Scientia Canadensis
Canadian Journal of the History of Science, Technology and Medicine
Revue canadienne d'histoire des sciences, des techniques et de la médecine

Technology Development at the Bedford Institute of Oceanography, 1962-1986

Michael Murphy

Volume 39, numéro 1, 2016–2017

URI : https://id.erudit.org/iderudit/1041379ar
DOI : https://doi.org/10.7202/1041379ar

Aller au sommaire du numéro

Éditeur(s)

CSTHA/AHSTC

ISSN

1918-7750 (numérique)

Découvrir la revue

Citer cet article

Murphy, M. (2016). Technology Development at the Bedford Institute of Oceanography, 1962-1986. *Scientia Canadensis*, *39*(1), 74–92. https://doi.org/10.7202/1041379ar

Résumé de l'article

Cet article explore la relation entre technologie et découverte en océanographie, en examinant des exemples de développement instrumental à l'Institut océanographique de Bedford (IOB). Entre 1962 et 1986, les chercheurs et les techniciens de l'IOB ont initié une vague de développements technologiques rapides, tout en adoptant des technologies développées ailleurs. Le développement de ces instruments a constitué une entrée dans l'ère numérique, puisque nombre d'entre eux incorporaient du matériel et des programmes informatiques. Cet article résume ces développements, leurs impacts sur les travaux de l'Institut, les facteurs ayant influencé ces travaux, ainsi que la manière dont ils ont évolué à travers une période où l'IOB a émergé comme une institution océanographique de renommée mondiale.

Technology Development at the Bedford Institute of Oceanography, 1962-1986

Michael Murphy

Abstract: *This paper explores the relationship between technology and discovery in oceanography, examining examples of instrumentation development at the Bedford Institute of Oceanography (BIO). Between 1962 and 1986, BIO researchers and technicians initiated a wave of rapid technological development, while also adopting technology developed elsewhere. These developments were a bridge into the digital age as BIO staff incorporated computer hardware and software into instrument development. This paper summarizes these developments, their impact on the work of the Institute, and factors that influenced this work, and how they changed over time BIO emerged as a world-class oceanographic institution.*

Résumé : *Cet article explore la relation entre technologie et découverte en océanographie, en examinant des exemples de développement instrumental à l'Institut océanographique de Bedford (IOB). Entre 1962 et 1986, les chercheurs et les techniciens de l'IOB ont initié une vague de développements technologiques rapides, tout en adoptant des technologies développées ailleurs. Le développement de ces instruments a constitué une entrée dans l'ère numérique, puisque nombre d'entre eux incorporaient du matériel et des programmes informatiques. Cet article résume ces développements, leurs impacts sur les travaux de l'Institut, les facteurs ayant influencé ces travaux, ainsi que la manière dont ils ont évolué à travers une période où l'IOB a émergé comme une institution océanographique de renommée mondiale.*

Keywords: oceanography, Bedford Institute of Oceanography, technology development, instrumentation

Introduction

> "It appears, therefore, that the most promising mode of advancing our knowledge…is to examine the laws which can be collected from observation, taking so great a number of observations, that the effects of all accidental causes may disappear..."[1]

William Whewell, the influential English philosopher and scientist, articulated the role of observation in the scientific process: indeed, that observation provided the base for scientific knowledge. We discover the laws of nature through observation and the collection of precise, reliable, and traceable measurements, at a scale and cost that fit the circumstances. In essence we need tools—instruments, equipment, and processes—to make measurements and to collect data. All branches of science are dependent on technology and instruments to some degree, but few more so than oceanography as it faces challenges from having to operate in the adverse conditions of marine environments.[2] As Helen Rozwadowski and David van Keuren have observed,

Michael Murphy, "Technology Development at the Bedford Institute of Oceanography, 1962-1986" *Scientia Canadensis* 39, 1 (2016-17): 74-92.

"what oceanographers have learned about the ocean has been based almost exclusively on what various technologies, or machines, have taught them."[3] Instruments such as the thermometer, the barometer, and the plankton net, among others, have driven oceanography. And as instruments have developed alongside advances in areas such as microelectronics and computing, oceanographers have been able to acquire more data, more precisely, and at a lower cost, allowing them to further develop and test oceanographic theory.

This paper will explore this relationship between technology and discovery in the field of oceanography, by examining examples of instrumentation development at the Bedford Institute of Oceanography (BIO) between 1962 and 1986. Established in October 25, 1962 with the mandate to be Canada's centre for oceanographic research and technical surveys for the Atlantic and Arctic Oceans, BIO's first twenty-five years were marked by a period of rapid technological development.[4] These advances were of two types: in-house developments and the adoption (and adaptation) of technologies developed elsewhere. Both reflected the transition to digital technologies as microelectronics and computing transformed oceanographic observation and theorizing. Focusing on in-house developments, this paper considers a number of features of instrumentation development at BIO: first, the developments themselves; second, their impact on the work of the Institute; and finally, the factors that encouraged or discouraged these developments. The examples have been chosen to demonstrate the range of work at BIO, particularly the integration of various oceanographic and technological disciplines, and highlight the critical transition from mechanical instruments to ones driven by microelectronics and computer technology, and finally, the evolution of trends in oceanographic research from 1962 to 1986. While oceanographers probed the mysteries of the oceans using these new technologies, historians can, through examining their development, analyse their influence on how institutions were organized, their chosen of areas of study, and what roles various groups played. The history of BIO shows how conscious choices established an atmosphere that encouraged technological innovation and how that changed through time as the Institute evolved into "one of the largest and most influential oceanographic laboratories in the world."[5]

Establishment of the Bedford Institute of Oceanography

> "The Bedford Institute was conceived as Canada's Atlantic and Arctic center for shipborne surveys and for marine research in the physical sciences. It was set up to meet national requirements in support of fisheries, navigation and maritime defence, and to provide assistance in the delineation of natural resources and in weather forecasting."[6]

Canada's efforts in oceanography after the Second World War are best described as diffuse, with numerous government agencies following separate agendas. The establishment of the Joint Committee on Oceanography (JCO) in 1946 attempted to coordinate research programs by bringing together federal departments with an interest in oceanographic research. Research had expanded during the war years, as the Canadian Navy realized its need to understand the physical properties of the ocean to improve sonar submarine detection. This focus on military research continued with the advent of the Cold War, expanding from strictly military concerns to sovereignty issues, especially in the Arctic. American interest in the high Arctic was driven by the threat from the Soviet Union: the polar region could be used as a staging area for nuclear attack from submarines and was also the flight path for bombers armed with nuclear weapons. This necessarily drew in Canada, which participated in the construction of the Distant Early Warning (DEW) line of radar installations across the Arctic and in the building of joint weather stations. Canada ventured into oceanographic work in the Arctic in response to American projects, such as the work in 1948 collecting temperature and salinity profiles by the USCG ships Edisto and Eastwind. Royal Canadian Navy (RCN) vessels began making sporadic trips into both the eastern and western Arctic and took oceanographic observations as part of their mission, although sovereignty was in all likelihood the prime reason.[7]

