Remote-Sensing Applications to Fisheries Management
Workshop with scientists, policy-makers and stakeholders

Fairmont Royal York, Toronto
5 and 6 January 2011

1. Summary

The first FARO national workshop with policy-makers was held on January 5-6, 2010 at the Fairmount Royal York, Toronto, Ontario. A total of 18 people, including scientific experts in Fisheries and Earth observations, policy-makers and representatives from the Canadian Space Agency and the fishing industry attended the workshop. The participants presented over a dozen lectures on the field of remote sensing, its application to the management of sustainable fisheries and aquaculture and the context within which remote sensing could be applied by the structure of the Department of Fisheries and Oceans (DFO). Examples of issues addressed by the participants include:

- *Improvement of fisheries operation:* The successful initiatives of the Indian government to identify Potential Fishing Zones from remotely-sensed images, and the communication of the information to the local fishermen were presented by S. Sathyendranath (Dalhousie University, Halifax).
- *Assessment of fish stock health, growth and recruitment:* Earth observation has proved useful in the assessment of Shrimp, Cod and Haddock survival and recruitment in the Northwest Atlantic (presented by K. Trzcinski and T. Platt, DFO, Dartmouth).
- *Ecosystem dynamics:* Fish catch in various ecosystems was related to various top-down and bottom-up factors such as chlorophyll and primary production, as estimated from remotely-sensed data and modelling (presented by V. Christensen, University of British Columbia, Vancouver).
- *Harmful Algal Blooms:* Canadian initiatives and international operational forecasting systems of various harmful algal blooms (HABs) antagonist to fisheries and aquaculture were presented by M.-H. Forget (DFO, Halifax)
- *Policy-making and management process:* The decision-making process within the Department of Fisheries and Oceans for management of human activities within Large Oceans Management Areas (LOMAs), of fisheries and aquaculture was described by representatives of different DFO branches (M. Giangioppi, Oceans Directorate, A. McMillan and R. Wysocki, DFO, Ottawa). The implementation of remote sensing as a useful tool in the management process and its status within the Canadian government were also discussed (presented by R. Stephenson, DFO, St. Andrews and P. Smith, DFO, Halifax)

In addition to the lectures, participants exchanged views on the status of remote sensing in the current management process and identified recommendations in a structured discussion session. The agenda and participant list for this meeting can be found in Appendix A.

2. Introduction to workshop

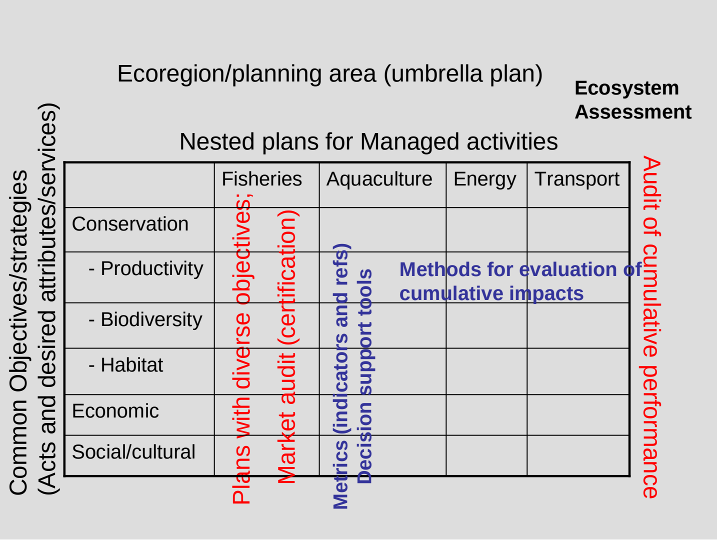
The colour of the ocean changes on a spatial and a temporal scale. Generally speaking, water that is more greenish indicates an area that is more biologically rich, due to high phytoplankton production, and therefore more favourable to fish. We can quantify these differences in colour using optical instruments and thus convert ocean colour into estimates of phytoplankton biomass and productivity for the surface layers of the ocean. Furthermore, we can obtain estimates over wide spatial scales using instruments carried on spacecraft orbiting the Earth, giving continuous information over the entire global ocean. This method, called ocean colour radiometry, yields rich information on the marine ecosystem. It allows us to observe the state of the ecosystem in real time at low incremental cost. We can observe the spatial distribution of phytoplankton biomass on regional to global scales, as well as seasonal and interannual variations (when the data are presented as time series).

Healthy fish populations depend on healthy ecosystems, so an economical way to keep watch on the ecosystem is essential. Furthermore, fluctuations in ecosystem characteristics may affect the recruitment and growth of exploited populations so the variables that lead to large and small year classes need to be quantified objectively. Such applications have already been demonstrated in Atlantic Canada for a groundfish (haddock) and an invertebrate (Northern shrimp). Other applications using satellite data to detect and monitor harmful algal blooms, and delineate sensitive marine habitats, are also showing promise. Despite the numerous demonstration applications published to date, little use is being made of satellite data to support ecosystem-based fisheries management. This workshop aimed to discuss some of the obstacles that lie in the way of the operational use of satellite data, and suggested actions that could facilitate its broader application.

Introductory statements of the workshop were addressed to the participants by Ann McMillan (DFO, Ottawa), Trevor Platt (DFO, Dartmouth) and Yves Crevier (CSA). Ann McMillan opened the workshop by expressing her views on the objectives of the workshop and asked to all participants what their goals were in participating in this FARO initiative. Dr Trevor Platt emphasised the Canadian leadership role in the field of remote sensing and described the context within which remote sensing can be useful to Canadians. Finally, Yves Crevier reflected on the importance of the outreach activities from the scientific community to the general public and to the end-users to showcase the importance of using remote sensing in addressing societal benefit areas, and more specifically fisheries and aquaculture.

2.1. Science for an evolving landscape of management: Challenges for practical use of remote sensing applications - Robert Stephenson, NSERC Canadian Capture Fisheries Research Network, DFO-SABS and UNB

The landscape of management is changing. The change includes a move to more structured decision-making approaches. Individual activities (fishing, aquaculture, transportation, etc) are being managed with an expanding suite of objectives that include conservation, social, economic and institutional elements. At the same time, these activities are being forced to conform to external marketplace pressures for certification of sustainability or responsibility. Further, there is increasing need to resolve space use conflicts among these activities that are currently managed separately (in many cases by different levels of government using different processes), and pressure to consider the cumulative effects of multiple activities in relation to overall sustainability of a region or within an ecosystem. There has been an increase in the need to make decisions between competing uses and among conflicting objectives. Increased public awareness of, and concern for, the coastal zone has resulted in demand for a more participatory governance and management structure and more transparency with respect to decisions. It is also anticipated that the management system will soon evolve to review or audit the cumulative impact of all activities of an area in terms of the combined impact (an ecosystem assessment).

