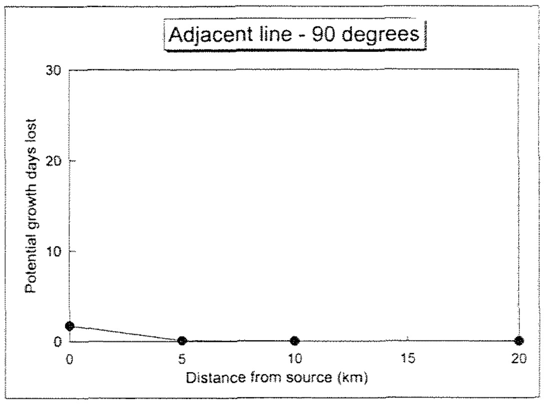
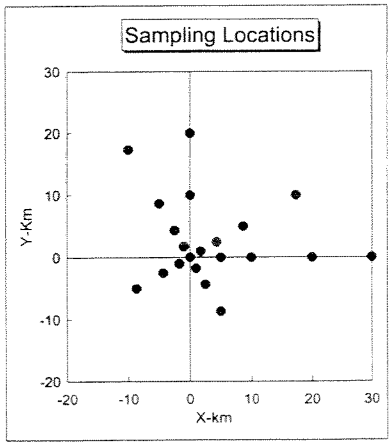
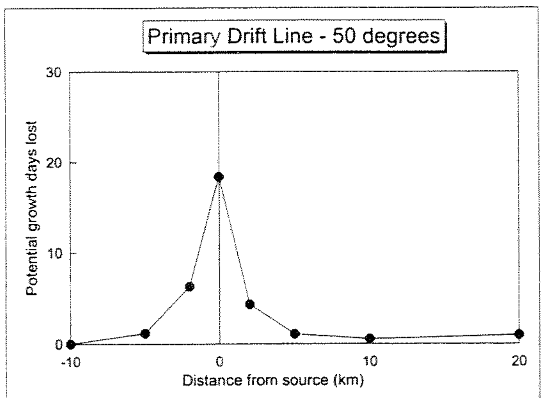


Table A2.34. Summary data and plots of potential scallop growth days lost during well Section 5 at GBFS1 using observed currents for Days 189 to239 and a settling velocity of 0.5 cm/s.

Zone: Side of Bank

Site	x km	y km	distance (km)	Growth Loss (%)	Growth Days Lost
1	0.00	0.00	0.00	36.7	18.4
2	-1.00	1.73	2.00	20.2	10.1
3	-1.73	-1.00	2.00	12.6	6.3
4	1.00	-1.73	2.00	6.6	3.3
5	1.73	1.00	2.00	8.6	4.3
6	-2.50	4.33	5.00	12.5	6.3
7	-4.33	-2.50	5.00	2.3	1.2
8	2.50	-4.33	5.00	0.1	0.1
9	4.33	2.50	5.00	2.1	1.1
10	-5.00	8.66	10.00	12.9	6.5
11	-8.66	-5.00	10.00	0.0	0.0
12	5.00	-8.66	10.00	0.0	0.0
13	8.66	5.00	10.00	1.1	0.5
14	-10.00	17.32	20.00	0.3	0.1
15	17.32	10.00	20.00	1.9	1.0
16	5.00	0.00	5.00	0.4	0.2
17	10.00	0.00	10.00	0.0	0.0
18	20.00	0.00	20.00	0.1	0.1
19	30.00	0.00	30.00	1.8	0.9
20	0.00	10.00	10.00	10.6	5.3
21	0.00	20.00	20.00	0.1	0.1
mean for drift axis stations				10.1	5.0
mean for		10 km radius		8.9	4.5
		5 km radius		11.3	5.7
		2 km radius		17.0	8.5





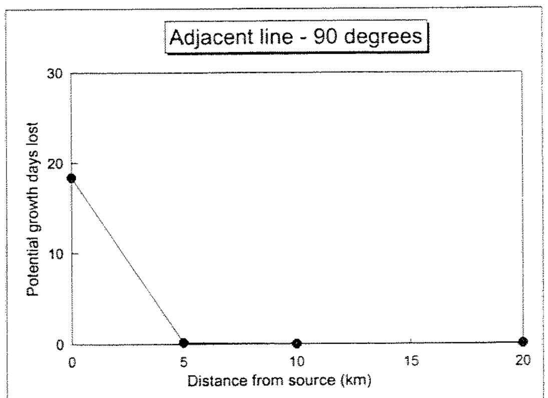
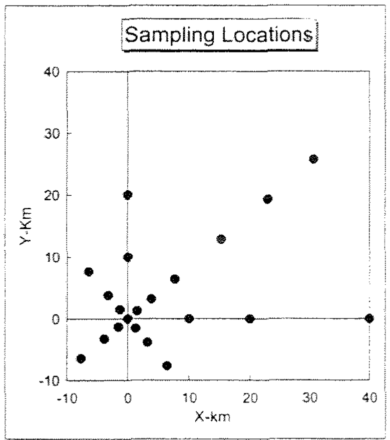
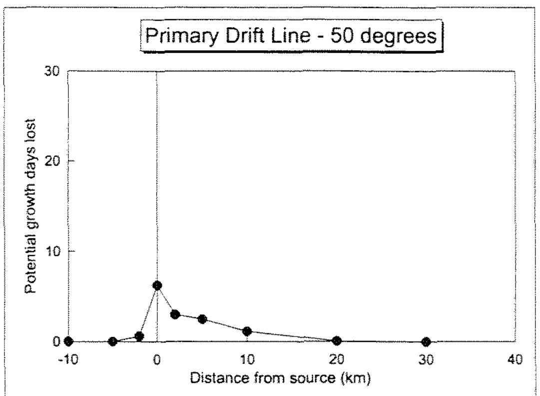


