Fisheries and Oceans Canada / Pêches et Océans Canada
Ecosystems and Oceans Science / Sciences des écosystèmes et des océans

Canadian Science Advisory Secretariat (CSAS)

Research Document 2017/047

Newfoundland and Labrador Region

Methods to determine the efficacy of utilizing artificial scallop and rock reefs as fish habitat compensation in inshore Newfoundland

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July 2017

Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Research documents are produced in the official language in which they are provided to the Secretariat.

Published by:

Fisheries and Oceans Canada
Canadian Science Advisory Secretariat
200 Kent Street
Ottawa ON K1A 0E6

http://www.dfo-mpo.gc.ca/csas-sccs/
csas-sccs@dfo-mpo.gc.ca

ISSN 1919-5044

Correct citation for this publication:

Warren, T.N., and Roberge, M.M. 2017. Methods to determine the efficacy of utilizing artificial scallop and rock reefs as fish habitat compensation in inshore Newfoundland. DFO Can. Sci. Advis. Sec. Res. Doc. 2017/047. v + 17 p.

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ABSTRACT

Fish habitat compensation to offset the loss of productive fish habitat (fish and/or shellfish) in the Northwest Atlantic, especially in the offshore marine environment, is challenging. Between 2001 and 2005 works or undertakings associated with two offshore oil projects included activities that, as a condition of regulatory approval, required the creation of scallop shell reefs and a rock reef. Monitoring for the reef compensation projects included metrics used to demonstrate the effectiveness of the compensation including those to determine whether there were any changes in structural integrity and stability and species utilization of the reefs. Methods used to determine structural integrity, substrate stability and fish utilization using SCUBA divers included visual and video surveys to determine shell movement, settling/sinking of materials, changes or impairments to new materials, utilization of reefs by species. As well, for the rock reef, control sites were established along the shoreline and adjacent seabed as a comparison to the observed conditions on the artificial rock reef.

An evaluation of the metrics used revealed that most were useful in identifying changes over time and have enabled the assessment of the status of the compensation and possible additional data that could be included in future projects. When assessing compensation, metrics should be collected over a sufficient time period, be used in conjunction with other metrics, and should be detailed enough to provide a clear picture of trends. Baseline data is also critical prior to the placement of reef material as well as having a control site to verify changes in the reef utilization.

Méthodes visant à déterminer l'efficacité de l'utilisation de récifs artificiels de pétoncles et de roches comme compensation de l'habitat du poisson dans les eaux côtières de Terre-Neuve

RÉSUMÉ

La compensation de l'habitat du poisson pour compenser la perte d'habitat du poisson productif (poissons, mollusques et crustacés) dans l'Atlantique nord-ouest est difficile, particulièrement dans l'environnement marin extracôtier. Entre 2001 et 2005, les entreprises ou ouvrages liés à deux projets pétroliers en haute mer comprenaient des activités qui, comme condition préalable à l'approbation réglementaire, demandaient la création de récifs de coquilles de pétoncles et d'un récif rocheux. La surveillance des projets de compensation des récifs comprenait des paramètres utilisés pour démontrer l'efficacité de la compensation, notamment s'il y a eu des changements dans l'intégrité structurale et la stabilité ainsi que l'utilisation des espèces des récifs. Parmi les méthodes utilisées pour déterminer l'intégrité structurale, la stabilité du substrat et l'utilisation du poisson à l'aide de plongeurs figurent des relevés visuels et vidéo pour déterminer le mouvement des coquilles, le tassement ou l'affaissement des matériaux, les modifications et perturbations ayant une incidence sur les nouveaux matériaux, l'utilisation des récifs par les espèces. De plus, pour le récif rocheux, des sites témoins ont été établis le long de la ligne de côte et du fond marin adjacent comme comparaison des conditions observées sur le récif rocheux artificiel.

Une évaluation des paramètres utilisés a révélé que la plupart étaient utiles pour déterminer les changements au fil du temps et qu'ils ont permis d'évaluer le statut de la compensation et l'ajout de données additionnelles potentielles aux projets à venir. Au moment d'évaluer l'efficacité de la compensation, il faudrait disposer de paramètres recueillis sur une période suffisamment longue, les utiliser en conjonction avec d'autres paramètres, et s'assurer qu'ils sont suffisamment détaillés pour donner un clair aperçu des tendances. Les données de base sont également essentielles avant la mise en place des matériaux d'un récif ainsi que l'utilisation d'un site témoin pour vérifier les changements dans l'utilisation du récif.

BACKGROUND

Fisheries and Oceans Canada (DFO) typically require proponents of authorized works that harm or destroy fish habitat to create or improve habitat elsewhere as a compensatory or offsetting measure. Habitat compensation or offsetting plans are designed to be comprehensive and scientifically defensible and include monitoring programs to collect the necessary information to determine their effectiveness. Marine ecosystems are highly complex and provide many challenges for compensation. They involve numerous species and multiple trophic levels, the relationships of which are not always clearly understood especially in offshore areas which make finding suitable compensation options challenging. This led to the need to consider other unique options such as the creation of artificial reefs in inshore areas to offset losses for offshore fish habitats.

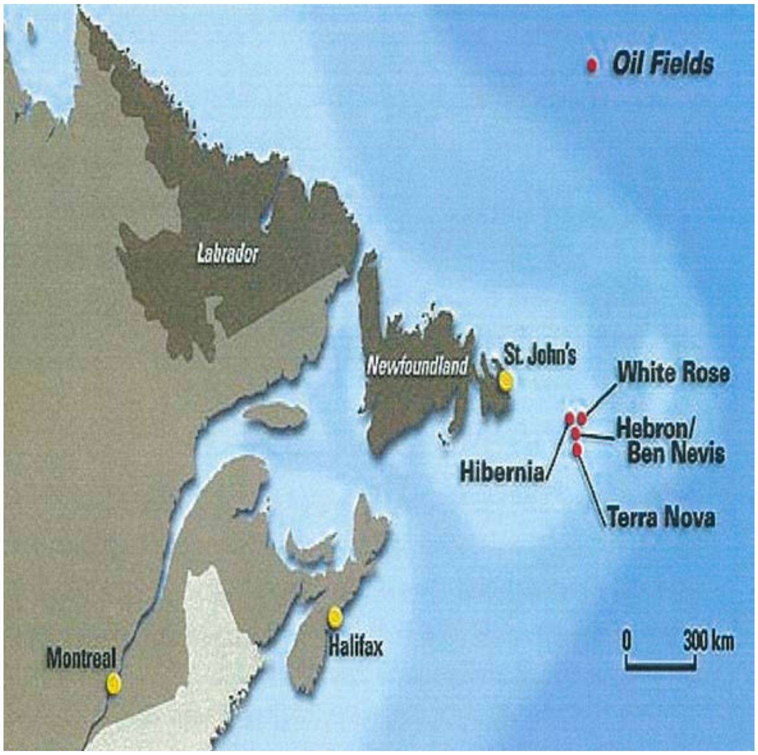

Figure 1. Locations of the Terra Nova Offshore Oil and White Rose Off Shore Oil Developments.