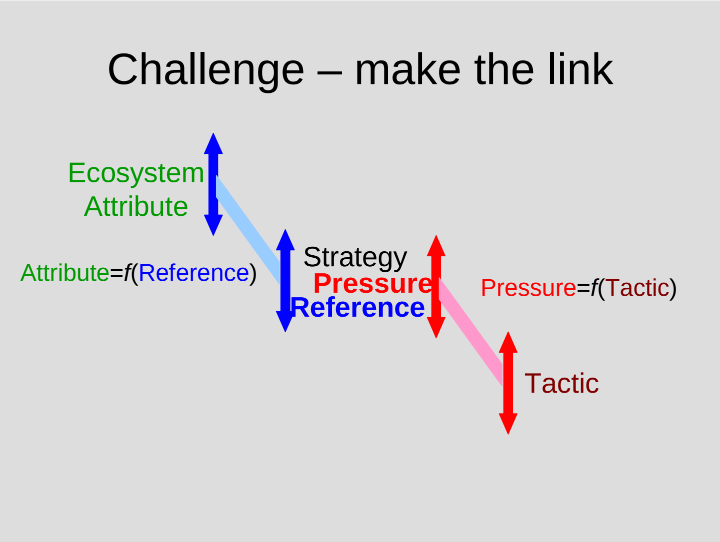


This poses a number of challenges for science, including the need for metrics (indicators and reference points) of an expanded set of objectives, methods for evaluation cumulative impacts, and decision support tools.

Remote-sensing data are appealing to consider, especially as indicators of productivity (timing and amount), climate variability and change, spatial distribution, and the monitoring of large marine areas. The challenge is to ‘make the link’ with the decision-making process. Making the link required demonstration of the relationship between an observed parameter and some aspect (reference level) associated with a management tactic.

One obvious profitable area of research is the demonstration of the link between satellite information and productivity (right through to strategies and decisions). This could include:

- Ocean variation and recruitment (production reference points)
- Ecosystem change (productivity reference points)
- Changing spatial distributions



Challenge – make the link

Ecosystem Attribute

Attribute=*f*(Reference)

Strategy

Pressure

Reference

Pressure=*f*(Tactic)

Tactic

Another profitable area of research is in the use of fishery information in establishing linkages and to ground-truth satellite imagery, including:

- Hypotheses concerning productivity and distribution (and their changes)
- Fisheries as active samplers.

3. Earth observation applications to fisheries and aquaculture

3.1. Applications of Satellite Ocean Colour Information, Venetia Stuart, International Ocean Colour Coordinating Group

Differences in the colour of the ocean can be attributed to the presence of microscopic phytoplankton cells, which form the foundation of the marine food web, and which can be quantified using satellite ocean colour sensors. Measurements obtained from satellite sensors can be used to estimate chlorophyll-a concentration (an index of phytoplankton biomass) as well as primary production, over the entire global ocean, almost on a daily basis, at relatively low incremental cost, thus allowing us to observe marine ecosystems from space. Marine phytoplankton consume CO_2 and synthesize organic compounds through the process of photosynthesis, thus play an important role in biogeochemical cycles, especially the carbon cycle. They are also responsible for ~50% of global primary production. There are a wide range of applications of ocean colour data including:

- fisheries applications (harvesting, management, protection of species at risk, delineation of marine protected areas, international high seas governance);
- aquaculture applications (determining carrying capacity, harmful algal blooms, site selection);
- coastal zone management (ecosystem health, ecosystem delineation, sediment transport, water quality, tracking oil spills, benthic habitat types, circulation features);
- climate change applications (ecosystem response to climate change, estimates of air-sea CO_2 fluxes, effects of ocean acidification on vulnerable phytoplankton species);
- defence (submarine visibility, international negotiation e.g. boundary disputes).

Examples were given of some of these applications. It was noted that satellite data is not a stand-alone tool but must be integrated with *in situ* measurements via modelling and data assimilation schemes for most applications.

3.2. Harmful Algal Bloom from Space, Marie-Hélène Forget, Bedford Institute of Oceanography

Phytoplankton blooms may occur under suitable oceanographic conditions and in some cases, these cells are harmful to the ecosystem, the organisms in this ecosystem or to human. These are the Harmful Algal Blooms (HABs). There are two major groups of HABs: i) the toxin producers, which can contaminate seafood or kill fish, even at low concentration; ii) those that do not produce toxin but can cause other deleterious impacts such as the consumption of oxygen as blooms decay. There is currently only limited knowledge on the suitable oceanographic conditions for proliferation of HABs. In some cases, they are related to nutrient inputs in coastal environment. But in many cases, these cells proliferate in ecosystems where human activity is not a contributing factor.

Two warning systems to monitor and forecast HABs using remotely-sensed data were presented, one is a government-based warning system and the second one is provided by the industry. In the United States, NOAA (National Oceanic and Atmospheric Administration) has developed a Harmful Algal Bloom Operational Forecast system (HAB-OFS), which currently provides operational forecast report for the dinoflagellate *Karenia brevis* in 4 regions of the Gulf of Mexico. The HAB-OFS data analysis is based on remotely-sensed ocean colour, *in-situ* optical measurements, taxonomic counts, and measured and modeled wind and current. Another early warning system was developed in Chile by Hatfield Consultants Ltd. in collaboration with Mariscope Chilena under the ESA-funded Chilean Aquaculture Project. This warning service is based on Earth Observation data and a complementary hydrodynamic model.

GEOHAB (Global Ecology and Oceanography of Harmful Algal Blooms) has put in place, in collaboration with IOCCG, a new working group on Harmful Algal Blooms and Ocean Colour. The resulting IOCCG report, to be published in 2012, aims at:

1. Summarising the state of knowledge concerning ocean colour-based HAB methods;
2. Examining and demonstrating the suitability of various ocean-colour approaches;
3. Outlining appropriate frameworks within which to further develop ocean colour-based HAB observation.

A few projects using remote sensing data to study and monitor HABs in Canada include the use of the Maximum Chlorophyll Index developed by Jim Gower (DFO) and applied to North American lakes by Caren Binding (EC), the study of an extensive bloom of *Alexandrium tamarense* in the St. Lawrence Estuary, Suzanne Roy, and the monitoring programme of *Alexandrium fundyense* in the Bay of Fundy from a team of researchers at the Bedford Institute of Oceanography and the St. Andrews Biological Station.

The future of the monitoring and forecasting of HABs in Canada should include more research on HABs using Earth observation data in Canadian waters, develop an operational model for monitoring and forecasting HABs and providing the information to aquaculture farmers and the public at large through a web portal.