Table A2.35. Summary data and plots of potential scallop growth days lost during well Sections 1 to 4 at GBFS1 using observed currents for Days 217 to 279 and a settling velocity of 0.1 cm/s.

Zone: Side of Bank

Site	x km	y km	distance (km)	Growth Loss (%)	Growth Days Lost
1	0.00	0.00	0.00	10.1	6.3
2	1.53	1.29	2.00	4.8	3.0
3	-1.29	1.53	2.00	4.1	2.5
4	-1.53	-1.29	2.00	1.0	0.6
5	1.29	-1.53	2.00	4.1	2.5
6	3.83	3.21	5.00	4.0	2.5
7	-3.21	3.83	5.00	1.4	0.9
8	-3.83	-3.21	5.00	0.0	0.0
9	3.21	-3.83	5.00	1.2	0.8
10	7.66	6.43	10.00	1.8	1.1
11	-6.43	7.66	10.00	0.0	0.0
12	-7.66	-6.43	10.00	0.0	0.0
13	6.43	-7.66	10.00	0.0	0.0
14	15.32	12.86	20.00	0.1	0.1
15	22.98	19.28	30.00	0.0	0.0
16	30.64	25.71	40.00	0.0	0.0
17	10.00	0.00	10.00	2.1	1.3
18	20.00	0.00	20.00	1.3	0.8
19	40.00	0.00	40.00	0.3	0.2
20	0.00	10.00	10.00	0.2	0.1
21	0.00	20.00	20.00	0.0	0.0
mean for drift axis stations				3.0	1.8
mean for	10 km radius			2.5	1.6
	5 km radius			3.4	2.1
	2 km radius			4.8	3.0





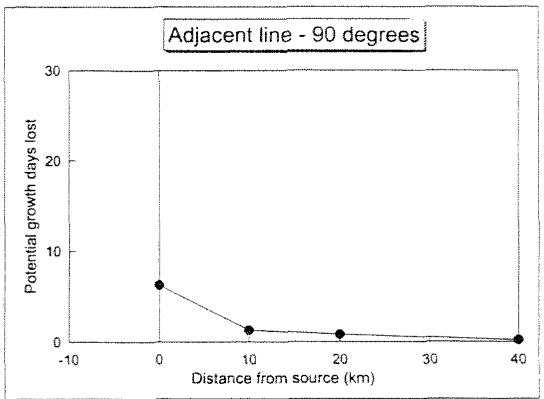
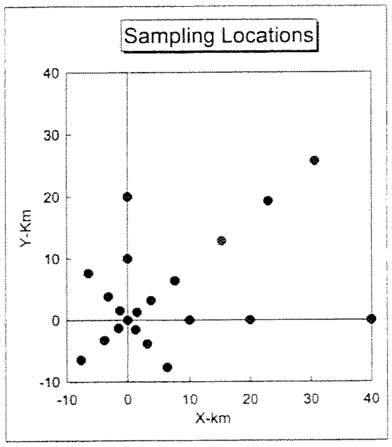
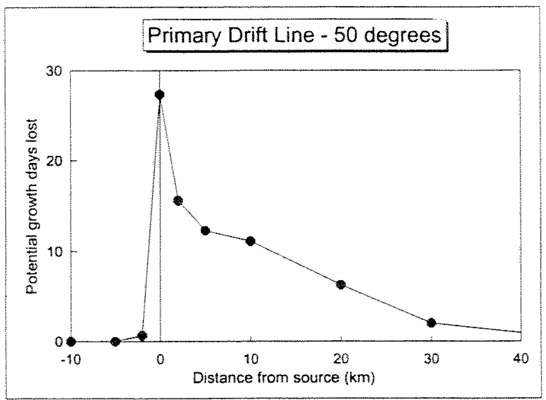


Table A2.36. Summary data and plots of potential scallop growth days lost during well Sections 1 to 4 at GBFS1 using observed currents for Days 217 to 279 and a settling velocity of 0.5 cm/s.