Two types of artificial marine reefs have been utilized in Newfoundland and Labrador (NL): scallop shell reefs and multi-species rock reefs. The first example of the use of an artificial reef as fish habitat compensation in NL was associated with the Terra Nova Offshore Oil Development (Figure 1). The physical area of the offshore habitat that would be resulted from the excavation of glory holes, associated smothering by deposition of the dredge spoils and berming of the flowlines within the project footprint area. The Iceland scallop (*Chlamys islandica*) was considered of greatest importance in the area of the project because of the organism’s limited mobility, sedentary behaviour and potential commercial value. To offset this loss 23,000 m^2 of inshore scallop shell habitats were constructed at Jers Cove and North and South Lake’s islands in Paradise Sound, Placentia Bay, NL to serve as a refuge for newly settled scallops in the area (Figure 2). Arsensualt and Himmelman (1996) found that the survival of small Iceland scallops in shallow waters (15 m) may be enhanced by the abundance of bivalve shells which could provide refuges from predators. The surface area of scallop shells was to provide a suitable artificial substrate to allow spat (post larvae scallops) to settle and attach.

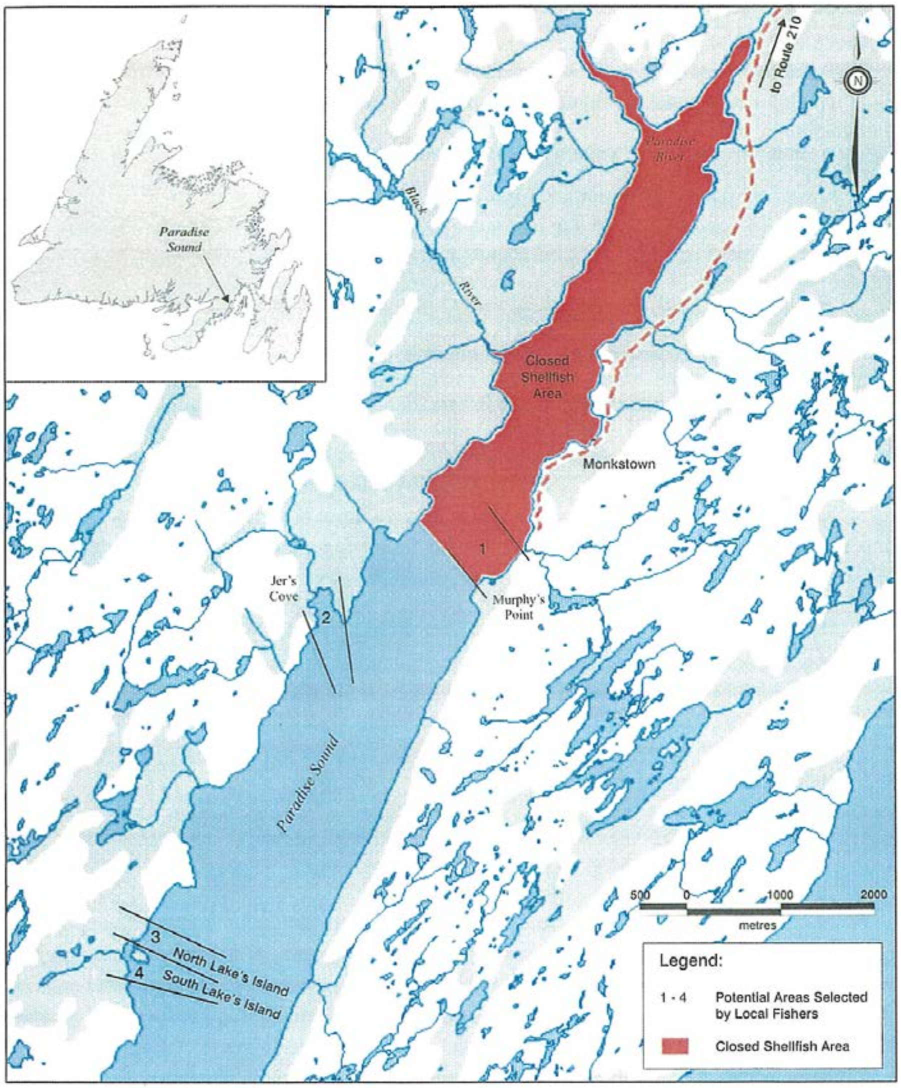

Figure 2. Location of compensation site in Paradise Sound, NL.

For the second offshore oil development project it was determined that the excavation of three glory holes along with the deposition of spoils associated with the White Rose Offshore Oil Development (Figure 1) would result in the loss of habitat utilized by offshore fish species. Similar to the Terra Nova Project, a fish habitat compensation included the construction of two separate types of reefs: an 8,000 m^2 multi-species rock reef and a 10,000 m^2 scallop shell reef in North Harbour, NL (Figure 3).