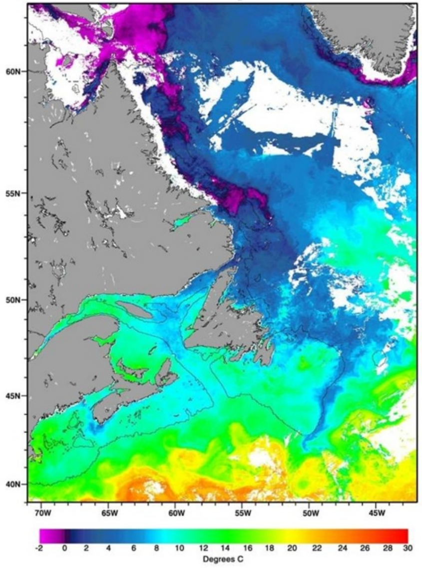
3.3. Remote Sensing in Support of Fisheries, Trevor Platt, Bedford Institute of Oceanography.

Earth observation can provide useful information to fisheries in the following applications:

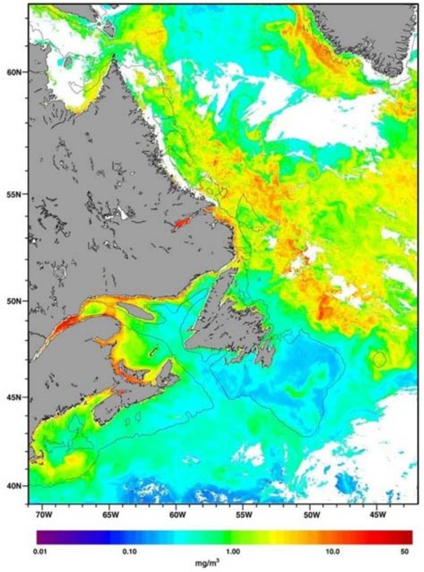
- Harvest fisheries,
- Fisheries management,
- Aquaculture industry
- Protection of species at risk
- Marine Protected Areas and vulnerable marine ecosystems
- Ecosystem health and ecosystem services
- High seas governance

In the context of stewardship of the ocean, there is a general consensus that marine resources should be managed through an ecosystem-based program. A suite of ecological indicators with objective metrics for the pelagic ecosystem should thus be developed and applied in an operational mode to detect changes in the ecosystems. A set of ideal characteristics were presented for the development of such indicators, and it was stressed that remotely-sensed ecological indicators fulfill all the requirements.

Sea Surface Temperature
1-15 June 1998 Composite



SeaWiFS Chlorophyll-a Concentration (OC4 algorithm)
1-15 June 1998 Composite



Some ecological indicators that can be quantified from remote sensing data were listed:

- Initiation of spring bloom
- Amplitude of spring bloom
- Timing of spring maximum
- Duration of spring bloom
- Total production in spring bloom
- Annual phytoplankton production

- Initial slope, light-saturation curve
- Assimilation number
- Particulate organic carbon
- Phytoplankton carbon
- Carbon-to-chlorophyll ratio
- Phytoplankton growth rate
- Phytoplankton loss rate
- Integrated phytoplankton loss
- Spatial variance in biomass field
- Spatial variance in production field
- Phytoplankton functional types
- Biogeochemical provinces

Dr Trevor Platt elaborated on some of these ecological indicators and fisheries applications. Finally, benefits to Canadians were presented and Canada's leadership role was highlighted.

3.4. Variation in ocean colour helps predict cod and haddock recruitment, presented by Kurtis Trzcinski, Bedford Institute of Oceanography, Dartmouth, work done in collaboration with E. Devred, T. Platt and S. Sathyendranath.

Fisheries sciences have long tried to explain wide variations in recruitment. A long-standing hypothesis is that larval survival is dependent on the timing of spawning relative to the peak abundance of resources. When spawning is well matched with abundant resources, survival will be high, otherwise larval survival will be low. This so-called match / mismatch hypothesis was examined by comparing characteristics of the phytoplankton bloom measured using satellite remote sensing data. Early studies have focused on the biomass (chl-a) of the spring bloom on larval survival. Our study also examines the effects of the fall bloom and is the first to test for the effects of diatoms on larval survival. Using data from cod and haddock spawning areas along the Scotian Shelf, we found several significant correlations. The fall bloom was less well defined than the spring bloom and diatoms made up a large proportion of both blooms where ~60% and ~80% of the 1.5km cells were dominated by diatoms. We found more significant relationships between recruitment and the fall bloom (6) than the spring bloom (2), an equal number of correlations between chl-a and percent diatoms (4 each) and an equal number of correlations across the two species (4 each) and two populations (4 each). Two correlations support the match-mismatch hypothesis: haddock survival increased when the spring bloom was earlier (Greater Western Bank) and cod survival increased the earlier the fall bloom (Middle Bank). These correlations can be used to affect management decisions in at least two ways. In the short term, management can adjust advice based on anomalously high or low indices of the bloom with the expectation that in 3 to 4 years fish biomass can be expected to be high or low. In the longer term, these correlations can be used to define production regimes, which directly modify the stock-recruitment relationship and the fisheries management reference points that decisions are based upon.

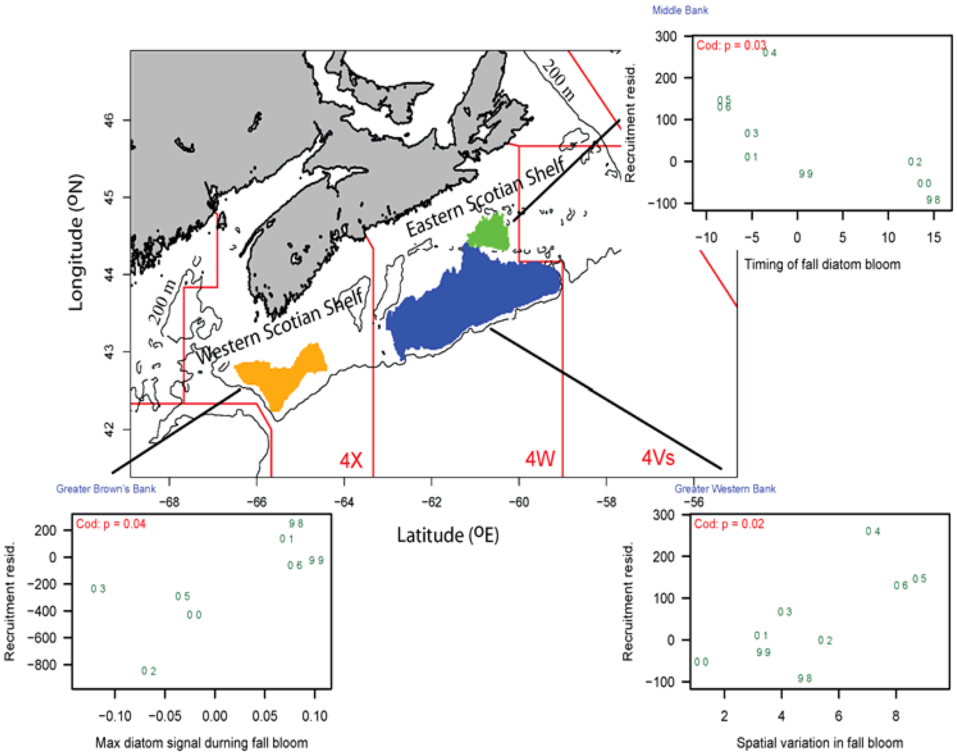


Fig. 3.4.1. Correlations between cod stock-recruitment residuals and characteristics of the spring and fall bloom on Middle Bank, Greater Browns Bank, Greater Western Bank.