Zone: Side of Bank

Site	x km	y km	distance (km)	Growth Loss (%)	Growth Days Lost
1	0.00	0.00	0.00	44.1	27.3
2	1.53	1.29	2.00	25.1	15.6
3	-1.29	1.53	2.00	21.4	13.3
4	-1.53	-1.29	2.00	1.1	0.7
5	1.29	-1.53	2.00	14.5	9.0
6	3.83	3.21	5.00	19.8	12.3
7	-3.21	3.83	5.00	10.2	6.3
8	-3.83	-3.21	5.00	0.0	0.0
9	3.21	-3.83	5.00	2.4	1.5
10	7.66	6.43	10.00	17.9	11.1
11	-6.43	7.66	10.00	4.1	2.5
12	-7.66	-6.43	10.00	0.0	0.0
13	6.43	-7.66	10.00	0.0	0.0
14	15.32	12.86	20.00	10.1	6.3
15	22.98	19.28	30.00	3.3	2.0
16	30.64	25.71	40.00	1.5	0.9
17	10.00	0.00	10.00	4.0	2.5
18	20.00	0.00	20.00	0.0	0.0
19	40.00	0.00	40.00	0.0	0.0
20	0.00	10.00	10.00	13.0	8.0
21	0.00	20.00	20.00	4.7	2.9
mean for drift axis stations				17.4	10.8
mean for		10 km radius		12.4	7.7
		5 km radius		15.4	9.5
		2 km radius		21.2	13.2





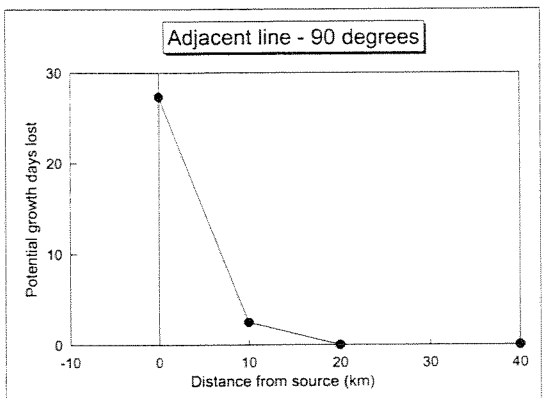
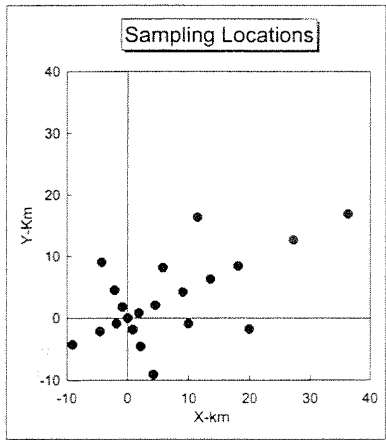
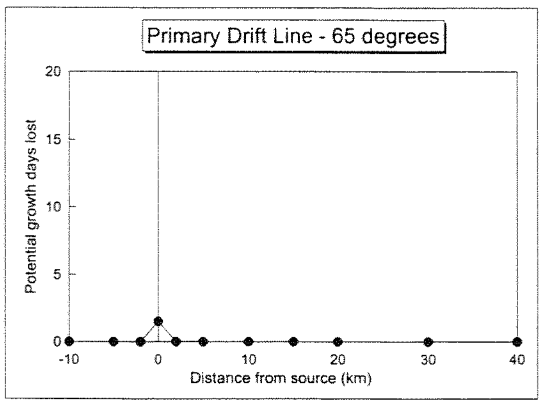


Table A2.37. Summary data and plots of potential scallop growth days lost during well Sections 1 to 4 at Node 2029 (GBFS1) during summer using 3-D model currents and a settling velocity of 0.1 cm/s.

Zone: Side of Bank

Site	x km	y km	distance (km)	Growth Loss (%)	Growth Days Lost
1	0.00	0.00	0.00	2.4	1.5
2	1.81	0.85	2.00	0.0	0.0
3	-0.85	1.81	2.00	0.0	0.0
4	-1.81	-0.85	2.00	0.0	0.0
5	0.85	-1.81	2.00	0.1	0.0
6	4.53	2.11	5.00	0.0	0.0
7	-2.11	4.53	5.00	0.0	0.0
8	-4.53	-2.11	5.00	0.0	0.0
9	2.11	-4.53	5.00	0.0	0.0
10	9.06	4.23	10.00	0.0	0.0
11	-4.23	9.06	10.00	0.0	0.0
12	-9.06	-4.23	10.00	0.0	0.0
13	4.23	-9.06	10.00	0.0	0.0
14	13.59	6.34	15.00	0.0	0.0
15	18.13	8.45	20.00	0.0	0.0
16	27.19	12.68	30.00	0.0	0.0
17	36.25	16.90	40.00	0.0	0.0
18	5.74	8.19	10.00	0.0	0.0
19	11.47	16.38	20.00	0.0	0.0
20	9.96	-0.87	10.00	0.0	0.0
21	19.92	-1.74	20.00	0.0	0.0
mean for drift axis stations				0.3	0.2
mean for		10 km radius		0.2	0.1
		5 km radius		0.3	0.2
		2 km radius		0.5	0.3