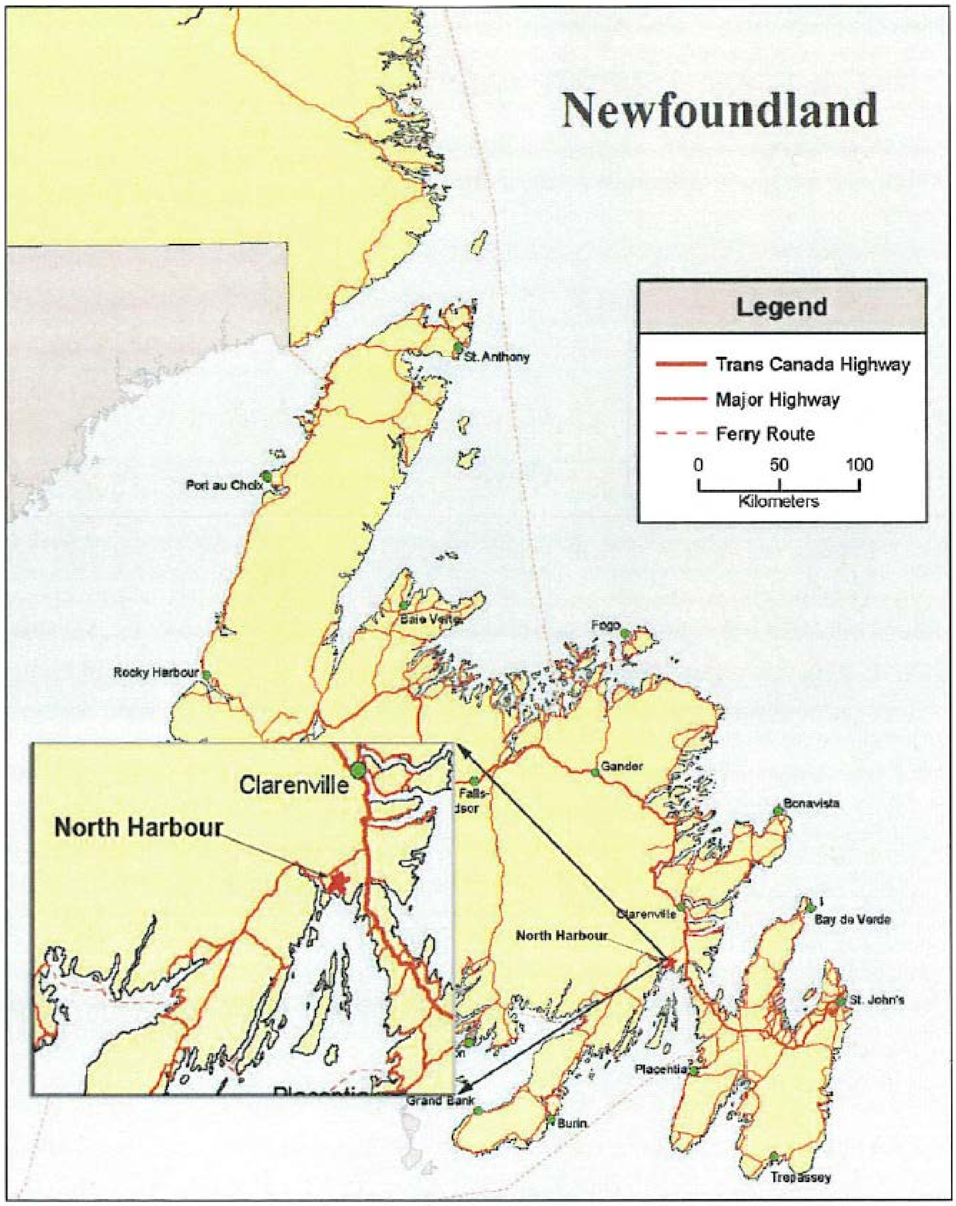

Figure 3. Location of compensation site in North Harbour, Newfoundland.

Prior to constructing either the rock or scallop shell reefs, the existing substrate habitats were considered very poor and homogenous in nature and thus considered of low value related to fish production potential. However the collection of baseline data was required to determine if the sites were appropriate for these types of compensation. Metrics used through baseline surveys were very similar for both type of reefs and included depth, salinity, temperature, and current, predator abundance, and substrate type. In addition for the scallop reefs, spat collectors were deployed to determine if scallop spat was present in the area as a source of seed for the reef. Traditional knowledge on the existence of scallop beds and fishing activity were also noted and utilized. For rock reefs, bathymetric profiles were also collected in addition to the above metrics.

For both the Paradise Sound and North Harbour scallop habitats, selection of areas to place shells was based on the highest spat density as indicated by spat collection data from the area.

The spats collected were subsequently used to initially seed the shell habitat. The scallop shell habitat was then created by depositing a layer of scallop shells approximately 3-4 cm thick over the selected site(s). In addition various habitat requirements needed to be considered in site selection including:

- Cool, uncontaminated water;
- Avoid areas subjected to a significant influx of freshwater;
- Active water to provide high food and oxygen exchange (currents up to 80 cm/sec.);
- Sites to be outside active commercial scallop fishing grounds, but close enough to active scallop beds to allow continued seeding of the created shell habitat with scallop larvae; and
- Hard, rocky substrate, free of silt.

For the rock reef, the area selected was to be located where habitats were considered of low value for fish production, i.e., sandy substrates. The ridge-form design was to provide habitat for a species or a life stage whose recruitment is limited by the amount of suitable habitat in the area. The use of cobble rock was determined to have the potential to be a highly productive marine habitat. As the reef was targeting juvenile fish and a community of perennial algal species, the selected cobble range was 200 to 250 mm in diameter which would ensure a range of interstitial space that may be suitable for a variety of sizes and species of fish, as well as ensure the physical stability required to establish perennial algal species.

The Section 35(2) *Fisheries Act* Authorization (Authorization) issued to allow for the destruction of fish habitat prescribed multi-year monitoring programs. The Paradise Sound monitoring program waas to occur over a five-year timeframe, i.e., from 2002 to 2006, however additional shells were required to be placed in 2002 resulting in a fourth monitoring year in 2007, i.e., 2002, 2003, 2005 and 2007. With experience gained from the Paradise Sound project, it was decided that a longer monitoring period be undertaken for the scallop and rock reefs in North Harbour. As such a seven-year monitoring program for both the scallop reef and rock reef were required (2006 to 2012). The following outlines the methods utilized in the collection of the data, metrics used and the assessment of the metrics in evaluating effectiveness of fish habitat compensation works. Information presented is based upon data provided in the proponent's monitoring reports which were required as conditions of their Authorization.

METHODS

Compensation monitoring programs were designed to obtain the necessary information to determine if the compensation works were functioning as they were intended. In general, the length of the monitoring program, the types of data to be collected and the methodologies to be employed vary and depend on the compensation option chosen.

A series of metrics were collected in order to evaluate the substrate suitability and integrity of all reefs as well as the utilization and colonization of the reefs by various fish and shellfish species. Methods associated with artificial scallop habitat and artificial rock reefs were similar. The following outlines the methodologies utilized in the collection of the metrics and the evaluation of the effectiveness of those metrics. Summaries of the information presented are based upon data provided in proponent's monitoring reports which were required as conditions of *Fisheries Act* Authorizations. For the Paradise Sound scallop reef, information was taken from Jacques Whitford Environmental Limited (JWEL; 1998, 1999, 2001, 2002(a), and 2003), Narwhal Environmental Consulting Services (2002), and Terra Nova Development (2008 and 2009). For the scallop and rock reef in North Harbour, information was taken from Husky (2002, 2007a, 2007b, 2008a, 2008b, 2009a, 2009b, 2011a, and 2011b and JWEL 2002b, 2002c.