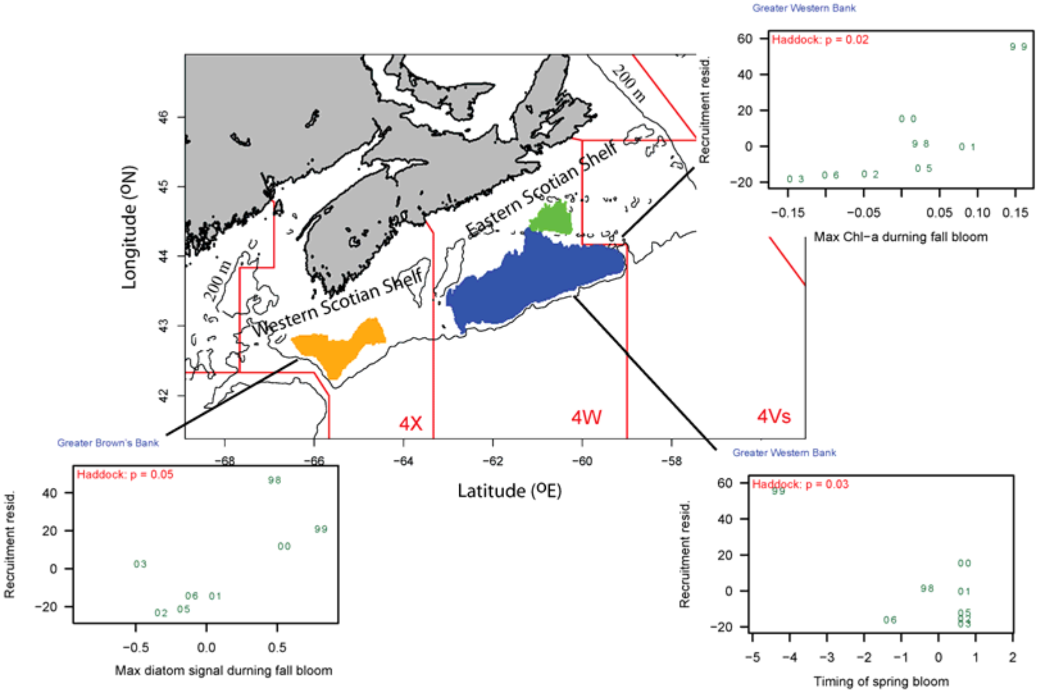


Fig. 3.4.2. Correlations between haddock stock-recruitment residuals and characteristics of the spring and fall bloom on Greater Western Bank, Greater Browns Bank.

3.5. Identification of potential fishing zones by remote sensing: the Indian experience, Shubha Sathyendranath, Plymouth Marine Laboratory, UK & Dalhousie University, Halifax.

Remote sensing of ocean colour is the only approach to provide a synoptic view of the abundance of the marine autotrophic community, which is at the basis of the marine food web. Areas with high phytoplankton biomass as well as temperature fronts have been related to increased abundance in fish. An Indian program, forecasting Potential Fishing Zones (PFZ), provides this useful information, free of charge, three times a week to artisanal fishermen to increase their fishing efficiency and reduce their use of fuel. The locations of the PFZs are distributed to the fishing community through different media, in many cases in the local language to facilitate the use of the information. Results strikingly show the benefits in using PFZ information, with a significant increase in fish catch and a reduction in search time. To generate a responsible fisheries forecasting program, the dissemination of the PFZ information is interrupted in areas known as nurseries and at time identified as spawning peaks.

3.6. Tracing environmental signals through the food web: implications for fisheries management, Villy Christensen, University of British Columbia.

Villy Christensen presented an overview of recent findings from ecosystem modeling of a large number of marine systems, titled "Tracing environmental signals through the food web: Implications for fisheries management". He pointed out that there is a strong disconnect between ocanographic and fishries research, but that ecosystem models clearly demonstrate tat in order to produce credible fit to historical data at the ecosystem level, the models must include environmental, trophic, and fisheries impacts. This provides a strong argument for the need of integrating ocenographic and fisheries research. It is clear from the ecosystem modeling (done using Ecopath with Ecosim) that environmental productivity patterns can be identified throughout the food web, and that there are variable time delays linked to turnover rates and food web constellations. He stressed the need for use of satellite-based productivity for integrated management of marine ecosystems, and emphasized the need for database systems that make it easier to access satellite data.

4. The status of remote sensing in Canada

4.1. Strategic Plan for Remote Sensing in DFO, presented by Peter C. Smith, Bedford Institute of Oceanography, work done in collaboration with and C. Hannah and J. Helbig

Introduction

Remote sensing (RS) provides a unique means for monitoring many important properties of the ocean surface layer in both a timely and synoptic fashion. As long time series data become available from remote sensing, they will provide an important tool to study long-term variability in the ocean climate and ocean ecosystems at large scales, and without losing the details at local scales. Furthermore, this can be achieved using a method that is consistent and systematic across all regions. Remote sensing is well-suited to:

a) resolve important aspects of, and support the protection of, the marine ecosystem with ocean colour and auxiliary data providing information on many properties of the marine ecosystem;

b) sample physical properties (e.g. waves, currents, winds, fronts/eddies, sea ice) for use in operational products related to the safety and efficiency of offshore operations, as well as to study long-term variability in ocean climate; and

c) study ocean climate and climate change.

These tasks constitute integral parts of the DFO mandate. Apart from DFO, several other federal departments and agencies support the development and use of ocean remote sensing in their own monitoring and operational roles, including the Canadian Space Agency (CSA), the Canadian Ice Service (CIS-EC), NRCan (through OERD), and the Canadian Coast Guard.