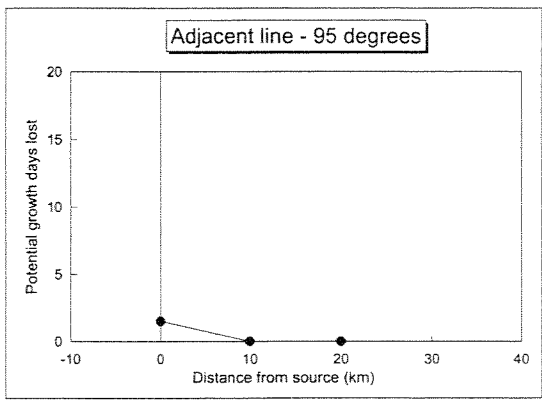
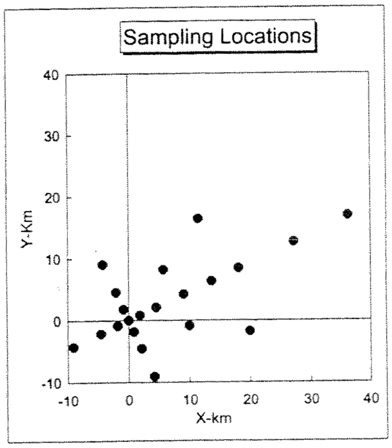
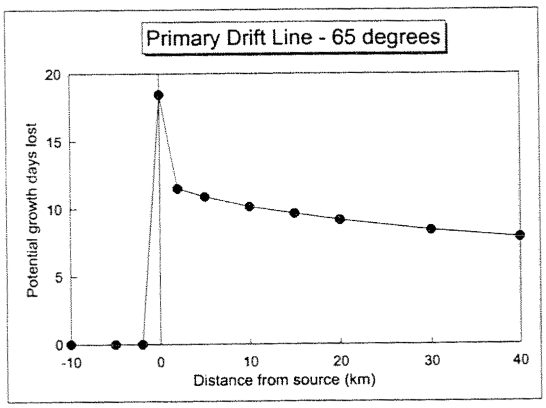


Table A2.38. Summary data and plots of potential scallop growth days lost during well Sections 1 to 4 at Node 2029 (GBFS1) during summer using 3-D model currents and a settling velocity of 0.5 cm/s.

Zone: Side of Bank

Site	x km	y km	distance (km)	Growth Loss (%)	Growth Days Lost
1	0.00	0.00	0.00	29.8	18.5
2	1.81	0.85	2.00	18.6	11.5
3	-0.85	1.81	2.00	7.5	4.6
4	-1.81	-0.85	2.00	0.0	0.0
5	0.85	-1.81	2.00	8.3	5.2
6	4.53	2.11	5.00	17.6	10.9
7	-2.11	4.53	5.00	1.8	1.1
8	-4.53	-2.11	5.00	0.0	0.0
9	2.11	-4.53	5.00	2.0	1.3
10	9.06	4.23	10.00	16.4	10.1
11	-4.23	9.06	10.00	0.0	0.0
12	-9.06	-4.23	10.00	0.0	0.0
13	4.23	-9.06	10.00	0.0	0.0
14	13.59	6.34	15.00	15.6	9.6
15	18.13	8.45	20.00	14.8	9.2
16	27.19	12.68	30.00	13.6	8.4
17	36.25	16.90	40.00	12.7	7.9
18	5.74	8.19	10.00	11.3	7.0
19	11.47	16.38	20.00	3.7	2.3
20	9.96	-0.87	10.00	10.0	6.2
21	19.92	-1.74	20.00	2.9	1.8
mean for drift axis stations				17.4	10.8
mean for		10 km radius		7.8	4.9
		5 km radius		9.5	5.9
		2 km radius		12.8	8.0





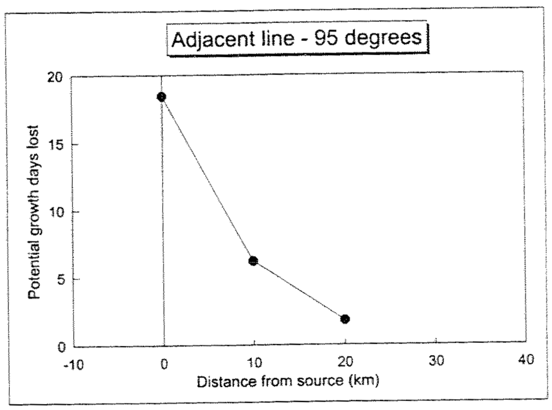
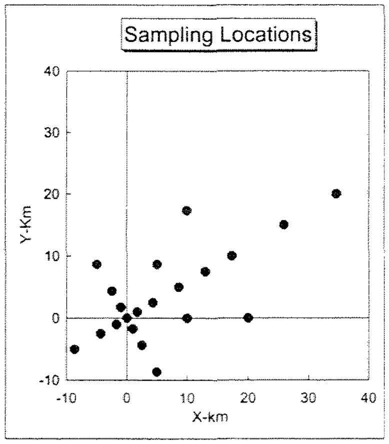
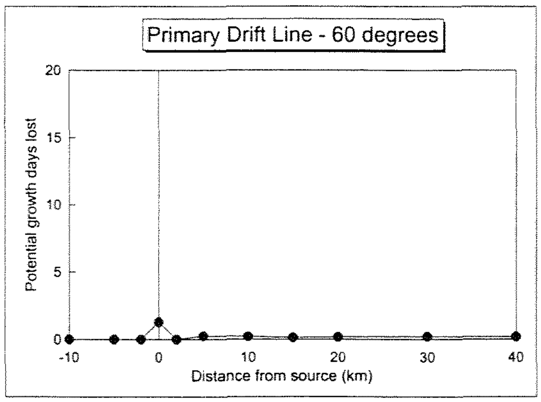