By the late 1950s, Dr. W.E. van Steenburgh had joined the Department of Mines and Technical Surveys (DMTS) as the Director-General of Science Services and had begun steering that department towards a greater involvement in oceanography, picking Halifax, with its large naval presence and the existing Defence Research Board (DRB) laboratory, as the site of east-coast activities. It seemed a logical choice with a newly established oceanography program at Dalhousie University under negotiation by 1958 and the Fisheries Research Board of Canada (FRB) proposing to move the Atlantic Oceanographic Group (AOG) from St. Andrews to Halifax in the same year. By December 1959, van Steenburgh, now the chair of the reorganized Canadian Committee on Oceanography (CCO), was in a position to announce the establishment of BIO and the construction of a scientific vessel, the CSS Hudson, to support its work.[8]

Staff moved into unfinished buildings at BIO in the summer of 1962 and began the task of implementing van Steenburgh's vision. Ninety-five staff representing three federal agencies—AOG, Canadian Hydrographic Services (CHS), and Marine Services Branch (MSB), both part of DMTS—were on site by the official opening on October 25, 1962. In 1963, the marine geology unit of the Geological Survey of Canada (GSC) joined BIO, a response to the leasing of offshore areas for petroleum exploration. In its early years, the Institute was clear that its activities directly served the needs of those involved in the fisheries, navigation, and maritime defence, making efforts in its annual report to outline the tangible results that BIO provided to what it termed its "customers." Not surprisingly, the Institute devoted more space to maritime defence than to fisheries and navigation in the 1963 report.[9] At the time of BIO's establishment, the Cold War was more hot than cold, with the building of the Berlin Wall in 1961, the Cuban missile crisis of 1962, the escalating conflict in Vietnam, and the assassination of President Kennedy in November, 1963.[10]

Envisioned as a bold experiment, BIO brought together, in one physical location, scientists whose work ranged across oceanography, hydrography, geophysics, chemistry, geology, and biology. The facility also housed technicians and support staff, provided vessels and docking facilities, and a high level of electronic and mechanical engineering design and support. BIO extolled itself as "the only example of its kind in North America," a statement with a touch of hyperbole.[11] While combining the capacity to conduct technical surveys for navigational charting and tide charts in an institute with oceanographic research was novel, certainly other institutes combined many disciplines in integrated facilities. The Scripps Institution of Oceanography (SIO) and Woods Hole Oceanographic Institution (WHOI) had similar organizational structures to BIO: a campus with a number of quasi-independent labs or organizations; common, shared facilities such as ships and wharves; and support staff for data processing and instrument development.[12] In its earliest days, BIO considered this dual role of research and applied science as appropriate, each depending on the other for support and synergy in the transfer of ideas and techniques. Especially important and noted explicitly from its beginnings was the desire for BIO to develop its engineering capacity, specifically for instrument development. By 1963, design and development work had already commenced in this area.[13]

Technology Development at BIO

> "The development of highly accurate and dependable instruments for Oceanography is one of the major problems facing man in his endeavors to understand and effectively utilize the wet continents."[14]

The first twenty years of BIO's existence marked a transition period for technology in general as instrument makers began incorporating microelectronics and computers. In the early 1960s, the tools used for physical oceanography (**Figure 1**) would not have been unfamiliar to members of the Challenger expedition of the 1870s.[15] But the revolution in solid state and microelectronics was underway and, coupled with the advent of microcomputers, would transform the collection and analysis of data in ways that the early pioneers of oceanography could not have imagined. By 1986, the world had changed: more analysis was done *in situ*: remote sensing and satellite usage was expanding; costs for computers and microelectronics were dropping quickly; and data-transmission methods through satellites and computer networks were becoming standard practice. No longer did oceanographers seek to collect detailed, highly accurate observations at a small number of stations, a method limited by the availability of ship time. Rather, oceanographers with new instruments began gathering masses of data over wide areas using relatively inexpensive methods, and analyzed them using new computer tools to derive insights.[16]

Other factors drove changes in a similar direction. Inflation, the scourge of fixed incomes, ran rampant through the 1970s with fuel costs skyrocketing as a result of OPEC's oil embargo after the Yom Kippur War in 1973.[17] The

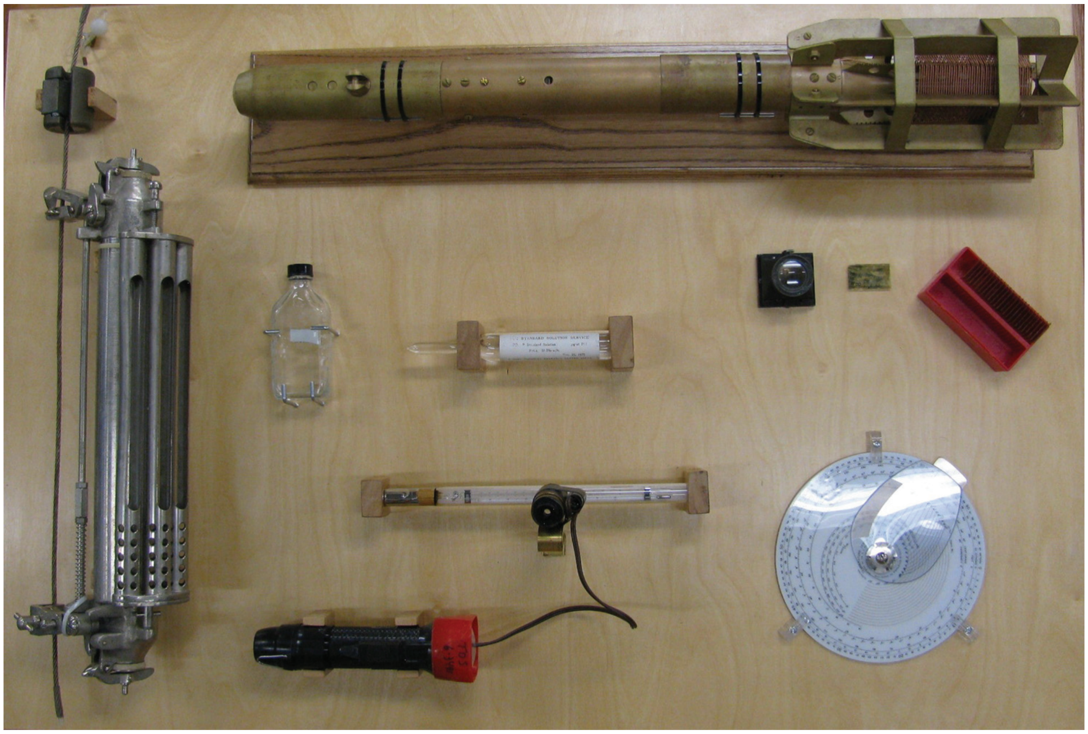

Figure 1. *Tools of the trade for physical oceanography in the early 1960s. From the top: bathythermograph (BT) for measuring water temperature at various depths; slide holder and glass magnifier for reading slides from the BT; special slide rule for converting thermometer readings to temperature and depth; illuminated magnifier for reading reversing thermometers; just above is a reversing thermometer; above that is a standard sample of sea water used to compare recovered samples; to its left is a sterile water bottle for storing seawater samples for later testing; far left is a Knudsen water bottle for collecting seawater samples. Credit: BIO Oceans Association, Physical Oceanography - Twentieth Century Tools of the Trade, http://www.bio-oa.ca/phys_oc/index.html downloaded Feb. 25, 2014.*