Primary Elements of Strategy:

The primary elements of the DFO strategy address the maintenance and support for the remote sensing research and development within the department:

1) Build and maintain DFO capacity in remote sensing research with elements of expertise in the four main data types (OC,SSH,SAR,SST) distributed across various institutions,
2) Continue to seek both internal and external (CSA, PERD, CCG) funding for building satellite data into DFO operations in support of priority outcomes, such as:
    a. Ecosystem-based management of fisheries (ocean colour, SST)
    b. Safe and secure waterways (search-and-rescue, forecast modelling)
3) Contribute to international programs to calibrate and validate emerging remote sensing data types with operational potential such as surface salinity and sea ice thickness.
4) Collaborate with modellers and field scientists in order to connect the surface observations with the ocean interior and improve operational ocean products.

External Funding Sources:

In addition to committed DFO resources, major external funding sources have assisted in the development of remote sensing research and operations required by DFO to carry out its mandate. Primary funding for ocean-based remote sensing science should be sought from the following sources:

- Government-Related Initiatives Program (GRIP), sponsored by the Canadian Space Agency (CSA),
- Program for Energy Research and Development (PERD), sponsored by Natural Resources Canada (NRCan).
- Search-And-Rescue New Initiatives Fund (SAR-NIF), sponsored by the Canadian Coast Guard (CCG), and
- Various targeted programs with specific needs for remote sensing (e.g. International Polar Year or IPY)

To gauge the level of external funding required to carry out the desired research and development, a summary of recent allocations from two external sources is listed in Table 4.1.1 below. Most prominent among these sources is the Government-Related Initiatives Program (GRIP), CSA's vehicle for promoting the use of Earth Observation (EO, i.e. satellite-based) data in the operations of other government departments (OGDs). These funds, plus OGD in-kind support, are fully devoted to remote sensing R&D. DFO benefits from GRIP research in numerous ways, including the assimilation of EO data into regional forecast models, application of ocean colour algorithms for monitoring the marine ecosystem at the surface, detection of ice hazards to navigation, etc. In addition, NRCan's PERD supports the exploration and use of remote sensing to mitigate marine hazards due to ice and waves under its Offshore Environmental Factors (OEF) Program of the Frontier Oil&Gas (FOG) Portfolio. Further PERD support is provided through projects in different programs of the FOG Portfolio, such as Northern Research (NRR) and Marine Transportation and Safety (MTS).

Table 4.1.1. Recent External Funding for DFO Projects

Program	*Overall Funding*	*Active Years*	*Funding/Yr.*
GRIP TOTALS:	**$6,431K**	**'04/'05 to '10/'11**	**$2,062K**
PERD TOTALS:	**$301K**	**'07/'08 to '10/'11**	**$75K**

The Canadian Coast Guard (CCG) also has special needs for accurate regional ocean forecasts in near-real time to support, among other things, Search-and-Rescue planning. The Search-and-Rescue New Initiatives Fund (SAR-NIF) has provided resources for the development and implementation of ocean forecast models in its SAR planning tool, known as CANSARP. SAR-NIF sponsors an annual call for proposals for projects up to three years duration.

Collaborations with other partners (e.g. EC, NRCan) in programs, such as IPY, have provided resources to DFO for addressing mutual operational needs. For example, the observation and forecast of winds and waves in the Arctic has been facilitated by access to the recently-deceased QUIKSCAT scatterometer, and various Synthetic Aperture Radar (e.g. RADARSAT2) signals. These developments must be further exploited in future, particularly in light of the planned RADATSAT Constellation, to be launched in the 2015-2017 time frame.

Communication & Outreach

Considering the geographically separation of DFO remote sensing scientists, particularly relative to the centers of funding sponsorship and management direction in Ottawa, the following two recommendations are put forward:

1) Establish a federal working group to guide DFO participation in remote sensing research and development. The group should be composed of one member from each DFO institution involved in remote sensing, plus an HQ representative. The group should communicate regularly (e.g. at least semi-annually), and meet in person bi-annually or as funding conditions dictate.
2) DFO should sponsor bi-annual open workshops to highlight remote sensing research and development it supports.

Conclusions

DFO has a good track record with a number of remote sensing funding agencies, including CSA, PERD, and CCG. For the future, DFO should plan to remain strong in the field of remote sensing R&D by actively pursuing external funding opportunities and endeavouring to maintain its focus on developing operational products based on sound scientific principles.

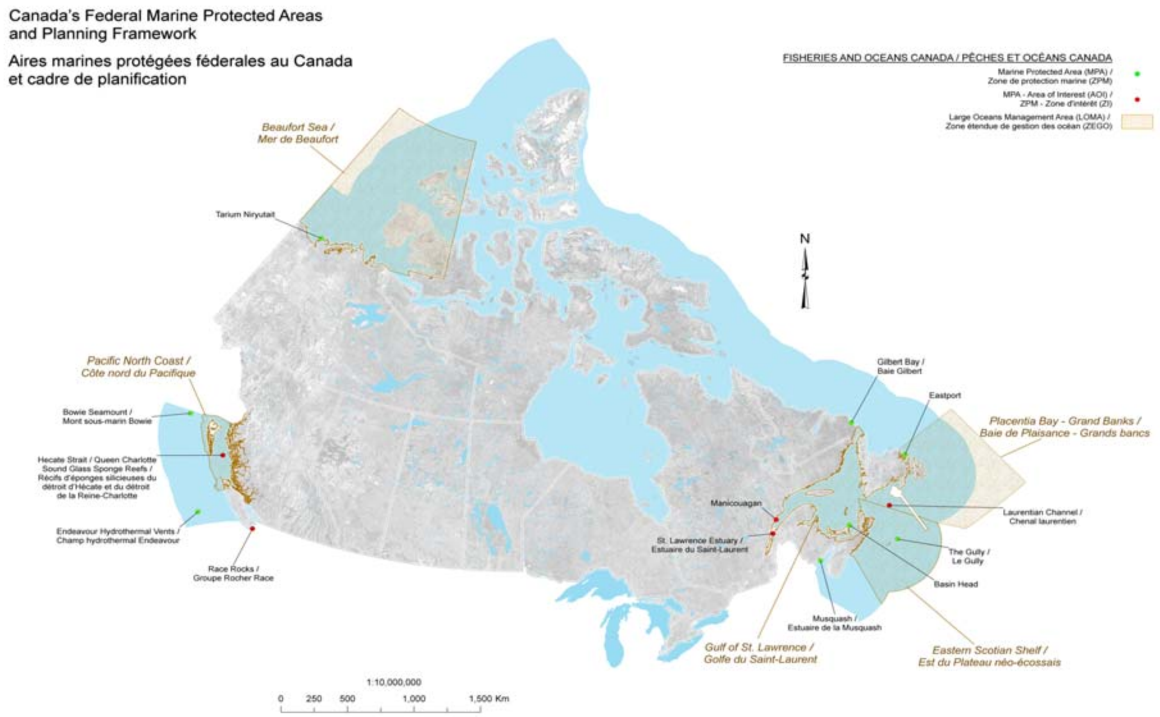
5. End-users

5.1. Integrated Oceans Management (IOM) Planning and Marine Conservation Tools, Martine Giangioppi, National Headquarter, Ottawa

The Oceans Act and the Canada's Oceans Strategy (COS) has commitments towards: i) Integrated Ocean Management (IOM); ii) National network of Marine Protected Areas (MPA); and iii) Marine Environmental Quality (MEQ) guidelines and standards, with the goal to ensure healthy, safe and prosperous oceans for the benefit of current and future generations of Canadians. IOM seeks to maintain the integrity of marine ecosystems & minimize user conflicts by proactively identifying key ecological & human use values, collaboratively establishing objectives & developing and implementing plans to ensure the optimal use of ocean spaces. The bulk of the work that has been done so far under the Oceans Act and the COS is within IOM and MPAs. Remote sensing could provide key products to advance IOM and MPA planning.