SCALLOP REEFS

Substrate stability

Methodologies to assess substrate stability for both the North Harbour and Paradise Sound scallop reefs were similar with SCUBA diver surveys recording visual observations and taking video and photograph to document substrate stability (i.e., shell movement). In Paradise Sound divers swam GPS-referenced transects and information was augmented with data from boat-towed underwater video (i.e. drop camera). In North Harbour divers swam the boundaries of the created shell habitat to perform visual assessments which were geo-referenced. Survey data collected from both monitoring programs were compared to previous years to determine if the shell habitat had remained in its original location or had undergone significant dispersal.

Visual inspections were conducted to determine if there were any major changes or impairment to structural stability of the created habitat, which were supplemented by underwater video. Changes in the shell habitat involving observations of the dimensions of the created habitat were recorded by measuring shell depths (i.e., thickness of shell layer), surface area covered by shells and evenness of shell distribution within footprint area to determine whether shells had remained at its original location or had undergone movement and decomposition.

In Paradise Sound, reef positions were recorded using a Wide Area Augmentation System (WAAS) enabled GPS. Dive transect locations were recorded using a GPS (adapted for attachment to a dive float) to record a continuous GPS track file of diver movement during the survey. The SCUBA surveys also used compass bearings as orientation for transects through the shell area. In North Harbour, reef locations were recorded using the Differential Global Positioning System (DGPS) GPS where available. However, if DGPS positioning was unavailable the WAAS GPS positioning was used. Dropped video and diver surveys were geo-referenced using the vessel mounted and diver towed GPS, respectively, to record positions during the surveys.

Scallop utilization/colonization

Qualitative suverys were conducted using visual observation from the divers along transect lines to detemine species presence and identification of epifauna. Generally along the transects, the diver would observe a 3 m wide swath. Underwater video by the diver and a boat-towed underwater drop camera as well as photograhs were taken as supporting documentation.

Quantitaive surveys were undertaken to estimate density of scallops on the reefs. In 2003 and 2005 in Paradise Sound this was done by exmaining 1 m^2 quadrants set throughout the reef. Quadrats were initially chosen randomly along each transect then subsequently revisited and assessed the following monitoring years (Figure 4). In 2007, to increase the coverage area, data from the diver surveys along the transect lines as well as information from the drop camera were used to estimate scallop densities. In North Harbour scallop densities were estimated from the direct observations of the diver as they traversed along the transect lines and underwater video and dropped video as well as photographs were used as supporting documentation. Overall for both monitoring programs a target of a minimum of 10% of the scallop shell reef was to be surveyed.

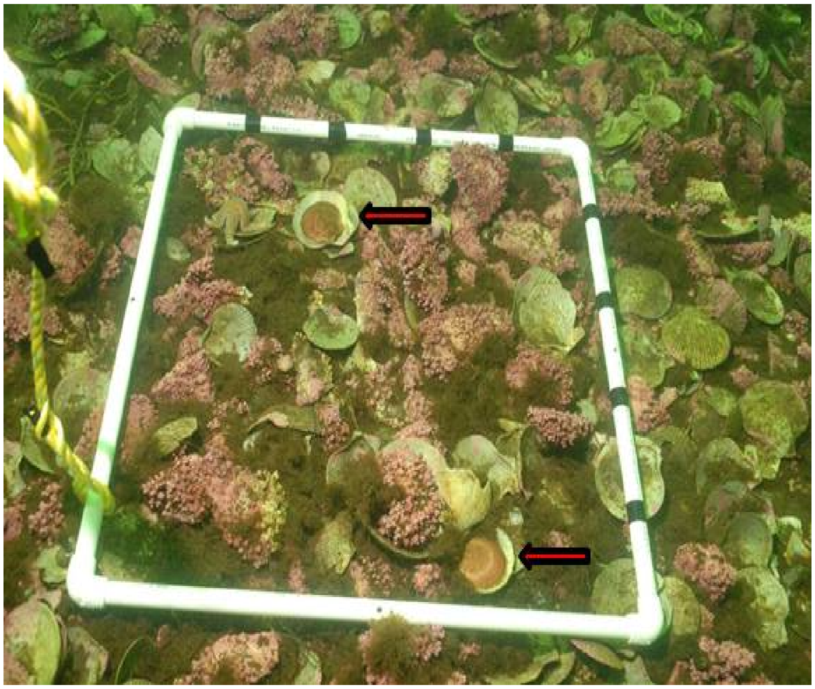

Figure 4. Quadrat for monitoring scallops, Paradise Sound, 2007 (red arrows depicts juvenile scallop).

Observations included numbers of juvenile and adult scallops as well as multispecies colonization, e.g., rock crab, cunners, kelp, etc. Data collected were used to calculate density, size/age class distribution of scallops to assess colonization. In Paradise Sound, dropped video was also used to cover a wider area to confirm that observations noted in transects were representative of the entire habitat.

Morphometrics

Information on scallop size (using shell measurement) was obtained for a subsample by using a 50 cm x 50 cm quadrat or comparing to an object of known size (e.g., diver's hand). Using the quadrat a digital image with the quadrat included was selected as a sample for the estimation of scallop shell size. From each quadrat, ten (10) scallop shells were selected for measuring and each quadrat photograph included a scale of marked intervals along two of the four edges. The marked increments equal 10 cm (100 mm). Using this scale as a reference, a measurement was made of the number of pixels per mm of distance. Pixel measurements were then made for each of the 10 selected shells. Using this measurement and the conversion factor derived from the quadrat scale, scallop shell height was determined for individual shells.

MULTISPECIES ROCK REEFS

Substrate stability

The primary method used to assess the structural integrity and stability of the rock reef was through underwater visual inspection by divers. SCUBA divers swam the boundaries of the reef making visual observations. This assessment was used to determine if there were any changes in the boundaries of the reef and to check for any settlement or sinking.

These visual observations were supported by the use of underwater video transects, high resolution photography to document the reef condition as well as establishing a series of

0.25 m^2 quadrats (Figure 5). Measurements of length and width were taken using GPS as well as the coordinates of the outside four corners to measure the dimensions of the reef.