Table A2.39. Summary data and plots of potential scallop growth days lost during well Sections 1 to 4 at Node 2029 (GBFS1) during winter using 3-D model currents and a settling velocity of 1 cm/s.

Zone: Side of Bank

Site	x km	y km	distance (km)	Growth Loss (%)	Growth Days Lost
1	0.00	0.00	0.00	2.1	1.3
2	1.73	1.00	2.00	0.0	0.0
3	-1.00	1.73	2.00	0.0	0.0
4	-1.73	-1.00	2.00	0.0	0.0
5	1.00	-1.73	2.00	0.6	0.4
6	4.33	2.50	5.00	0.4	0.3
7	-2.50	4.33	5.00	0.0	0.0
8	-4.33	-2.50	5.00	0.0	0.0
9	2.50	-4.33	5.00	0.3	0.2
10	8.66	5.00	10.00	0.3	0.2
11	-5.00	8.66	10.00	0.0	0.0
12	-8.66	-5.00	10.00	0.0	0.0
13	5.00	-8.66	10.00	0.0	0.0
14	12.99	7.50	15.00	0.2	0.1
15	17.32	10.00	20.00	0.3	0.2
16	25.98	15.00	30.00	0.3	0.2
17	34.64	20.00	40.00	0.3	0.2
18	10.00	0.00	10.00	0.4	0.2
19	20.00	0.00	20.00	0.0	0.0
20	5.00	8.66	10.00	0.0	0.0
21	10.00	17.32	20.00	0.0	0.0
mean for drift axis stations				0.5	0.3
mean for		10 km radius		0.3	0.2
		5 km radius		0.4	0.2
		2 km radius		0.5	0.3





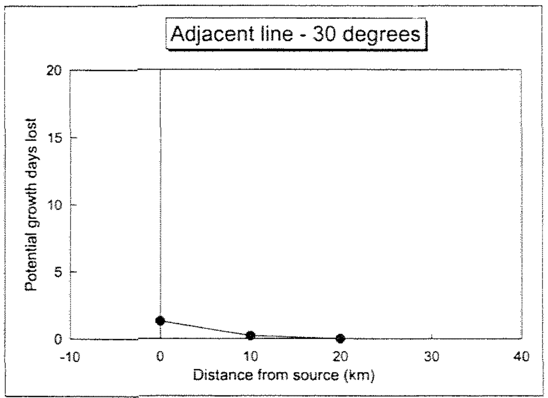
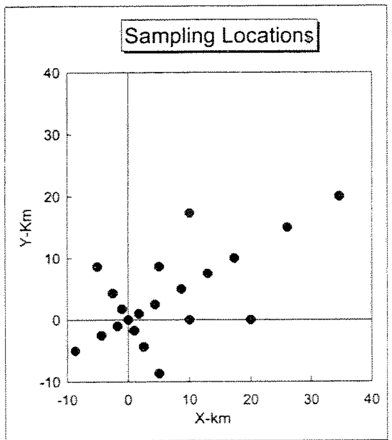
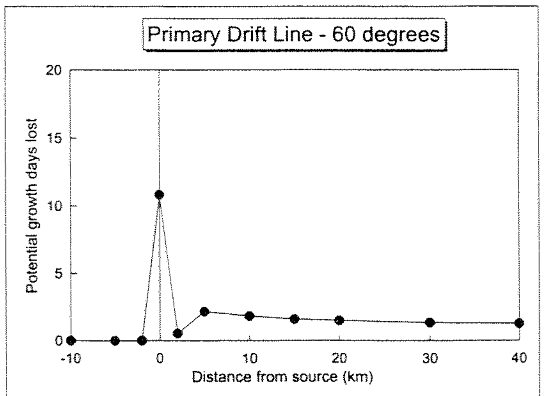


Table A2.40. Summary data and plots of potential scallop growth days lost during well Sections 1 to 4 at Node 2029 (GBFS1) during winter using 3-D model currents and a settling velocity of 0.5 cm/s.