Canada's five Large Oceans Management Areas (LOMAs) were established as initial pilot areas for moving forward with IOM. 2 Integrated Management plans have been completed while the others are underway.

DFO has also reported some progress on the MPA file, with a number of MPAs established and Areas of Interest (AOIs) identified. Moreover, DFO is also responsible to develop and implement a national network of MPAs. The network will include different types of marine protected areas including DFO Oceans Act MPAs, Park Canada National Marine conservations areas and Environment Canada National Wildlife areas as well as provincial and territorial marine protected areas.



Some of the current and future IOM priorities are to identify individual & cumulative impacts of human activities and associated pressures on ecosystem components and ultimately on ecosystem services, societies and economies, as well as, to characterise their levels of impacts. Operationalizing the current conceptual conservation objectives identified for some Ecologically and Biologically Significant Areas (EBSAs) and Ecologically Significant Species (ESSs) is another priority for IOM.

Overlaying human uses spatial data with significant ecosystem components will help IOM identifying potential hot spots areas to identify management priorities. Below is a list of coastal, nearshore and offshore information requirements for IOM and MPA planning:

- High resolution of ocean bottom topography (<10m depth), e.g. Lidar bathymetry
- Ocean floor composition; (<10m depth)
- Vegetation cover: estuary and marine (<10m depth)
- Turbidity, erosional and deposition zones
- Terrestrial vegetation cover
- Terrestrial land-uses
- Hydrology of estuaries (flushing rates, tidal regime, etc.)
- Water quality (sewage, land and nearshore spills)
- Surveillance information for enforcement purposes (MPAs and eventually IOM)
- At sea environmental disaster monitoring (e.g. oil spills)
- Sea ice cover changes
- Sedimentation changes (e.g. renewable energy, etc)
- Discharge zones (e.g. ballast water, illegal discharge)
- Marine traffic (e.g. densities, compliance of recommanded shipping lanes)
- Areas with high biodiversity (e.g. seamounts, coral communities, sponge communities)

5.2. Summary of Presentation by Environment and Biodiversity Science Branch, Roger Wysocki, National Headquarter, Ottawa

Environment and Biodiversity Science Branch (National Headquarters, Ottawa) was identified as one of the major programs within the National Ecosystem Science program, whose work falls within three main sub-programs. Via a presentation of these sub-programs, the potential synergies with remote sensing research by FARO and SAFARI was explored for: (i) Fish Habitat Science, (ii) Biodiversity Science, and (iii) Aquatic Invasive Species.

In general terms, the Fish Habitat Science program is charged with provision of scientific advice on the potential impacts of human activities on fish and fish habitat, including:

- Oil and gas development (impacts and mitigation)
- Contaminants and pesticides
- Hydroelectric development
- Oceans renewable energy technologies (e.g. tidal energy).

In further discussing the program, attention was drawn to a recent report by the Commissioner of Environment and Sustainable Development (CESD), towards it would be worth exploring potential linkages and benefits that might be realized via utilization of remote sensing technology. The Department's Habitat Management program has been urged by the CESD to; (i) develop and review standard scientific methodologies to examine the effectiveness of compensation in achieving the ‘no net loss’ guiding principle, and to (ii) develop habitat indicators to apply in ecosystems with significant human activity.

A summary of the National Biodiversity Science program was also presented, which included the coordination of national initiatives related to assessment and conservation of aquatic ecosystems and biodiversity, including the provision of scientific advice on:

- Identification of vulnerable marine ecosystems and biologically/ecologically significant areas (EBSAs),
- Convention on International Trade in Endangered Species (CITES),
- Impact of fishing on fish habitat,
- Support of the international Convention on Biological Diversity (CBD) as related to issues in marine ecosystems.

In terms of the Biodiversity Science program, there appeared to be great potential for collaborative work with research scientists working on remote sensing issues, as well as their suggested involvement in forthcoming scientific advisory processes.

The last major sub-program discussed was DFO Science support towards management of Aquatic Invasive Species (AIS). The roles of this AIS program include:

- Coordination of national programs regarding aquatic invasive species, including:
- Research efforts in respect of AIS,
- Monitoring (e.g. green crabs, tunicates, zebra mussels, ballast water)
- Risk assessment/analysis of AIS.

Finally, a number of scientific data and information gaps and needs were discussed in a general sense. Workshop participants were asked to consider potential linkages between the work of FARO, SAFARI and a variety of emerging scientific issues towards which the provision of remote sensing expertise might prove particularly valuable. These emerging scientific questions include:

- Expanding scope of factors considered within fish stock assessments,
- Evaluation of status, trends, fishing impacts and sustainability benchmarks of non-commercial species
- Conducting analyses of fish community patterns / dynamics
- Calculation and use of reference points for management of fish stocks
- Supplying of scientifically defensible indicators for biodiversity status and impacts
- The need for more data availability for benthic communities (both marine and freshwater,
- The need for increased monitoring of the coastal zone
- Expanding the scope of analyses and data availability to include freshwater monitoring and assessment (currently limited despite potential for significant losses),
- Tools for evaluating and monitoring of fish habitat quality need improvement and wider application,
- Limited capacity for early detection of invading species coupled with minimal capacity for rapid response.
- Need for research on better tools for eradication/management of established invader species.