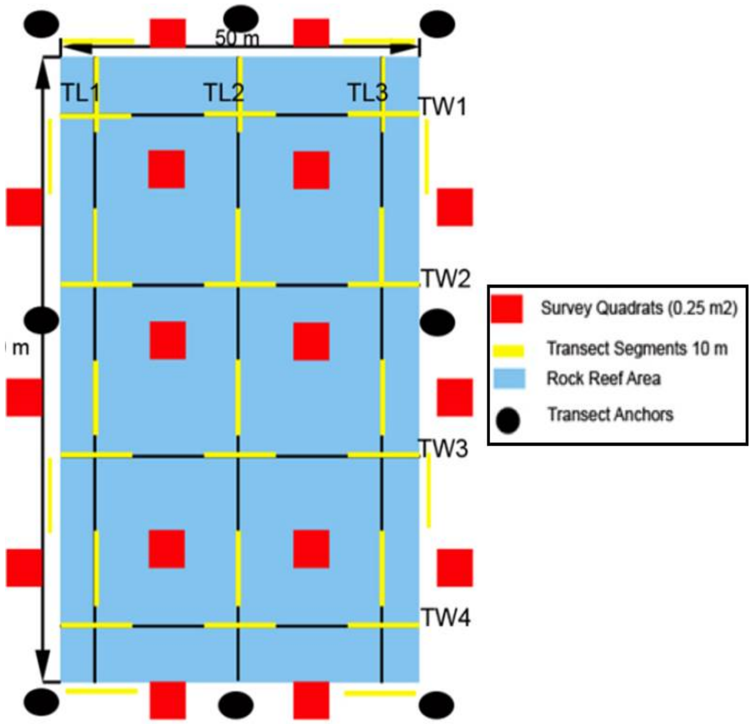

Figure 5. Survey grid for rock reef, 2007-12.

Similar to the scallop reef, all transects for reef monitoring were recorded using the either DGPS or WAAS. DGPS was preferred but WAAS was used if the correction signal was blocked by topographic features.

In addition, changes in size and/or shape of the reef ridges were monitored by measuring the height of the ridges at each edge and in the center. Any disturbances due to fishing gear or natural storm activity were also noted.

Reef position and perimeter were monitored through a bathymetric and positioning survey using a depth sounder and GPS mounted on the survey vessel between 2006 and 2012 to verify the boundaries of the reef against the original boundaries created in 2005. Since 2006, the reef developed a dense algal cover precluding the use of physical transect lines as they were not readily visible so the diver survey was the main method to determine structural stability along transect lines over the reef.

Fish utilization

A visual survey was conducted to identify, quantify and measure fish and shellfish species that were utilizing the reef (Figure 6). This was carried out by running a series of transects along the artificial reef. The methodologies for running transects for both juvenile and adult as well as for sessile and mobile species were generally the same. However, minor adjustments were made to the speed and the examination of interstitial spaces to accommodate the mobile/immobile nature of the fish/shellfish species as well as their various life stages. Transects were approximately 2 m wide and ran at 3 m/min and 1 m/min for fish and shellfish, respectively. Visual surveys were also supported by video and still photography. Fish and shellfish lengths were also collected using an extension scale and/or rulers that had been installed on the reef. In addition information was also collected on any algal growth.

Figure 6. Diver conducting underwater survey on rock reef, North Harbour.

Control sites were also selected to provide a comparison to the observed conditions on the newly created rock reef habitat. They were located 0.5 km from the constructed reef (Figure 7). Surveys were conducted on the natural rock habitat to compare similar types of habitat (i.e., rock reef to natural rock). Surveys were also conducted on the sandy bottom habitat adjacent to the created reef that was representative of baseline (or pre-construction) conditions before the artificial reef was constructed. The visual survey methodology for the control sites was similar to the methods outlined above.

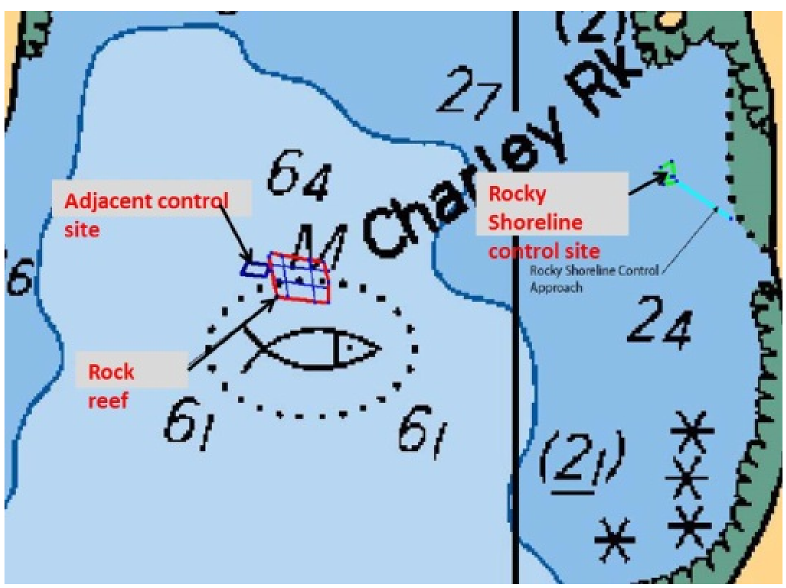

Figure 7. Rock reef and control sites, North Harbour.

RESULTS AND DISCUSSION

SCALLOP REEFS

In order to evaluate whether the metrics were efficient in detecting any changes in the structural stability, a measure of success was assigned. Since the goal of the compensation program was to construct a reef that is sustainable, then structural stability and shape should be maintained. Any change in the coordinates, dimensions, or visual observations of movement, dispersal, or deterioration would mean that the structural stability could be compromised.

Substrate stability

The visual survey indicated that there was no change in the overall structure of either scallop reef. However, there was some evidence indicating the shell material was becoming brittle and deteriorating as well as some minor damage due to fishing gear on the North Harbour Reef. Boundary coordinates have remained the same indicating that there has been no shift in the boundaries.

The GPS boundary coordinates of the created shell reefs for both Paradise Sound and North Harbour did not change and were verified with the use of visual observation and confirmed with video and still photography. The methodology used for obtaining these coordinates is accurate within 1 m and easily replicable.