Zone: Side of Bank

Site	x km	y km	distance (km)	Growth Loss (%)	Growth Days Lost
1	0.00	0.00	0.00	17.5	10.8
2	1.73	1.00	2.00	0.9	0.5
3	-1.00	1.73	2.00	1.4	0.9
4	-1.73	-1.00	2.00	0.0	0.0
5	1.00	-1.73	2.00	3.6	2.2
6	4.33	2.50	5.00	3.5	2.2
7	-2.50	4.33	5.00	0.1	0.0
8	-4.33	-2.50	5.00	0.0	0.0
9	2.50	-4.33	5.00	1.4	0.9
10	8.66	5.00	10.00	3.0	1.8
11	-5.00	8.66	10.00	0.0	0.0
12	-8.66	-5.00	10.00	0.0	0.0
13	5.00	-8.66	10.00	0.0	0.0
14	12.99	7.50	15.00	2.6	1.6
15	17.32	10.00	20.00	2.4	1.5
16	25.98	15.00	30.00	2.2	1.3
17	34.64	20.00	40.00	2.0	1.3
18	10.00	0.00	10.00	2.0	1.3
19	20.00	0.00	20.00	0.0	0.0
20	5.00	8.66	10.00	0.1	0.1
21	10.00	17.32	20.00	0.0	0.0
mean for drift axis stations				4.2	2.6
mean for		10 km radius		2.4	1.5
		5 km radius		3.1	1.9
		2 km radius		4.7	2.9





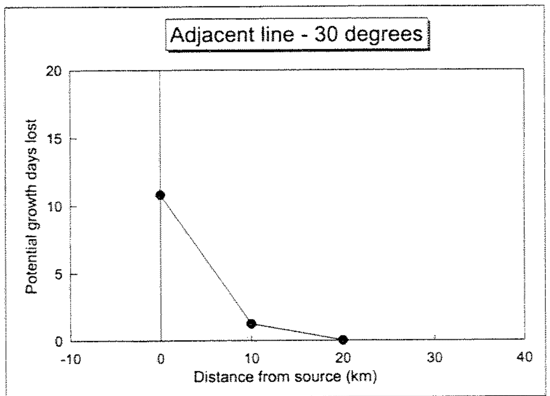
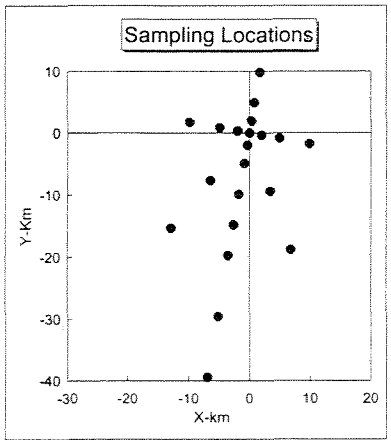
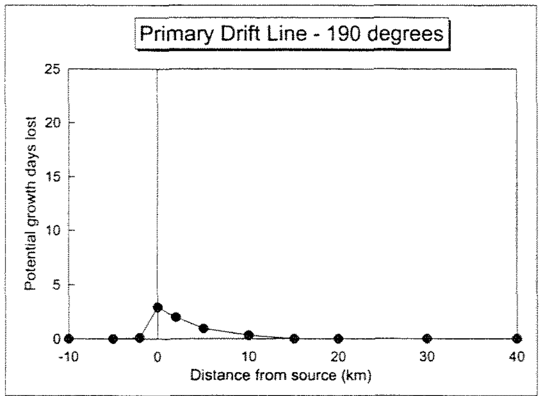


Table A2.41. Summary data and plots of potential scallop growth days lost during well Sections 1 to 4 at Node 1537 (Growler) during summer using 3-D model currents and a settling velocity of 0.1 cm/s.

Zone: Side of Bank

Site	x km	y km	distance (km)	Growth Loss (%)	Growth Days Lost
1	0.00	0.00	0.00	4.8	3.0
2	-0.35	-1.97	2.00	3.2	2.0
3	1.97	-0.35	2.00	0.0	0.0
4	0.35	1.97	2.00	0.2	0.1
5	-1.97	0.35	2.00	1.8	1.1
6	-0.87	-4.92	5.00	1.5	0.9
7	4.92	-0.87	5.00	0.0	0.0
8	0.87	4.92	5.00	0.0	0.0
9	-4.92	0.87	5.00	0.0	0.0
10	-1.74	-9.85	10.00	0.5	0.3
11	9.85	-1.74	10.00	0.0	0.0
12	1.74	9.85	10.00	0.0	0.0
13	-9.85	1.74	10.00	0.0	0.0
14	-2.60	-14.77	15.00	0.0	0.0
15	-3.47	-19.70	20.00	0.0	0.0
16	-5.21	-29.54	30.00	0.0	0.0
17	-6.95	-39.39	40.00	0.0	0.0
18	3.42	-9.40	10.00	1.6	1.0
19	6.84	-18.79	20.00	0.7	0.4
20	-6.43	-7.66	10.00	0.0	0.0
21	-12.86	-15.32	20.00	0.0	0.0
mean for drift axis stations				1.3	0.8
mean for		10 km radius		0.9	0.6
		5 km radius		1.3	0.8
		2 km radius		2.0	1.2