5.3. Oceanography, Climate and Remote Sensing – Ann McMillan, National Headquarter, Ottawa

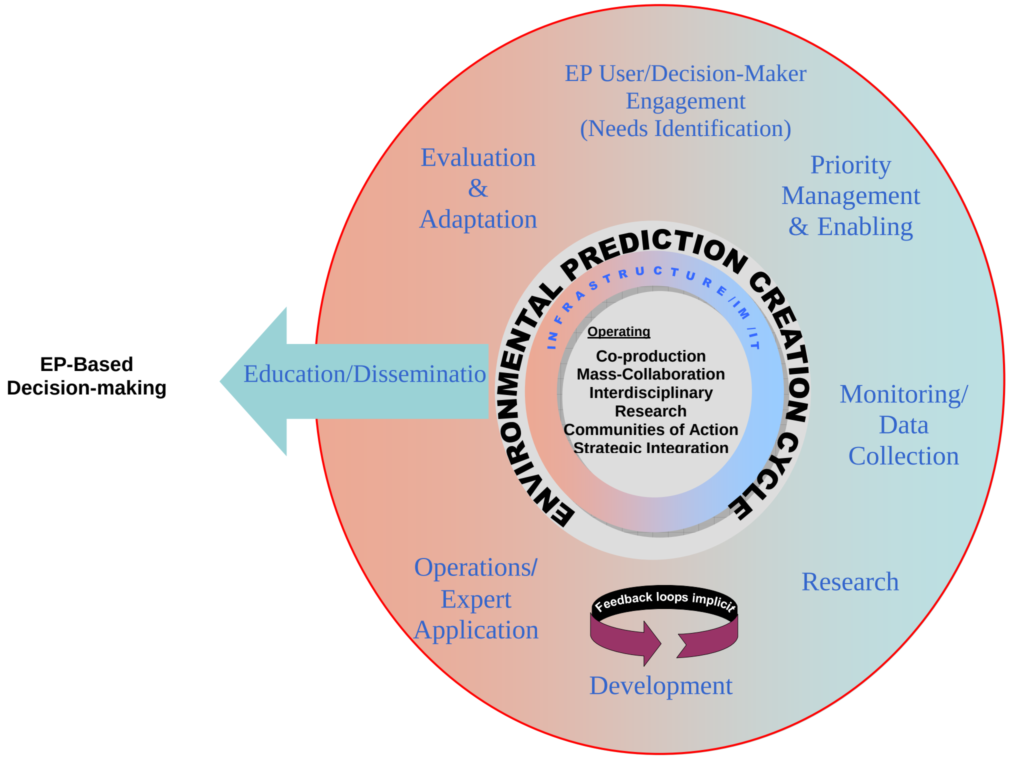
Traditionally, oceans, as part of the global “commons” have attracted even less attention than the atmosphere in terms of understanding its role and connections with respect to the climate. A number of factors are changing this situation in Canada, including:

- Fish stocks worldwide are, on the average, in decline leading to the realization that we need improved ecosystem tools to do integrated ocean modelling.
- Coastal zones worldwide are experiencing impacts such as flooding and erosion leading to the needs for tools for sea level prediction, ocean storms and the management of coastal habitats and spawning areas.
- The ice covering the Arctic Ocean is melting forcing recognition of this northern sea in the context of fishing, resource development transportation, and sovereignty.
- Until recently scientific knowledge and computing resources were not sufficient to recognize, for example, that ocean models are required to be coupled to atmospheric models to improve weather and climate predictions, but now this recognition has occurred there is pressure to move forward with integrated programs and to mount “operational oceanography” programs to link with the meteorological/climatological side.

At the same time, it has never been more difficult to mount new science programs in Canada, and it is clearly not possible to do the ocean monitoring required to address these issues using traditional ship-based methods alone. Remote sensing offers a series of scientifically proven techniques for addressing these issues.

Within the series of techniques, ocean colour applications are some of the best positioned to move into operational applications in the near future, but there are issues to address. These applications provide another layer of information necessary for DFO’s ecosystem science framework. Ocean colour can provide increased understanding of existing knowledge about the linkages between fisheries, aquaculture, habitat, and oceans activities and important ecosystem features. This could potentially help distinguish between natural variation and responses to human activities based on management decisions.

On the meteorological side, operation is expanding to include more services than the weather forecast and moving toward “environmental prediction” of which “operational oceanography” could be seen as a subset. They see the process of generating decisions through environmental prediction in the following way:



This diagram may not exactly represent the processes required to bring remotely sensed oceans data into decision making, but it does describe a number of concrete steps that need to be taken. Several points may be important:

- It is essential to have senior management support and endorsement for projects as high priorities or they will not get into the “menu” of operationally delivered products.
- It is essential to have identified users/stakeholders who can not only guide the development of applications, but who can also champion the value and priority of the work.
- Evaluation of initial products and services and adaptation of them to changes or developments in user/client needs is an important step that is often missed in development of pilot projects and dooms them to remain pilots.
- All of this takes time and money which organizations typically do not have a “pot” to provide.

These aspects relate to several issues that need to be thought through and pursued if progress is to be made:

- *The link from science into policy or operations.*

The route from science to policy has not traditionally been easy. Scientists tend to have a culture that supports seeking truth, understanding and linkages based on facts. This culture accepts that things take time to be understood, and builds on a basis of facts through work that addresses focused questions and is contextually driven by peer review and eventually reaching scientific consensus. The community works in a transparent way and all points of view are welcomed and considered although many may fall to the wayside in light of subsequent results.

Policy on the other hand is often done quickly in response to some urgent political matter and may not take the time to include all points of view. Further, it is often created through a power chain which does not directly relate to the competence of the decision makers but rather to their ability to sway certain factions or get votes.

There is a lot of interest in the process by which science can move to support policy more smoothly. Given that remote sensing and ocean colour have quite a large "community of practice" available to promote the science, it should be relatively straightforward to ensure that every person in Canada who influences the policy process are acquainted with the promise of these techniques.

- *The need to get focus and priority to move forward*

In Canada, issues do not usually become high priority because scientists say they are important. However, if a "smoking gun" is identified where there is an association of a situation with some bad outcome, the situation will move up the priority scale.

For example, environmental managers have long understood that air pollution is a bad thing. Acid rain drew some attention because lakes were dying, however, when Health Canada researchers developed science that associates air pollution with mortality, suddenly the air pollution issue was recognized as an important one which has drawn millions of dollars of support and has generated the development of new science based operational approaches such as the Air Quality Health Index (AQHI).

In order to position remote sensing of ocean climate related issues as a priority, some thought needs to be given to what problems can be solved using this technique. It may possibly be that the important problem that needs solving is not the one that is ideally solved by the remote sensing….however, it is always the problem that trumps the technique in terms of priority setting. In other words, if remote sensing/ocean colour provide a 10% solution to an important problem, that problem will drive the development of the future applications, not an unimportant problem that can be 100% addressed.

- *Need to translate international respect for scientific work into support at home.*

Without the support of key government people initiatives do not move ahead. Since this is essentially a DFO initiative, it is important that senior DFO Managers support the direction and the priority.

Regional science issues are not well understood or supported by senior DFO Managers in general…this is a highly diffused department. It will be essential to develop a national focus and perspective including all the players nationally to move forward. It will only take one respected dissenting scientist to derail efforts to move forward in specific directions.