Iranian Revolution in 1979 and the subsequent Iran-Iraq war also drove up oil prices, which reached $35/barrel—ten times the early 1970s price. These events also drove up the costs of ship time and conducting on-board research.[18] This period also saw significant changes in government policy regarding research and development in Canada, guided by the work of the Senate Special Committee on Science Policy chaired by Maurice Lamontagne. Beginning with its first three reports issued from 1970 to 1973 and continuing to its last report late in the 1970s, the Committee exerted great influence on science in Canada and on the development of technology at BIO in particular.[19] The government accepted several of the Committee's recommendations, including the establishment of the Natural Sciences and Engineering Research Council (NSERC) as the primary granting agency for Canadian scientific research; the requirement for more industry involvement in research and design through targets and technology-transfer programs; and the implementation of new funding processes, particularly what became known as the unsolicited proposal process. BIO's response to these initiatives was part co-operation, part soft resistance.[20] When the situation suited, BIO cooperated, such as when an instrument or platform developed by BIO staff could be transferred to industry for production and sale. But BIO was less accommodating when it came to its research programme and the government's requirement that 50% per cent of BIO activity be conducted by the private sector. BIO outlined numerous challenges to meeting this requirement, citing the small size of Canada's research and instrumentation industries, its inability to meet quality standards, and the difficulties in dealing with administrative hurdles associated with the contracting process. It even attempted to sidestep this requirement, and protect its research programme, by including maintenance and servicing of equipment in its calculation of private-sector activity. By 1974, however, this resistance to contracting-out for services softened after a review of all research activities was undertaken to determine suitable candidates for private-sector delivery. This resulted, by 1976, in the identification of such partners as Huntec (70), Guildline Instruments, and Hermes Electronics.[21] BIO management was not above using this new emphasis on partnership with the private sector, for example, when proposing a building expansion to relieve overcrowding. The pitch for additional capital funding anticipated significant benefits for the private-sector partners resulting from such an expansion without mentioning, of course, how it might benefit the staff of the institute.[22]

In its beginnings, the philosophy of BIO was clear: research was dependent on the utilization of the newest equipment and, while the production of that equipment could be left to commercial interests, the design and development of those tools should be done by BIO staff in conjunction with the researchers at BIO. That philosophy led to the establishment in 1964 of the Instrument Design Group headed by Dr. R.L.G. (Reg) Gilbert to work on developing new electrical and mechanical equipment, and improving the operation of existing equipment.[23] During its growing pains, BIO searched for the right organizational structure to reflect these changes: in 1965, the recently formed Instrument Design Group was subsumed into the Engineering Services Group and in 1966 the Metrology Division was split off from Engineering Services. The division was headed by Dr. Gilbert until 1970, when he left BIO for a position in Ottawa with the Department of Fisheries and Forestry. He was succeeded by Dr. Clive Mason and later by Dr. David McKeown in 1976.[24] The Metrology Division would become the driving force behind the research and development of oceanographic instrumentation at BIO for more than twenty years, continuing to exist with minor changes until the 1994-5 merger of the Department of Fisheries and Oceans (DFO) with the Canadian Coast Guard (CCG) brought about significant change to BIO's organizational structure.[25]

The following examples of technological development are illustrative of the shift to microelectronics, computer applications, industry participation, and increased operating costs at BIO. These projects are representative of the hundreds of projects carried out at BIO between 1962 and 1986, and convey the breadth of work that crossed oceanographic and technological disciplines, and illustrate how oceanographic research has evolved into a multidisciplinary endeavour during this twenty-five-year period in BIO's history.

Hydrostatic Rock-Core Drill

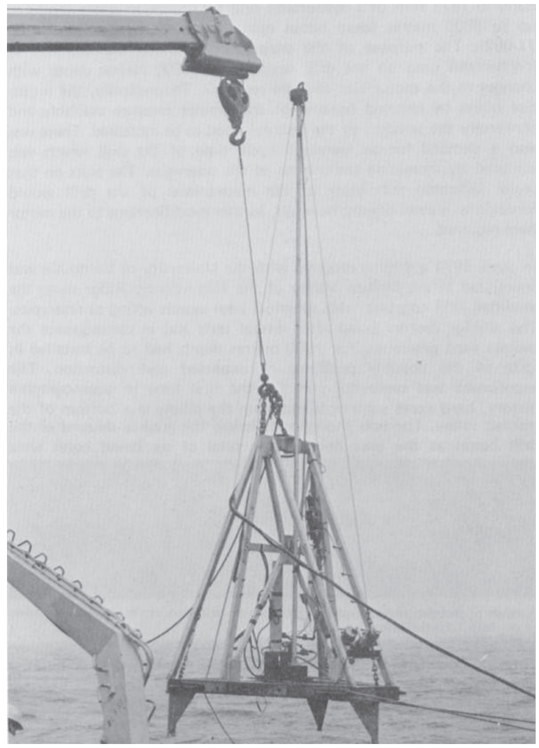

Figure 2. Shallow-water electric rock-core drill with 20 foot barrel. BIO, Biennial Review 1971/72, 150.

In 1965, John Brooke and Reg Gilbert of the Metrology Division led the development of a hydrostatic rock-core drill with the goal of creating a tool capable of collecting rock cores from depths between 800 and 2000 meters. This was part of BIO's efforts to investigate the new theory of plate tectonics and the incidence of sea-floor spreading by examining shallow areas of the Mid-Atlantic Ridge. Existing drills were limited by the lack of an independent power source and required power cables from the surface. The hydrostatic drill used the water pressure at depth as its means of power, with the flow of water into an empty reservoir providing sufficient power to drive a small drill system. But challenges remained particularly with downloading, the need to apply downward pressure for the drill to penetrate the rock. While the usual solution was to fix mass at the top of the drill, this decreased its stability. Instead, Brooke and Gilbert devised an automatic load-sensing download mechanism that sensed the power consumption of the hydraulic motor and, through the pressure along the hydraulic circuit coupled with a hydraulic cylinder, applied the appropriate amount of downward pressure on the drill bit. By 1969—the year Brooke and Gilbert patented it—the drill was producing one-inch diameter cores up to 15 inches long from the Ridge area in water over 800 metres deep. Unfortunately, the depth range of the drill limited its work to the relatively shallow peaks of crests found in the Median Valley of the Ridge and work began on an improved version capable of drilling in waters 4000 metres deep. Although controlling and monitoring the drill was difficult, it was used to obtain samples for various research programs at much cheaper cost than alternative means such as specialized drill ships.[26]