Scallop utilization/colonization

Metrics collected through diver surveys to determine species utilization and colonization included species identification, density estimates, scallop size/age, and percent of algal cover. In Paradise Sound, while Iceland Scallop and Atlantic Deep-sea Scallop (*Placopecten magellanicus*) spat were collected from spat collectors placed in the area of the reef, only the deep-sea scallop were found on the reef in all monitoring years. The density of scallop between 2003 and 2005 were generally similar however the density decreased by ten-fold in 2007 (Table 1). This change is likley due to the area surveyed as in 2003 and 2005 one m^2 quadrats were used to estimate density but in 2007 density was calculated based on scallops observed along the surveyed tansect lines. Given the small survey area using quadrats in 2003 and 2005, observations from the transect lines in 2007 is considered to be a better measure of the overall scallop density on the reef.

Table 1. Scallop densities and area surveyed from Paradise Sound, 2003-07.

Year	Density (scallops/m^2)	Area surveyed (m^2)
2003	0.525	40
2005	0.458	59
2007	0.053	7,005

Since 2005, filamentous red and coralline algae were noted over the scallop reef, with rockweeds and large bladed kelp also being observed. In addition, sea stars, gastropod snails, Rock Crab, and cunners were also found to utilize the reef habitat; however no densities of these species were estimated. By 2007 filamentous red algae was recorded as covering over 40% of the reef. It is believed that given the large area of the reef was covered by filamentous red algae as well as coralline algae over time reduced the available reef footprint whereby scallop spat could settle. In addition while it is believed that the count of large adult scallops were accurate because they are readily visible and easily counted, juvenile scallop were much more difficult to see among shell and shell fragments and as such may be unrepresented. Very small scallop (young-of-the-year <25 mm) were also very difficult to observe and were easily obscured by algal cover or shell fragments. As such the overall density estimates for scallop on the scallop reef may be underestimated.

In North Harbour scallop densities on the scallop shell reef were estimated from observations collected along the surveyed transect lines (Table 2). Between 2007 and 2012, the average area of dive survey coverage was 2,452 m^2 of the 10,000 m^2 shell reef habitat (range 939-4,548 m^2) which was considered a reasonable subsample of the area in order to estimate scallop densities. However, even with continued spat seeding (2004-07) the density continued to decline until 2012 when a slight increase was noted in scallop density.

Table 2. Scallop density and area surveyed from North Harbour, 2006-12.

Year	Density (scallops/m^2)	Area surveyed (m^2)
2006	0.014	939
2007	0.007	1,845
2008	0.001	2,070
2010	0.001	2,859
2012	0.002	4,548

Information from the diver surveys and video, indicate sea stars, cunners, cod, flounder, and rock crabs were common through the reef area. One or two skate were also observed in the area in 2007 and 2010. In 2012 additional fish species were noted for the first time, i.e., ocean pout, lumpfish and haddock. Since 2010 brown algae species cover most of the reef (~80%). Other smaller algae have also been found including Irish moss and sea lettuce. Densities for these other species were recorded between 2007 and 2012 when numbers increased (Table 3). When combined with the scallop densities for the same time period, the overall densities of species utilizing the reef ranged from 0.09 to 0.47 thus indicating an increase in overall fish productivity within the compensation area between 2007 and 2012.

Table 3. Density (number/m^2) of fish species including scallop on scallop shell reef, North Harbour 2007-12.

Year	Sea Stars	Flounder	Cunners	Rock Crab	Atlantic Cod	Scallop	Total
2007	0.033	0	0.054	NA	NA	0.007	0.09
2008	0.112	0.039	0.143	0.019	NA	0.001	0.31
2010	0.140	0.009	0.315	0.003	NA	0.001	0.47
2012	0.110	0.006	0.176	0.001	0.015	0.002	0.31

The low scallop densities were likely due to heavy algal cover on the shells thereby making counts difficult and/or inhibiting spat settlement. In addition the presence of predators such as sea stars would also likely have affected the scallop survivability and densities.

Morphometrics

In both Paradise Sound and North Harbour, the shell of the scallop was measured to determine size (mm) and subsequently age group (i.e., adult or juvenile). In Paradise Sound, while densities of juvenile and adult scallops were very low and fluctuated between 2003 and 2007 it is indicative that scallop were in fact growing on the reef (Figure 8).

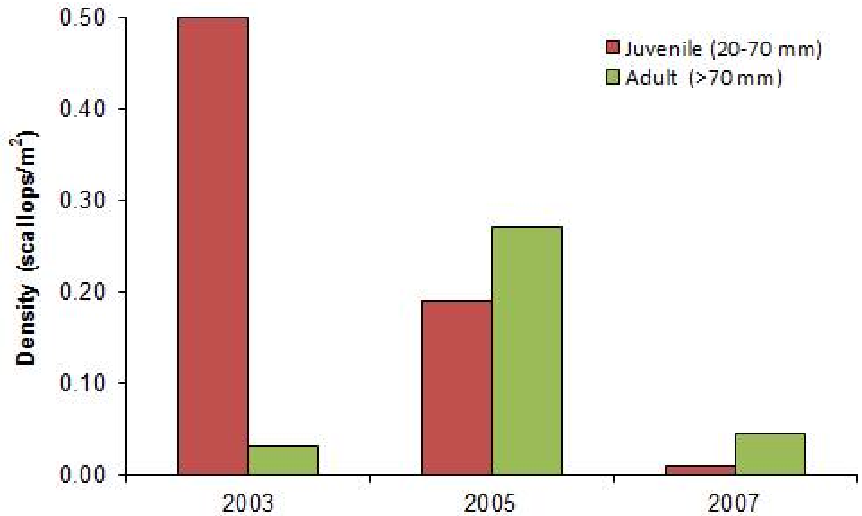

Figure 8. Density of scallops by size and age group (adults and juvenile) utilizing the scallop shell reef from Paradise Sound 2003-07.

On the North Harbour reef, the density of adult scallop on the reef was similar between 2006 and 2007 and then dropped off and remained consistently low between 2008 to 2012 (Figure 9). The presence of juvenile scallop on the reef decreased between 2006 and 2007 with none found in 2008. Juvenile density then slightly increased in 2010 and 2012. Similar to the Paradise Sound reef this is an indication, even though densities were low, scallops were in fact growing on the reef.