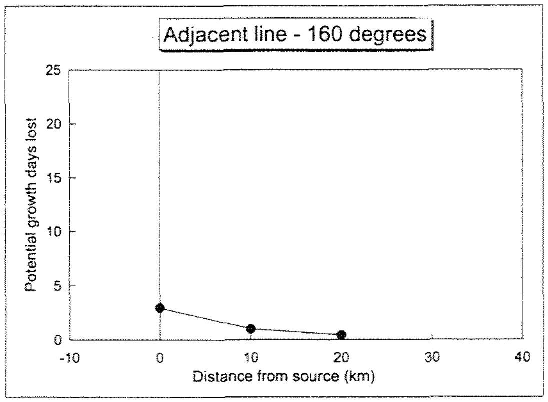
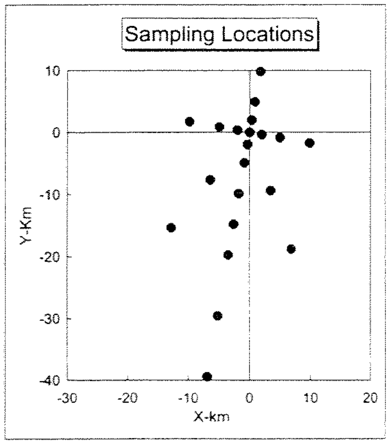
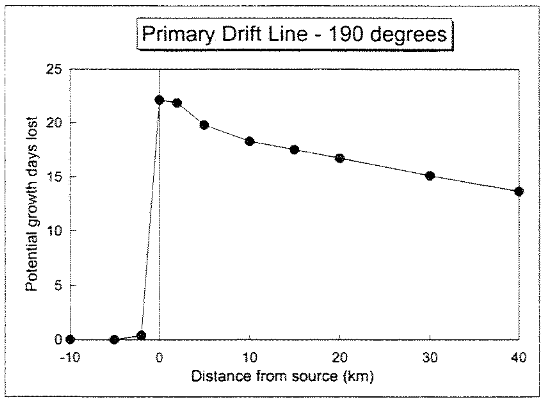


Table A2.42. Summary data and plots of potential scallop growth days lost during well Sections 1 to 4 at Node 1537 (Growler) during summer using 3-D model currents and a settling velocity of 0.5 cm/s.

Zone: Side of Bank

Site	x km	y km	distance (km)	Growth Loss (%)	Growth Days Lost
1	0.00	0.00	0.00	35.7	22.1
2	-0.35	-1.97	2.00	35.3	21.9
3	1.97	-0.35	2.00	0.0	0.0
4	0.35	1.97	2.00	0.6	0.4
5	-1.97	0.35	2.00	29.8	18.5
6	-0.87	-4.92	5.00	32.0	19.8
7	4.92	-0.87	5.00	0.0	0.0
8	0.87	4.92	5.00	0.0	0.0
9	-4.92	0.87	5.00	20.4	12.6
10	-1.74	-9.85	10.00	29.5	18.3
11	9.85	-1.74	10.00	0.0	0.0
12	1.74	9.85	10.00	0.0	0.0
13	-9.85	1.74	10.00	5.5	3.4
14	-2.60	-14.77	15.00	28.3	17.5
15	-3.47	-19.70	20.00	27.0	16.7
16	-5.21	-29.54	30.00	24.4	15.1
17	-6.95	-39.39	40.00	22.0	13.6
18	3.42	-9.40	10.00	12.1	7.5
19	6.84	-18.79	20.00	0.4	0.2
20	-6.43	-7.66	10.00	25.6	15.9
21	-12.86	-15.32	20.00	17.2	10.7
mean for drift axis stations				29.3	18.1
mean for		10 km radius		14.5	9.0
		5 km radius		17.1	10.6
		2 km radius		20.3	12.6





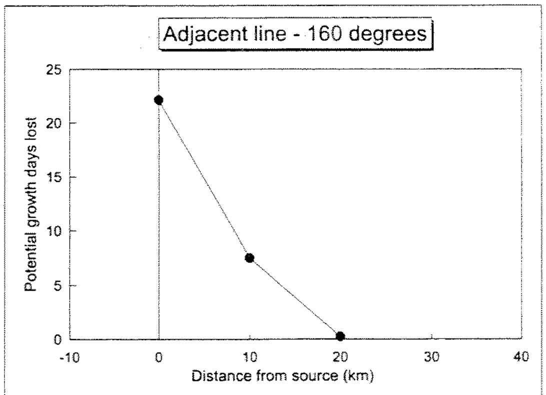
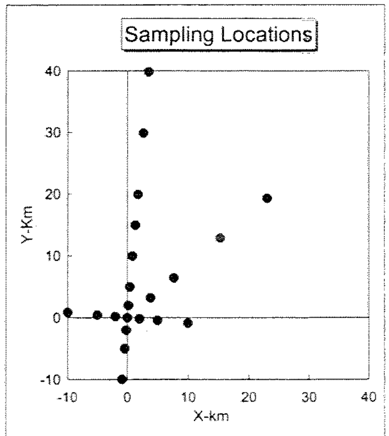
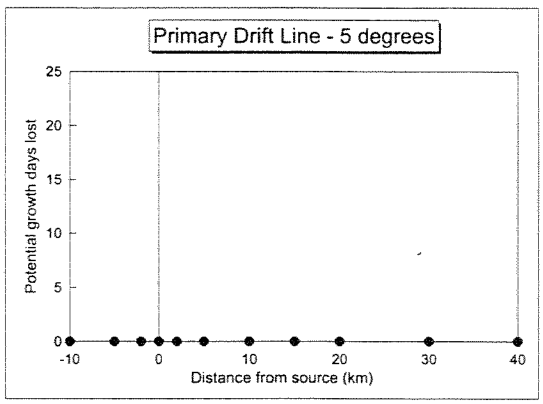