The success of the hydrostatic drill stimulated further development work on drills capable of working in shallower water. The shallow-water drill (**Figure 2**) could not rely on water pressure to drive the drill, so the designers added a small three-phase pump motor to the drill. This connection also provided the opportunity to constantly monitor and control the drill. Initially designed for work on the continental shelf in waters up to 400 meters deep, a version was later modified for use in waters ten times deeper, equivalent to the depth location of the mid-ocean ridges. Capable of drilling up to nine meters into the seafloor, the electric rock-core drill was used extensively to collect core samples from hundreds of stations from the Bay of Fundy up to the high Arctic region. These cores still represent the only source of information on the geological bedrock of many sections of Hudson Strait and the Baffin Island Shelf, an area with potential for hydrocarbon development. Like the hydrostatic drill, the electric rock-core drill saved money as it was less expensive to operate than a specialized drill ship.[27]

Hydro-acoustic Assessment of Fish Stocks

During the 1970s, more fish stocks came under quota-management systems that used stock assessments and abundance estimates to determine catch levels. As regulatory regimes became more segregated with stocks subdivided into smaller management units, the demand for stock information increased and drove scientists to look for more accurate tools for estimating fish abundance. The traditional method in the 1960s was the trawl survey, which provided a basis to determine the catch-per-unit of effort and thus an estimate of abundance. In 1966, the Marine Ecology Laboratory (MEL) began experimenting with echo sounders and the properties of acoustic signals produced when passing through an assembly of fish. By 1974, Dick Dowd and Ross Shotton of MEL had developed the Computerized Echo Counting System (CECS, **Figure 3**), which was capable of sorting the returning acoustic signals from a transducer into size categories that could be then used to calculate the number of fish per 1000 cubic metres of water, providing a real-time measure of fish density. Initially developed for demersal species, Dowd and Shotton soon expanded this work to include herring and other pelagic species. The basic components of the system were an echo sounder, a transducer, and a computer, but the real work was performed by their computer programs that crunched the numbers on stock-abundance estimates.[28]

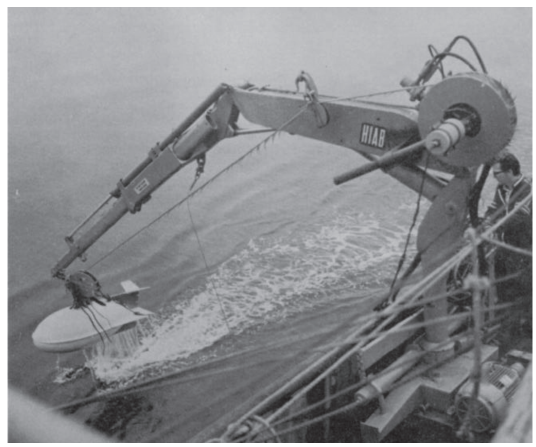

Figure 3. *A hydraulic crane is used to lower and raise the CECS towed body, which contains the echo sounder's transducer, as part of the acoustic fish-counting program. BIO, Biennial Review 1973/74, 242.*

But users of CESC faced challenges that put into question their reliability for stock-assessment work. Echo-sounder systems exhibited high variability in return signals, a problem caused by different sizes of fish and their relative position to the sound beam. Fish closer to the center of the beam, for example, returned a stronger echo than those at the edges. As well, different vessels surveying the same stock gathered different results showing high degrees of variability in the returns. To resolve these issues, Dowd and Shotten continued work on the concept into the 1980s with the development of a new system called ECOLOG that used two transducers to obtain better estimates of fish size and stock abundance. By 1983, the system had been built and tested with encouraging results, but it needed further development before it was accepted.[29]

Seabed Mapping

Understanding the topography and composition of the seabed floor is critical to the exploration of the oceans. The increased interest in marine geology after World War II led to a drive to collect samples of materials on the subsurface as well as the seabed. The development of seabed mapping programs at BIO—beginning in 1974 with Huntec Ltd. and continuing through Project Seabed I and Project Seabed II which ended in 1985—to address these needs brings a focus to many of the themes discussed here, including the use of new technologies, collaboration between different groups at BIO, and the use of public-private partnerships. The genesis of seabed mapping occurred in the late 1960s with Lewis King and other researchers from the Marine Geology Section who realized that the echo sounders on the BIO fleet provided more information than water depths at their sample sites. The echo sounders recorded the results on rolls of paper and King realized that there was a correlation between the type of sediment on the seabed and the image on the paper roll; for example, the echoes penetrated mud bottoms, returning a different pattern than echoes from bedrock or till where the echoes do not penetrate. This discovery led to the use of echo sounders to map and characterize large areas of the seabed using echograms and seabed-sediment analyses.[30]

By the 1970s, geologists used a variety of tools based on King's discovery with echo sounders using high-frequency sound waves and seismic profilers using low frequencies being the most popular. But neither system worked well in all conditions, either because of the type of sediment layers on the sea floor or due to wave and wind conditions on the surface. Given the level of interest in exploration for offshore oil in the early 1970s, a system capable of providing clearer profiles of the surficial sediment stratigraphy was needed. Marine geologists would then be able to "see" beneath soft, muddy clay sediments that had previously obscured hard sediments such as till or sand and allow them to find specific features such as stacked tills which indicate areas of glacial movements. To address these needs, Huntec met with the Metrology Division and Atlantic Geoscience Centre to develop a proposal for review under the new unsolicited proposal process established in 1972 to stimulate research and development and encourage commercialization. Huntec proposed in 1974 to develop a deeply-towed seismic system (DTS) capable of achieving high levels of resolution of the seabed and deeper penetration into the sediment even when towed at relatively high speeds.[31]

Testing of the new DTS system in the summer of 1974 led to numerous improvements and the results were considered to be outstanding, leading to