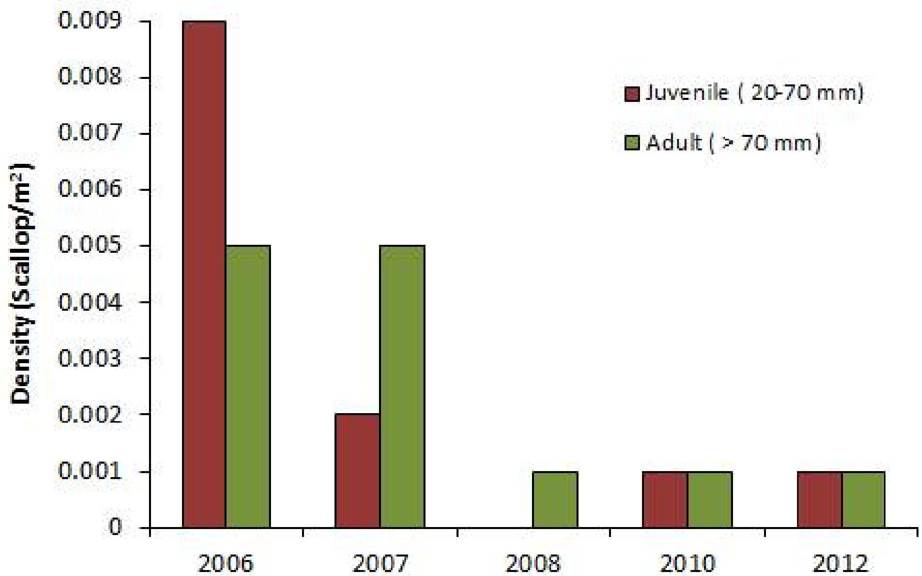

Figure 9. Density of scallops by size and age group (adults and juvenile) utilizing the scallop reef from North Harbour 2006-12.

MULTISPECIES ROCK REEFS

As with scallop shell reefs, a series of metrics were utilized to evaluate structural stability and utilization. Diver surveys via the use of transects have proven to be a reliable technique in collecting data on both natural and artificial reefs. The transect method is useful for surveys compiling lists of motile species, overall community trends and utilization of habitat (Brock 1982). Visual diver surveys are non-disruptive and are easily replicated with minimal field gear requirements, less selection when compared to other sampling methods and can be easily adapted to a variety of situations and habitats (Seamam and Spraque 1991). Species identification, abundance, size, and distribution as well as habitat features are all types of data that are easily recorded. However limitations were found with this method, if used alone, especially as the reef communities developed as well as unplanned changes in field conditions, e.g., poor weather and limited daylight. As well Brock (1982) found this method tended to underestimate the most common species as well as smaller and more cryptic species (Stanley and Wilson 1995). Another parameter that is not easily measured by the transect method is algal cover and counts on sessile organisms. Therefore between 2007 and 2012, surveys of the rock reef employed several overlapping survey methods (i.e., diver and video transects, high resolution photographs; quadrats, and habitat complexity measurements). These survey components were designed to provide complementary survey information and ensure a complete standardized, objective, quantitative and qualitative account of the reef community and progression compared to similarly surveyed control habitats.

Substrate stability

Visual (Diver) Survey

Initial measurements of the reef were taken during the first survey in 2006 and later verified in subsequent surveys in 2007, 2008, and 2010 confirming that the size and shape had been maintained to that created in 2005. The average length was 80 m (range 75-85 m), average width was 50 m (range 50-55) and the average height was 1 m above seabed with maximum at 1.5 m.

Bathymetric data was also collected post-construction in 2005 (Figure 10). Comparisons of GPS coordinates from 2006 through to 2012 have shown that the boundaries of the reef have not changed. As well, it was observed that no shifting or sinking of substrates had occurred and the general overall shape and dimensions had remained the same. This is also confirmed through visual surveys and documented by underwater video and still photographs.

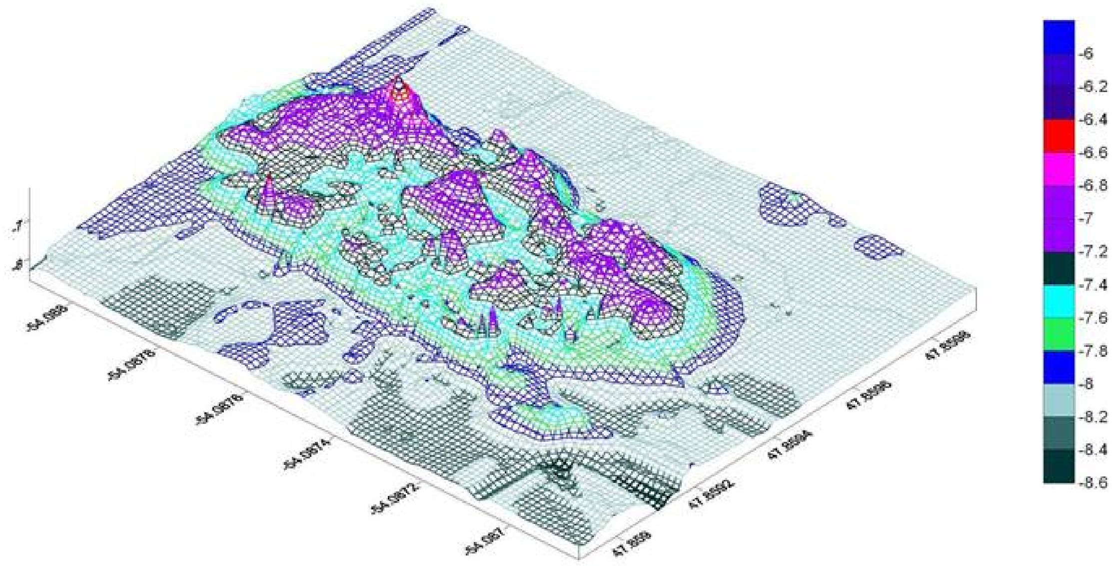

Figure 10. Bathymetric contour of rock reef, North Harbour, 2005.

Fish utilization

The area where the reef was to be constructed consisted mainly of a sandy bottom. Pre-construction video surveys indicated minimal numbers of star fish, sea urchins and sand dollars within the proposed construction area. As such the productive capacity of the fish habitat prior to the addition of the rock reef was considered minimal. Monitoring was undertaken over a seven-year period (2006, 2007, 2008, 2010 and 2012). Fourteen species were found on the reef; five-species (fish and invertebrates) found were in such low numbers that density could not be calculated. Densities are presented for 6 commercial species (Table 4) and other invertebrates (Table 5).

Table 4. Density (number/m^2) for commercial fish and shellfish species, North Harbour rock reef, 2007-12.