Table A2.43. Summary data and plots of potential scallop growth days lost during well Sections 1 to 4 at Node 1081 (Hunky Doryr) during summer using 3-D model currents and a settling velocity of .01 cm/s.

Zone: Side of Bank

Site	x km	y km	distance (km)	Growth Loss (%)	Growth Days Lost
1	0.00	0.00	0.00	0.0	0.0
2	0.17	1.99	2.00	0.0	0.0
3	-1.99	0.17	2.00	0.0	0.0
4	-0.17	-1.99	2.00	0.0	0.0
5	1.99	-0.17	2.00	0.0	0.0
6	0.44	4.98	5.00	0.0	0.0
7	-4.98	0.44	5.00	0.0	0.0
8	-0.44	-4.98	5.00	0.0	0.0
9	4.98	-0.44	5.00	0.0	0.0
10	0.87	9.96	10.00	0.0	0.0
11	-9.96	0.87	10.00	0.0	0.0
12	-0.87	-9.96	10.00	0.0	0.0
13	9.96	-0.87	10.00	0.0	0.0
14	1.31	14.94	15.00	0.0	0.0
15	1.74	19.92	20.00	0.0	0.0
16	2.61	29.89	30.00	0.0	0.0
17	3.49	39.85	40.00	0.0	0.0
18	3.83	3.21	5.00	0.0	0.0
19	7.66	6.43	10.00	0.0	0.0
20	15.32	12.86	20.00	0.0	0.0
21	22.98	19.28	30.00	0.0	0.0
mean for drift axis stations				0.0	0.0
mean for		10 km radius		0.0	0.0
		5 km radius		0.0	0.0
		2 km radius		0.0	0.0





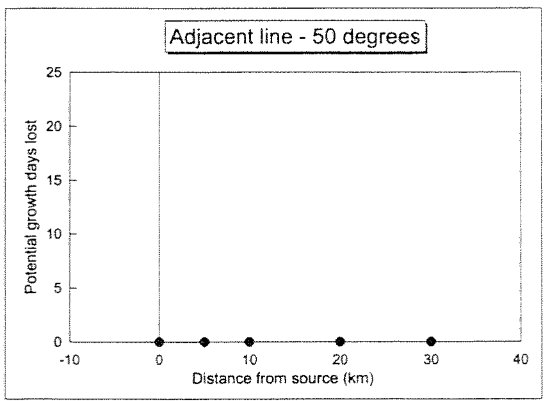


Table A2.44. Summary data and plots of potential scallop growth days lost during well Sections 1 to 4 at Node 1081 (Hunky Doryr) during summer using 3-D model currents and a settling velocity of 0.5 cm/s.

Zone: Side of Bank

Site	x km	y km	distance (km)	Growth Loss (%)	Growth Days Lost
1	0.00	0.00	0.00	29.8	18.5
2	0.17	1.99	2.00	18.6	11.5
3	-1.99	0.17	2.00	7.5	4.6
4	-0.17	-1.99	2.00	0.0	0.0
5	1.99	-0.17	2.00	8.3	5.2
6	0.44	4.98	5.00	17.6	10.9
7	-4.98	0.44	5.00	1.8	1.1
8	-0.44	-4.98	5.00	0.0	0.0
9	4.98	-0.44	5.00	2.0	1.3
10	0.87	9.96	10.00	16.4	10.1
11	-9.96	0.87	10.00	0.0	0.0
12	-0.87	-9.96	10.00	0.0	0.0
13	9.96	-0.87	10.00	0.0	0.0
14	1.31	14.94	15.00	15.6	9.6
15	1.74	19.92	20.00	14.8	9.2
16	2.61	29.89	30.00	13.6	8.4
17	3.49	39.85	40.00	12.7	7.9
18	3.83	3.21	5.00	11.3	7.0
19	7.66	6.43	10.00	3.7	2.3
20	15.32	12.86	20.00	10.0	6.2
21	22.98	19.28	30.00	2.9	1.8
mean for drift axis stations				17.4	10.8
mean for		10 km radius		7.8	4.9
		5 km radius		9.5	5.9
		2 km radius		12.8	8.0