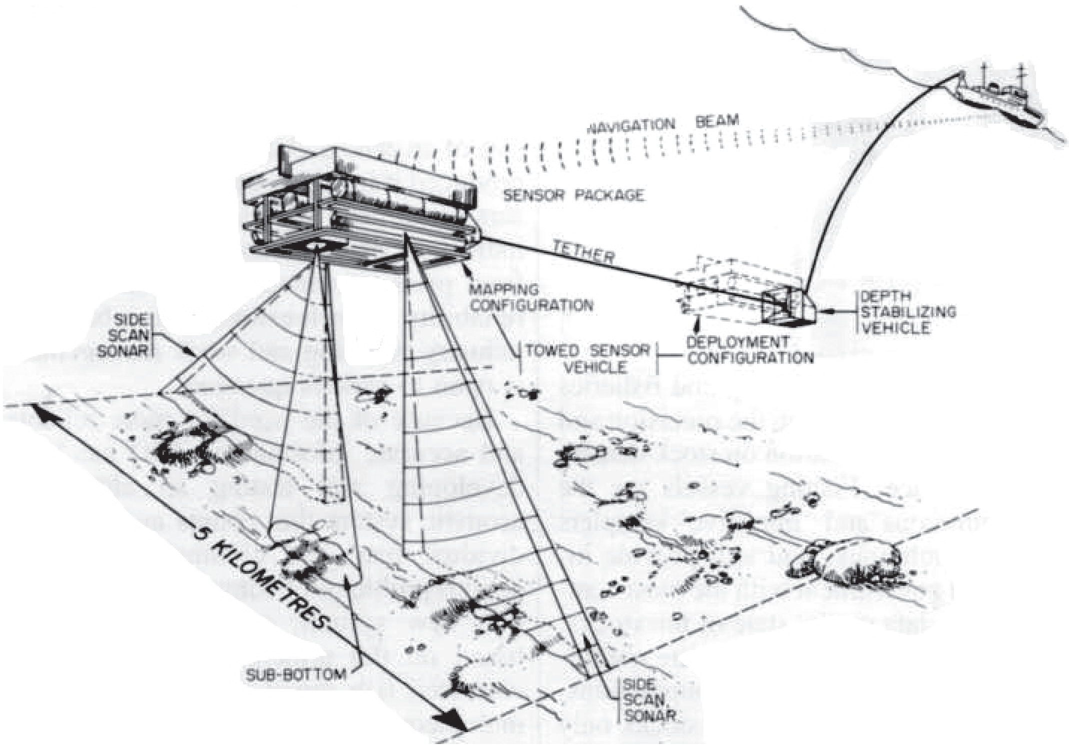

Figure 4. A schematic depicting the principle of operation of the two-stage Seabed II integrated mapping system. BIO, BIO Review '83, 41

recommendations to include the system in BIO's toolkit and to prepare a long-term program of system development. To this end, Huntec entered into a five-year partnership in 1975 with BIO and Memorial University called Seabed I to further develop the tool and begin mapping the seabed floor. Through the five years of the program, numerous improvements were made to the system and by 1980 Huntec was successfully marketing operational units to international clients.[32]

Seabed II (1981-1985, **Figure 4**) built on the efforts of the first project and extended the range of the submersible so it could work in much deeper waters and cover larger areas. Equipped with improved technology, it could work below depths of 2000 metres and its side-scan sonar covered 2.5 km on either side of the submersible. Although successfully tested in 1983 and 1984, the project was terminated in 1985 due to reductions in government spending. By incorporating some of the new technology developed for the Seabed II into the older Huntec DTS, BIO continued its program of geological mapping in the offshore territories and collected data along lines stretching more than 250,000 kms to date.[33]

Temperature Probes: Digibridge, OCTUPROBE (Oceanic Turbulence PROBE) and EPSONDE

This period saw a rapid evolution in the capability of measuring ocean temperatures, from the reversing thermometers of the 1960s to probes capable of transmitting extremely precise data instantaneously to the surface. This ability to measure temperature variations on very small scales (representing small-scale turbulence in the ocean) was an innovation that significantly altered the conceptions of physical oceanography at that time.[34] One of the earliest examples of an integrated digital-electronic instrument developed at BIO was the Digibridge. Developed in 1970 by a team led by Andrew Bennett of the Metrology Division, the Digibridge recorded a precise time-series of ocean temperatures. The device, which could operate continuously for up to 20 days, featured a recorder that measured the resistance of three glass-bead thermistors every five minutes, thus providing a temperature reading with an accuracy approaching 0.003°C. The Digibridge was secured on a mooring with a pop-up frame, and was activated by an acoustic command from the surface.[35]

As the sensitivity and precision of instruments improved, oceanographers discovered variations in temperature profiles throughout the water column that were not earlier suspected. The Digibridge was limited in studying these variations as it was fixed on a secure mooring, which led to improved instruments such as the OCTUPROBE (Oceanic Turbulence Probe. **Figure 5**), a device designed by Neil Oakey of the Instrumentation Group of the Ocean Circulation Division to measure variations in temperature, salinity, and turbulent velocity in the water column. The OCTUPROBE was allowed to free-fall through the water column with data being recorded using an internal tape drive. When the desired depth was reached, the probe was retrieved using an attached line, and the process was repeated until the tape drive was filled. Oakey and his team continued to make design and technical changes based on improving computer and electronic capabilities for measuring, storing, and transmitting data and, by 1982, the OCTUPROBE evolved into the EPSONDE. While the EPSONDE used similar sensors as the earlier OCTUPROBE, it was capable of transmitting data digitally directly to the surface through the tether line, making the internal tape recorder obsolete.[36]

Navigational Accuracy—BIONAV

Accurate positioning at sea has long challenged mariners and scientists, at the same time that our definition of accuracy has evolved with increasingly precise technology such as GPS. By the 1970s, BIO ships utilized a number of different navigation systems because ship cruises performed a variety of tasks during each voyage, including retrieving buoys, running survey lines, locating drill sites, or maintaining position over several hours. Each of these tasks was under the direction of a different group, who usually used a different navigation system suited to the task at hand. Each system had strengths and weaknesses, working well in certain applications and under certain conditions but not in others. After surveying users in 1975 to determine their needs, programmers Stephen Grant and David Wells began to develop a software package that could integrate the various systems then in use, such as Transit satellite navigation, Loran-A and Loran-C, Decca, speed logs, and gyrocompasses. The result was

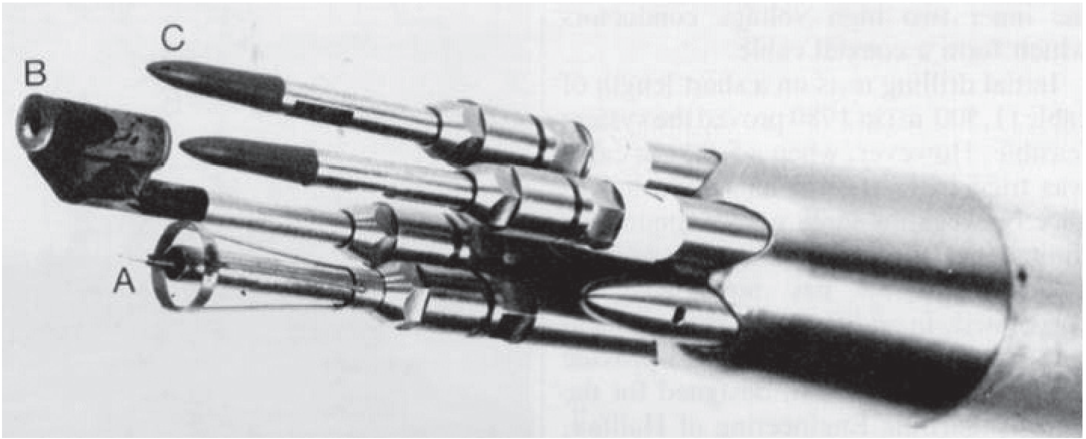

Figure 5. OCTUPROBE, showing the internal structure of the 2 metre probe with three sensors: A is a thinfilm sensor to measure temperature microstructure; B is the conductivity sensor; C are two lift probes to measure two perpendicular components of velocity microstructure or turbulence. BIO, BIO Review '83, 47.