Cunner	**Reef**	**Adjacent**	**Control**	**Flounder**	**Reef**	**Adjacent**	**Control**
2007	2.006	0.025	0.769	**2007**	0.036	0.042	0
2008	1.496	0.127	1.613	**2008**	0.03	0.047	0.009
2010	1.250	0.071	0.561	**2010**	0.019	0.018	0.022
2012	2.732	0.092	1.136	**2012**	0.037	0.049	0
Cod	**Reef**	**Adjacent**	**Control**	**Rock Crab**	**Reef**	**Adjacent**	**Control**
2007	0.03	0	0	**2007**	0.007	0.067	0
2008	0.123	0	0	**2008**	0.006	0.039	0.002
2010	0.009	0	0	**2010**	0.006	0.012	0.002
2012	0.183	0.01	0	**2012**	0.005	0.015	0.005
Scallop	**Reef**	**Adjacent**	**Control**	**Mussel**	**Reef**	**Adjacent**	**Control**
2007	0.025	0.083	0.069	**2007**	0	0	3.846
2008	0.02	0.032	0.028	**2008**	0	0	2.306
2010	0.014	0.012	0.078	**2010**	0	0	2.244
2012	0.009	0.029	0.118	**2012**	0	0	4.55

Table 5. Density (number/m^2) for other invertebrate species, North Harbour rock reef 2007-12.

Sea Urchin	Reef	Adjacent	Control
2007	0	0	0
2008	0	0	0.069
2010	0	0	0.224
2012	0	0	0.459
Periwinkle	**Reef**	**Adjacent**	**Control**
2007	0	0	0
2008	0.051	0	0.461
2010	0.048	0	0.451
2012	0.09	0	0.914
Sand Dollar	**Reef**	**Adjacent**	**Control**
2007	0.06	0	0
2008	0.047	0.067	0
2010	0.007	0.004	0

In addition, surveys documented the rapid colonization of the reef by kelp, primarily *Laminaria* sp., with some filamentous algae. Between 2007 and 2012 algal coverage remained at 100% with some *Laminaria* plants reaching 5 to 6 m in height by 2012.

Cunner and flounder densities were higher on the created rock reef than on the control site, however flounder were more prevalent in the areas adjacent to the reef itself. Schutz et al. (2012) found that at distances <50 m from a reef, fish assemblage had a strong association with rocky reef and it was strongest within 25 m of reef. Monitoring of this area, which was primarily sandy prior to reef construction, indicated that there was an edge effect around the created reef particularly for rock crab and scallop. Some species (i.e., mussels and sea urchins) were only observed on the control site. Observation made during the surveys also indicated the presence of juveniles and adults in particular for cunners, flounder and cod on the created reef however no actual counts were reported for each life stage.

When comparing density results for the created rock reef from year to year, the densities for scallop and sand dollars have decreased on the created reef. This may be the result of increased algal cover thereby making visual observations less effective over time. However, other than diver survey and video documentation, there does not appear to be another non-destructive method for surveying the created rock reefs long term.

CONCLUSIONS

Through the use of diver surveys it was determined that the stability of the substrate on both scallop and rock reefs had been maintained. First, the use of GPS coordinates that outlined the edges of the reefs indicated that no change in boundaries had occurred. Since georeferencing is easily replicable with a high degree of certainty, any change of the boundaries would be an indication of such structural issues as slumping, sinking or spreading. The number of times of sampling is also very important when considering change over time, which was considered in determining the monitoring periods. The use of GPS coordinates has been a useful metric in determining the status of the boundaries of the reefs. These monitoring programs were designed to be conducted over several years, which means that not only can the same methodology be used year after year, but of a duration that will detect any changes.

While the use of GPS coordinates can verify that the boundaries of the reefs have not changed, visual observations are required to ensure that the material used for the reef is structurally stable and that the dimensions (e.g., length, height) of the reefs have been maintained. For example by doing a visual survey on the North Harbour scallop reef, it was noted there has been some movement of shells inside the reef boundaries but the visual survey determined that damage due to fishing gear going through the reef area had been very minimal and that the structural integrity of the reef was still intact, including the evenness and depth of the shells. As well, for monitoring conducted in Paradise Sound in 2007, while the overall stability of the scallop reef was positive, inspection through diver surveys had indicated that shells were becoming very brittle and easily crushed by hand. This was an indication that the shells are beginning to deteriorate and could impact the substrate stability of the reef in the long term.

In order to detect any changes in the utilization/colonization of the reefs, density metrics should be collected on all species encountered during the diver and video surveys to be able to compare to pre-construction conditions. Unfortunately, one concern with the use of the diver/video surveys is that once a reef becomes colonized visibility may be impaired due to algal growth, thus resulting in underestimates of densities, and in particular for sessile species such as scallops. While determining scallop densities on the shell reefs was useful in identifying trends and issues with this type of compensation option, in particular the change in use of the habitat not only of scallops, estimates of densities of other marine species utilizing the new habitat is equally important. Unfortunately, while species were noted, numbers were not recorded and thus no density estimates were calculated. For the shell habitat in North Harbour, estimates of densities for marine fish and invertebrates when combined with the scallop densities indicated a much higher overall production level for the shell habitat than if just looking at scallop densities. Another density issue that should be addressed in a monitoring program is the consistency in the area of coverage which can also affect the density estimates. Based upon data collected for the Paradise Sound artificial reefs, only 0.2-0.3% of the shell reef was surveyed initially while in the last year over 30% was surveyed. The sample size area could potentially affect the density metric, as such the sample size should be considered when developing monitoring program to ensure it covers an adquate percentage of the habitat and remains relatively consistent for the survey duration.

While only used for the rock reef, control sites are effective in measuring change and determining the level of success of the compensation and are recommended to be included as part of a monitoring program. From the monitoring of the rock reef, other than for mussels, it showed that the constructed reef in comparison to the control site was more productive for commercial vertebrate species.

To further assess effectiveness of the compensation, the metrics of age, size and weight should be collected to determine if there are young-of-the-year and juvenile scallops present and their health and growth. Age metrics, other than age groups (i.e., adult or juvenile), were not collected for scallops on the shell reefs nor were individual sizes or weights provided in the report. Both these metrics would have been of value in measuring the effectiveness of this type of reef. For the rock reef only the size range for some species was provided in the report and as such information was not presented. However it is important to ensure both these metrics are collected on individuals or a representative sample to verify long term recruitment success.

ACKNOWLEDGEMENTS

The authors thank Petro Canada and in particular Urban Williams, and Husky Energy and in particular Greg Janes for agreeing to the use of their information contained in their monitoring reports to be used in the preparation of this report. The authors also wish to express their appreciation to Karen Smokorowski and Roger Wysocki for their comments on drafts of the report; they were extremely benificial in finalizing the document.

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