- *The users/clients/stakeholders need to be identified and engaged*

There needs to be a conversation, and likely a fairly lengthy one with users/clients and stakeholders. The involvement of the Canadian Space Agency and their support is a huge step toward facilitating this work. It is important to identify a couple of high priority needs to be addressed first.

In summary, both scientists and potential clients/users/stakeholders need to commit to doing some work beyond regular science/policy interaction to take remote sensing forward in a DFO context. It would be very helpful if the scientists could, as a group nationally, come up with a statement on the potential of remote sensing from their perspective. It would also be helpful if clients/users/stakeholders from within the department could provide a list of the issues that remote sensing might be able to help them with.

Setting priorities to identify a couple of priorities and focus efforts on them is really difficult, but really necessary.

1. Discussion:

Trevor Platt raised a few issues to initiate the discussion:

i) Anne McMillan had highlighted the strong expertise in ocean colour in Canada. However, this is no longer true for DFO, for example, on the east coast, there is currently no remote sensing specialist within DFO. On the west coast, there is still one scientist, but near retirement. At BIO there are currently 2 knowledgeable scientists (i.e. Emmanuel Devred and Venetia Stuart) but they are hired under sunset positions funded by the CSA, and thus their status is rather fragile. There are also 2 post-doctoral fellows (Marie-Helene Forget and Li Zhai) hired under the NSERC visiting fellowship (also funded from CSA). In Quebec, Pierre Larouche is also retiring soon.

ii) The relationship between CSA and DFO has undergone some transformation over the last couple of years, which resulted in bi-lateral discussions taking place with no technical expert present. The contact with CSA is now going through DFO senior policy makers but it would be desirable to have a remote sensing expert present. For example, when applying for GRIP funding to CSA, the request has to go through a screening of letters of intent (LOIs) at the Ottawa level, with no remote-sensing expertise in the committee screening these LOIs. The information flow and the input from experts are thus highly channelled.

iii) The issue regarding the priorities within the government was also discussed as to who should set the national priorities. Scientists are usually ahead of the managers, and national priorities usually originate within the scientific community. However, at the DFO level, the information flow is becoming more restricted, with only limited inputs from scientists. The products have been developed by the remote sensing community, but due to a lack of communication between the different parties, these products have not been used for various national priorities. For examples, why was there no use of remote sensing tools in the bio-geographical classification of the Canadian seaboard?

Ann McMillan pointed out the eagerness in DFO Ottawa to fill up a PC4 position with a scientist who would have the technical background in remote sensing. This may be the first step in addressing the concerns raised by Trevor Platt.

Kurtis Trzcinski's main concern is the erosion of the knowledgeable scientists within DFO. Most of the remote sensing workforce within DFO has retired or will retire in the near future. Many young scientists have been trained by these scientists, who are in many cases well-known internationally, but no mechanism has been put in place to hire these ascending scientists within the government system.

Robert Stephenson pointed out that it was difficult to foresee the direction of Science within DFO and suggested that if the remote sensing expertise is no longer within DFO, maybe the creation of a network of remote sensing scientists would alleviate the problem.

It was also suggested that DFO should identify a national vision for remote sensing, which would include applications to fisheries and aquaculture.

Finally, Trevor Platt suggested that the next step for the FARO project should include a workshop directly targeting the Fisheries industry.

6. Recommendations:

1. Build a Canadian community of practice around the people at the workshop. Expand the community to a wide range of fishing interests, including stock assessment scientists and fisheries industry leaders. Action: FARO project.

2. A document is required outlining the value of remote sensing for meeting the goals of DFO and other clients with an ocean interest or mandate. Core programmatic challenge for Canada is related to management of marine ecosystem. The role of remote sensing to address the challenge should be included in the document. The scope of the report should be broader than fisheries applications, and include applications such as in climate, ecosystem management, transport and natural disasters. Canada has world-class strength in this area. What is required is to build on this strength, and rejuvenate parts where key personnel has returned. Include renewal strategy, including manpower. Use IOCCG Report No. 7 as starting point, but examine from Canadian context and prioritise. Provide document to DFO and others. Consider having a CSAS review of the document. Action: Ann McMillan for follow-up.

3. Explore the possibility of incorporating remote sensing elements into health of the oceans, fisheries act initiatives. Action: Mathew Surch.

4. Identify what are the needs for end-users for future missions or access to data, e.g. would DFO scientist require Sentinel-3 data in the future? Communicate to CSA. Include this as part of the strategy document (Action 2).

5. Prepare proceedings of the meeting, and make it available on FARO website, and distribute to participants. (Action: All participants, to write down some text with figures, on their contributions to the meeting, for inclusion in the proceedings.)

Appendix A

Wednesday, January 05, 2011 **British Columbia Boardroom**	
1:00pm to 1:10pm	Ann McMillan - Introductory Remarks, Policy
1:10pm to 1:20pm	Yves Crevier - Introductory Remarks, CSA
1:20pm to 1:30pm	Trevor Platt - Introductory Remarks, Research
1:30pm to 1:50pm	Robert Stephenson – science for an evolving landscape of management
1:50pm to 2:10pm	Venetia Stuart – Applications of Satellite Ocean Colour Data
2:10pm to 2:30pm	Marie-Hélène Forget – Harmful Algal Blooms from space
2:30pm to 3:00pm	Trevor Platt – Ecological indicators of the ocean by remote sensing
3:00pm to 3:30pm	Break
3:30pm to 3:50pm	Kurtis Trzcinski – Variation in ocean colour helps predict cod and haddock recruitment
3:50pm to 5:00pm	Discussion session – chaired by Peter Smith

Thursday, January 06, 2011 **Territories Boardroom**	
8:30am to 8:50am	Shubha Sathyendranath – Identification of potential fishing zones by remote sensing: the Indian experience
8:50am to 9:10am	Villy Christensen - Tracing environmental signals through the food web: implications for fisheries management
9:10am to 9:30am	Peter Smith – The remote sensing strategy plan in DFO
9:30am to 9:50am	Jean-Marc Chouinard – Canadian Space Agency
9:50am to 10:20am	Break
10:20am to 10:40am	Ann McMillan - Oceanography and Climate
10:40am to 11:00am	Martine Giangioppi – Oceans Policy
11:00am to 11:20am	Roger Wysocki – Fish Habitat Science
11:20am to 12:00pm	Discussion session – chaired by Trevor Platt
12:00pm to 1:00pm	Lunch
1:00pm to 3:00pm	Discussion session – chaired by Trevor Platt
3:00pm to 3:30pm	Break
3:30pm to 4:30pm	Identification of the recommendations – chaired by Ann McMillan
4:30pm to 4:45pm	Trevor Platt – the next step
4:45pm to 5:00pm	Ann McMillan - Concluding remarks