the BIONAV system, developed in 1978 to maximize the strengths of individual navigational systems, plot survey-data in real time, guide the ship to an exact position, and reduce operating costs by using ship time more efficiently. Written in-house in Fortran IV by Grant and Wells, BIONAV consisted of 150 individual computer programs, library routines, and procedures totalling over 30,000 lines of code.[37]

The free distribution of the system to other institutions and private companies promoted its extensive use throughout Canadian marine waters. Users could modify BIONAV for different hardware and the system became remarkably successful, allowing scientists and hydrographers to navigate more accurately. It was only replaced with the advent of the Global Positioning System (GPS) in the late 1990s.[38]

Biological Sampling—BIONESS

The uneven spatial distribution, or patchiness, of plankton has challenged oceanographers who have attempted to estimate populations of these miniscule organisms, the foundation of oceanic food and energy chains. Opening-closing nets, developed in the late nineteenth century, were the main tool available to scientists until Alister Hardy introduced his Continuous Plankton Recorder (CPR) in the 1930s. Designed to be towed behind ships of opportunity, it was roughly one meter in length, with spools of silk mesh situated to capture plankton as the seawater flowed through the CPR. After the Second World War II, researchers improved on this design and other mechanical instruments and by the 1960s began developing electronic and acoustic-control systems.[39] The technology revolution in the 1970s finally enabled researchers to move beyond simple opening-closing net systems to gain a fuller understanding of the patchiness of plankton.[40]

This was evident at BIO, where close cooperation between engineers and researchers led to new methods for determining planktonic spatial patterns using advances in control systems and technology that could measure salinity, temperature, and other variables. Doug Sameoto of the Marine Ecology Laboratory developed the Bedford Institute of Oceanography Net and Environment Sensing System (BIONESS) consisting of a system of ten nets capable of being opened or closed allowing the researcher to take samples at various depths, providing a vertical distribution of plankton in the water column. As well, additional smaller mesh nets could be inserted into the mouth of the other ten nets, allowing a total of twenty separate samples to be collected in each tow. Alex Herman, an engineer in the Metrology Division, added computer technology to the system with a microprocessor capable of controlling the unit underwater. With sensors to provide physical oceanographic data such as temperature, salinity, and depth connected to the controller, the nets could be opened or closed based on predetermined information; for example, at a certain depth or temperature, a specific net would open or close. The control system also collected data on water speed and volume, chlorophyll *a* fluorescence, and light. The adaptation of these controls to pumping systems to correct for the motion of the ship allowed biological sensing and sampling with a discrimination of one metre in 100 metres of depth. Another example of the technology transfer program, this system went into commercial development and units are still available for purchase.[41] The use of microcomputers to control systems and the development of sophisticated sensors capable of connecting to those control systems provided researchers with the tools needed to acquire an accurate picture of both vertical and horizontal patterns of plankton distribution.[42]

Physical and Biological Data Capture—Batfish (towed CTD and plankton counter)

The development of the Batfish (**Figure 6**), a towed vehicle capable of moving vertically through the water column carrying multiple sensors, brought together many of the themes evident in the other examples. It evolved from its initial design as an automatic bathythermograph capable of collecting temperatures as it oscillated between pre-set depths of 50’ and 250’, into a sophisticated platform for collecting physical and biological data throughout the water column as it was towed and controlled from a ship at normal cruising speeds. A young, recently hired engineer, J.G. Dessureault, led the work from 1966 for many years and based his Master’s thesis on its development.[43] The evolution from its conception to its state in 1986 captures many of the developments discussed previously: the rapid expansion of the use of microelectronics and digital equipment; the transfer of technology from the public to the private sector; the increased use and power of computing technology; and the interaction between various groups at BIO resulting in a co-operative approach to solving problems.[44]

By 1975, the Batfish had been developed into a vehicle with a bottom-avoidance system, able to collect data on temperature and salinity variations in the top 400 metres on a continual basis as the vehicle moved horizontally

Figure 6. *Batfish on CSS Hudson during a 1980 Gulf of St Lawrence cruise. Photo: Andrew Bennett.*

and vertically through the water. This ability revealed complexities in the wave field that could not be observed with conventional vertical casts of conductivity, temperature and depth (CTD). Importantly, that year marked the shift into biological sensing in addition to the CTD work. In 1974, the Batfish had been used to collect CTD information and then was fitted with a fluorometer to get a two-dimensional picture of chlorophyll concentrations. This work was advanced in 1975 as the Metrology Division adapted fluorometers for use on the Batfish in conjunction with CTD sensors and work commenced on developing a zooplankton counter that could be integrated into the data-collection array on the vehicle.[45]

Improvements were continually made to address difficulties encountered with the counter, such as its need for continual cleaning, leading to short towing periods of less than three hours and its inability to measure animals longer than 3mm. With advances in optical technology, particularly in the field of low-power light-emitting diodes, BIO, through the work of Dr. Alex Herman, developed an optical plankton counter that could be fitted onto the Batfish. Patented as the Laser Optical Particle Counter, a newer version is still available for sale through ODIM Brooke Ocean.[46] A light beam was used to determine the size of animals that broke the beam, getting an estimate of the zooplankton; and the same beam could provide an estimate of phytoplankton biomass by measuring the light attenuance of the water. Freed from the need for a net, tows were no longer limited in duration. By 1986, the Batfish was a more complete data-collection platform with some sensors developed solely by BIO, others in conjunction with industry partners, all of it available commercially through various technology-transfer arrangements.[47]

Conclusion

The various technologies developed in the early years of BIO serve as examples of how data gathering and analysis have been revolutionized by the technological advances of that period. A complete survey of the vast number of projects carried out by BIO in its first twenty-five years was beyond the scope of this work, but even the examination of a limited number of examples can be instrumental in highlighting critical factors evident in that time.

The decision in the very early years of BIO to build the capacity to design and develop instruments and technology served it well over the period, evident in the examples presented and the many others detailed in the annual reports of BIO. The co-location of many disciplines on the BIO campus created a cross-fertilization of ideas and concepts. The consultations that led to the development of BIONAV and the evolution of Batfish into an instrument for biological oceanography doubtless happened because these diverse groups all worked in the same location. The role of the Metrology Division in its various forms was critical; the group maintained links with all the various users and served as a form of clearing house for ideas that could be transferred from one field to another.

Along with the transfer of ideas was the acceptance of new technology and processes that propelled development in this period. An openness to experiment and to challenge existing orthodoxy prevailed. But the experience of BIO was not unique; this spirit was evident in the universities, the culture, and throughout society in the 1960s and 1970s. This openness was evident at BIO in the invention and rapid adoption of new technology, as well as the enthusiastic adaptation of these new tools for uses in other fields or modification for another use, exemplified by the hydrostatic rock drill.

The questions in biological oceanography largely remain the same as in the early 1960s. What controls the production cycle and what governs the biological cycle? What are the chemical reactions between sediments and ocean water, and the influences of the biological communities on these reactions? What has changed is the technology used to answer these questions.[48] Regardless of any changes in the focus of research, it is evident that this period was transformative, as oceanographers progressed from collecting data while aboard ships using bottles, nets, thermometers and slide rules to utilizing vast arrays of remote sensors and satellite images all analyzed by powerful computers at their fingertips. The advances made in this period were due to the ability to collect and analyze large sets of data.

The challenge today becomes not the collection of data but the management and quality assurance of it, that is, the need for practitioners to understand the technical aspects of the data-collection process and have the ability to relate that to the questions at hand.[49] While the methods get increasingly sophisticated and the technology allows the oceanographer, in theory, to collect data without ever being near the source—through the use of arrays of sensors, remotely operated vehicles, acoustics, or modelling—there is a danger of missing a connection. There is also a danger of getting lost in this mass of data. Would philosopher William Whewell still think the most promising way to advance knowledge is to collect a mass of observations if he knew that the power to collect data could not just remove all accidental causes, but perhaps obscure possible causes?

Michael Murphy is a Research Associate with the Gorsebrook Research Institute, St. Mary's University. After a long career with Fisheries and Oceans Canada at various places across Canada, including a number of years at the Bedford Institute of Oceanography, he completed a MA (Hist) at Dalhousie University. His research interests currently center on the development of the Maritime provinces after the Second World War.

Endnotes

1 William Whewell, *On the Empirical Laws of the Tides in the Port of London; With Some Reflexions on the Theory,* Phil. Trans. R. Soc. Lond. 1834 124, doi: 10.1098/rstl.1834.0004, published 1 January 1834, 18. I need to thank a number of people for their contributions to this project. Dr. Eric Mills was most helpful in the early stages of this paper and his comments guided me throughout. Dr. Shirley Tilliston provided detailed comments after my presentation at a Stokes Seminar at Dalhousie University. The anonymous reviewers and editors provided thoughtful comments that improved the paper immensely. I would like to add a thank you to the BIO Oceans Association for their efforts in preserving the history of the Bedford Institute of Oceanography, especially the equipment. A number of members have been active in documenting and preserving the various pieces of equipment used or developed at BIO. As well, the management of BIO has been helpful in providing space for the storage and display of the artifacts. A special "thank you" needs to be given to Dr. David McKeown who has led the project and provided me with guidance on areas of research as well as some helpful tools to search the BIO Annual Reports.

2 Margaret Deacon, *Scientists and the Sea—650-1900 a study of marine science* (London, New York: Academic Press, 1971), 167. While Deacon outlines the link between technology and instrumentation throughout this work, it is most appropriate to refer to a section from the chapter dealing with the investigations of that great instrument maker, Robert Hooke.

3 Benson, Rozwadowski, van Keuren, "Introduction," xiv.

4 Bedford Institute of Oceanography, *Second Annual Report 1963*, BIO 63-6, December 1963, 1-2.

5 Eric L. Mills, "Canadian Marine Sciences from before Titanic to the Establishment of the Bedford Institute of Oceanography in 1962," in *Voyage of Discovery: Fifty Years of Marine Research at Canada's Bedford Institute of Oceanography,* ed. D.N. Nettleship, D.C. Gordon, C.F.M. Lewis, & M.P. Latremouille (Dartmouth, N.S.: BIO-Oceans Association, 2014) 3.

6 BIO, *Annual Report 1963*, 2.

7 Mills, "Canadian Marine Sciences from before Titanic to the Establishment of the BIO," 3-11. Mills provides a substantial overview of marine science in Canada tracing its development from the late 1800s up to the creation of BIO in 1962. He outlines developments in charting, tidal studies, and various disciplines of oceanography. Considerable detail on the organizational struggles in the federal bureaucracy, culminating in the decision of W.E. van Steenburgh to establish BIO is provided. Also useful is Jennifer M. Hubbard, *A Science on the Scales: The Rise of Canadian Fisheries Biology, 1898-1939* (Toronto: University of Toronto Press, 2006). Particularly pertinent is Chapter 8 (p. 192-224) outlining the struggle of the St. Andrew's Biological Station and the rise of Halifax as the predominant center for oceanographic studies on the Atlantic coast of Canada.

8 Mills, "Canadian Marine Sciences from before Titanic to the Establishment of BIO," 10.

9 BIO, *Annual Report 1963*, 2-3.

10 Simone Turchetti, "Sword, Shield and Buoys: A History of the NATO Sub-Committee on Oceanographic Research, 1959–1973," *Centaurus* Vol. 54 (2012): 205–231. Turchetti provides a comprehensive examination of NATO's involvement in oceanographic research in this period, especially efforts connected to anti-submarine warfare.

11 BIO, *Annual Report 1962*, 1-2.

12 See for example Scripps Institution of Oceanography, *Annual Report for the Year Ending June 30, 1967*. Downloaded from http://scilib.ucsd.edu/sio/annual/Annual_report_1967.pdf (April 12, 2014). It outlines the work of the Special Development Group charged with developing new instruments for oceanographic research (see p. 11, 21, 28-31, and 33 for examples). Also, Woods Hole Oceanographic Institution had a Department of Applied Oceanography that was charged with a similar mandate – to develop and test instruments. See for example Woods Hole Oceanographic Institution, *Annual Report 1966,* (p. 21-23) for some description of their activity. Downloaded from http://www.whoi.edu/fileserver.do?id=20506&pt=10&p=16574 (April 10, 2014).

13 BIO, *Annual Report 1963*, 2-6.

14 Gilbert Jaffe, "The Systems Approach to Oceanographic Instrumentation – An Introductory Address," in *Systems Approach to Oceanographic Instrumentation*, ed. Fred Alt (Pittsburgh: Instrument Society of America, 1967), 1.

15 The *Challenger* expedition left Portsmouth, England in December 1872 on a three and a half year voyage. Led by Wyville Thomson, it travelled more than 130,000 kms around the world and its findings laid the basis for the science of oceanography. The expedition was charged to investigate the physical, chemical, and biological properties of the oceans. Deacon, *Scientists and the Sea,* 331-365, provides an excellent overview of the expedition and its importance.

16 D.J. Baker Jr., "New Devices and Concepts for Ocean Measurements," in *Oceanography, the Present and Future*, ed. Peter G. Brewer (New York: Springer-Verlag, 1983), 363-376.

17 OPEC – Organization of Petroleum Exporting Countries.

18 WRTG Economics, http://www.wtrg.com/prices.htm, accessed Apr. 5, 2014.

19 Maurice Lamontagne (chair), *A Science Policy for Canada, Report of the Senate Special Committee on Science Policy*, 4 volumes. Downloaded from http://www.albertasenator.ca/?mainloc=savvy51 accessed Apr. 5, 2014. The web site of Sen. Elaine McCoy contains links to the Lamontagne report. Also of interest is G. Brent Clowater, "Canadian Science Policy and the Retreat from Transformative Politics: The Final Years of the Science Council of Canada, 1985-1992," *Scientia Canadensis: Canadian Journal of the History of Science, Technology and Medicine / Scientia Canadensis : revue canadienne d'histoire des sciences, des techniques et de la médecine* Vol. 35, n° 1-2, 2012, p. 107-134. While the article deals specifically with the Science Council of Canada, it provides a comprehensive overview of science policy from 1945 through to 1992, and addresses the Lamontagne Report on p.114.

20 R. L. G. Gilbert and C. S. Mason, "The Bedford Institute of Oceanography and Industry - Experience and Progress in the Past Decade," in Bedford Institute of Oceanography, *Biennial Review 1971/72*, 58-66.

21 BIO, *Biennial Review 1975/76*, 47.

22 BIO, *Biennial Review 1973/74*, 1.

23 BIO, *Third Annual Report 1964*, BIO 64-18, December 1964, 34-35.

24 All three received their doctorates from Cambridge University (Cantab) considered at the time to be a hotbed of geophysical research.

25 BIO, *Fifth Annual Report 1*966, BIO 66-10, December 1966, 54-59.

26 Brian MacLean, Graham L. Williams, and George A. Fowler, "Bedrock Studies of the Baffin

Island Shelf and Hudson Strait: A Technological and Scientific Adventure," in *Voyage of Discovery: Fifty Years of Marine Research at Canada's Bedford Institute of Oceanography*, ed. D.N. Nettleship, D.C. Gordon, C.F.M. Lewis, & M.P. Latremouille, (Dartmouth, N.S.: BIO-Oceans Association, 2014), 331-332. Also BIO, *Annual Report 1966*, 59-61 and BIO, *Biennial Review 1969/70*, 126-127.

27 MacLean, Williams, and Fowler, "Bedrock Studies of the Baffin Island Shelf and Hudson Strait," 332-333. Also BIO, *Annual Report 1966*, 59-61; BIO, *Biennial Review 1969/70*, 126-127; BIO*, Biennial Review 1975/76*, 52. Leading the development of the electric drill were W.C. Cooke, G.A, Fowler, and W.J. Whiteway. Later innovations were done in partnership with Dalhousie University – P. Ryall and J.Ade-Hall.

28 BIO, *Biennial Review 1973/74*, 139-140 and 241-251.

29 BIO, *BIO Review '83*, 42-43.

30 Gordon B.J. Fader et al., " Seadbed Sediment Mapping at the Bedford Institute of Oceanography: From Single Beam to Multibeam,' in *Voyage of Discovery: Fifty Years of Marine Research at Canada's Bedford Institute of Oceanography*, ed. D.N. Nettleship, D.C. Gordon, C.F.M. Lewis, & M.P. Latremouille, (Dartmouth, N.S.: BIO-Oceans Association, 2014), 191.

31 David L. McKeown, Peter G. Simpkin, Gordon B.J. Fader, D. Russell Parrott, and David C. Mosher, "The Huntec Deep Tow Seismic System: A Revolution in High Resolution Profiling," in *Voyage of Discovery: Fifty Years of Marine Research at Canada's Bedford Institute of Oceanography*, ed. D.N. Nettleship, D.C. Gordon, C.F.M. Lewis, & M.P. Latremouille, (Dartmouth, N.S.: BIO-Oceans Association, 2014), 337-340.

32 Ibid., 338 and BIO, *Biennial Review 1977/78,* 169-173.

33 Ibid., 340 and BIO, *BIO Review '83*, 41.

34 BIO, *BIO Review '83*, 47.

35 BIO, *Biennial Review 1969/70*, 124.

36 BIO, *BIO Review '83*, 46-47, Peter C. Smith et al., "Coastal Ocean Circulation Studies," in *Voyage of Discovery: Fifty Years of Marine Research at Canada's Bedford Institute of Oceanography,* ed. D.N. Nettleship, D.C. Gordon, C.F.M. Lewis, & M.P. Latremouille, (Dartmouth, N.S.: BIO-Oceans Association, 2014),151-153.

37 Stephen T. Grant and David E. Wells, "The Bedford Institute of Oceanography Integrated Navigation System (BIONAV)," in *Voyage of Discovery: Fifty Years of Marine Research at Canada's Bedford Institute of Oceanography,* ed. D.N. Nettleship, D.C. Gordon, C.F.M. Lewis, & M.P. Latremouille, (Dartmouth, N.S.: BIO-Oceans Association, 2014), 353-356; BIO, *Biennial Review 1975/76*, 42-43 ; and BIO, *BIO Review '81*, 59-60.

38 Grant and Wells, "The Bedford Institute of Oceanography Integrated Navigation System (BIONAV)," 356, and BIO, *BIO Review '81*, 59-60.

39 Peter H. Wiebe and Mark C. Benfield, "From the Hensen net toward four-dimensional biological Oceanography," *Progress in Oceanography* 56 (2003): 7–136. Wiebe and Benfield provide an exhaustive view of the developments in plankton collecting systems from the 1880s to the present. See pages 38-41 for details on Hardy's CPR.

40 A. Herman and T. Platt, "Meso-scale Spatial Distribution of Plankton" in *Oceanography: The Past*, ed. Mary Sears and Daniel Merriman (New York: Springer-Verlag, 1980), 204-222.

41 BIO, *BIO Review '83*, 55-56; Bedford Institute of Oceanography, *BIO Review '86*, 4-8.

42 BIO, *BIO Review '86*, 4-8.

43 Jean-Guy Dessureault, *The Lateral and Directional Stability of Batfish, an Underwater Towed Body withWings*, (Halifax: Nova Scotia Technical College, 1977). Thesis as a requirement for a M.Eng. Copy at Dal Sexton Library.

44 Bedford Institute of Oceanography, *Biennial Review 1967/68*, 69. A complete description of the engineering development behind the Batfish is presented in J. G. Dessureault, " 'Batfish' – A

Depth Controllable Towed Body for Collecting Oceanographic Data," *Ocean Engineering* 3 (1976): 99-111; see also Tim Foulkes, "Technology in Marine Science at the St. Andrews Biological Station, 1908-2007", in Jennifer Hubbard, David J. Wildish, and Robert L. Stephenson, eds. *A Century of Maritime Science: The St. Andrews Biological Station* (Toronto: University of Toronto Press, 2016), 156-178, for a similar discussion on these developments.

45 BIO, *Biennial Review 1975/76*, 47-50 and BIO, *Biennial Review 1973/74*, 109-111.

46 ODIM Brooke Ocean, Laser Optical Particle Counter (LOPC™)—Next-Generation Particle Measurement Instrumentation. http://www.brooke-ocean.com/lopc.html (accessed April 15, 2014).

47 BIO, *BIO Review '86*, 4-8.

48 Eric Mills, *Biological Oceanography: An Early History 1870-1960* (Toronto: University of Toronto Press, 2012), xxvi. His discussion refers specifically to the biological questions and the use of new technology.

49 John Cullen, "Foreword" in Eric Mills, *Biological Oceanography: An Early History 1870-1960* (Toronto: University of Toronto Press, 2012), ix-xvii.