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QBRAT v2 assessment: *Codium fragile* ssp. *tomentosoides* in the Gulf of St. Lawrence as a case study

Évaluation de QBRAT v2 : étude de cas pour *Codium fragile* ssp. *tomentosoides* dans le golfe du Saint-Laurent

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Abstract

The green macroalgae *Codium fragile* ssp. *tomentosoides* (herafter, *Codium*) is native to Japan and has invaded water in eastern Canada. This study evaluated the risk associated with the spread of *Codium fragile* ssp. *tomentosoides* in the Gulf of St. Lawrence. Several specific objectives were thus addressed: 1) to review and synthesize the available literature on the ecology and impacts of *Codium*; 2) to seek the judgement of *Codium* experts with respect to dispersal vectors, critical habitat attributes, and probabilities and magnitudes of environmental, economic and social impacts related to the establishment of *Codium* by soliciting participation using a survey; 3) to evaluate the use of an Analytic Hierarchy Process (AHP) to interpret the expert judgements; 4) to do a risk assessment of *Codium* in the Gulf of St. Lawrence; and 5) to evaluate the utility of using the Quantitative Risk Assessment Tool (QBRAT v2) framework and software by using the *Codium* risk assessment as a case study.

Qualitative analysis of the literature review and the survey results suggest that *Codium* is quite likely to continue its expansion in the Gulf of St. Lawrence and is likely to cause damage to various components. Spread by plants or plant fragments were considered the greatest single vector for the spread of *Codium*. With respect to natural processes, spread by propagules was considered to be much less important. Expert judgements suggest that the most important anthropogenic vector for *Codium* spread is the translocation of infested objects. The presence of artificial structures and biofouling on ships were considered the next most important anthropogenic vectors whereas recreational and commercial boating and ballast water were considered to be less important. The most important criteria for habitat suitability were factors associated with substrate quality (wave exposure, area of available habitat, and substrate type) and mean water temperature. Expert judgements suggest that two of the four environmental criteria (biodiversity and trophic interactions) are considered at high risk from *Codium* invasion. Economic criteria were judged to be at moderate risk and social criteria at moderate or negligible risk. The AHP was quite efficient for summarizing the expert judgements and describing the error associated with the judgements for each criterion and was thus good for organizing qualitative data quantitatively. The risk assessment using the QBRAT framework showed that the Gulf of St. Lawrence is at high risk from *Codium* and that most of that risk was associated with further spread of the alga within the area. Future runs of QBRAT for *Codium* should be done for ecological, economic and social criteria separately to provide the most precise information for management purposes. The use of QBRAT v2 allowed novice users to focus their research to research to acquire all the information needed to run the risk assessment and made choices more objective. The use of the AHP combined with QBRAT v2 gave the user the ability to well define values for different criteria as well as their associated error structure. Several specific recommendations about QBRAT are made.

Résumé

La macroalgue verte *Codium fragile* ssp. *tomentosoides* (appelée ci-après *Codium*) provient du Japon et a envahi les eaux de l'est du Canada. La présente étude évalue le risque associé à la propagation de *Codium fragile* ssp. *tomentosoides* dans le golfe du Saint-Laurent. Plusieurs objectifs spécifiques ont été par le fait même examinés : 1) procéder à un examen et à une synthèse de la littérature disponible sur l'écologie et les impacts de *Codium*; 2) solliciter, dans le cadre d'une enquête, l'avis d'experts de cette espèce en ce qui concerne les vecteurs de dispersion, les attributs de son habitat essentiel ainsi que les probabilités et l'importance des impacts environnementaux, économiques et sociaux associés à l'établissement de *Codium*; 3) évaluer l'utilité de la méthode de hiérarchie multicritère (MHM) pour interpréter l'avis des experts; 4) évaluer le risque posé par *Codium* dans le golfe du Saint-Laurent; 5) évaluer l'utilité de l'outil d'évaluation du risque quantitatif (QBRAT v2) (cadre et logiciel) en utilisant l'évaluation du risque lié à *Codium* en tant qu'étude de cas.

L'analyse qualitative de l'examen de la littérature et les résultats de l'enquête laissent sous-entendre que *Codium* poursuivra fort probablement son expansion dans le golfe du Saint-Laurent et devrait causer des dommages à divers composants. La propagation par des thalles ou des fragments de thalles est considérée comme le plus grand vecteur pour la propagation de *Codium*. En ce qui concerne les processus naturels, la propagation au moyen de propagules est considérée beaucoup moins importante. Selon les experts, le plus important vecteur anthropique lié à la propagation de *Codium* est la translocation d'objets infestés. La présence de structures artificielles et l'encrassement biologique des navires sont considérés comme étant le deuxième plus important vecteur anthropique, tandis que la navigation de plaisance et commerciale ainsi que les eaux de ballast sont considérées comme moins importants. Les plus importants critères associés à l'adéquation de l'habitat sont les facteurs associés avec la qualité du substrat (exposition aux vagues, aire d'habitat disponible et type de substrat) et la température moyenne de l'eau. Les experts semblent également croire que deux des quatre critères environnementaux (biodiversité et interactions trophiques) seraient très exposés à une invasion de *Codium*. Les critères économiques sont considérés comme étant à risque modéré et les critères sociaux, à risque modéré ou négligeable. La MHM nous a permis assez efficacement de résumer l'opinion des experts et de décrire l'erreur associée à l'évaluation de chaque critère. Cette méthode nous a donc permis d'effectuer une organisation quantitative des données qualitatives. L'évaluation du risque effectuée à l'aide du cadre QBRAT a démontré que le golfe du Saint-Laurent était exposé à un risque élevé d'invasion par *Codium* et que la majeure partie de ce risque était associée à la poursuite de la propagation de l'algue dans la région. On devrait utiliser de nouveau QBRAT avec *Codium* pour évaluer séparément les critères écologiques, économiques et sociaux afin de fournir aux gestionnaires l'information la plus précise. L'utilisation de QBRAT v2 a permis à des utilisateurs novices d'orienter leurs recherches pour acquérir toute l'information nécessaire à l'exécution de l'évaluation du risque et procéder à des choix plus objectifs. L'utilisation de la MHM combinée avec QBRAT v2 a permis aux utilisateurs de bien définir les valeurs associées à différents critères ainsi que la structure d'erreur connexe. Plusieurs recommandations spécifiques à QBRAT sont formulées.

1.0 Background

Interactions between organisms and the environment are complex and the importance of various factors to the establishment success of aquatic invasive species (AIS) is often unclear. However, management actions must be decided upon despite this uncertainty in order to prevent, eradicate or control AIS, thus reducing economic, social and environmental impacts. In this context, risk assessment may be used to predict risk to invasion and identify knowledge gaps and provide scientific advice to managers and decision makers (Ruiz and Carlton 2003). Thus risk assessment has been identified as an effective tool by Fisheries and Oceans Canada (DFO) to address the threat of the aquatic invasive species in Canada. To this end, DFO created the Centre of Expertise for Aquatic Risk Assessment (CEARA), to develop the necessary expertise in risk assessment across the country. The present case study assess the utility of a risk assessment tool that may be used to provide science advice on risks of AIS.

The present risk assessment will aid in the development of management strategies to address the invasion of the seaweed *Codium fragile* ssp. *tomentosoides* in the Gulf of St. Lawrence. The increasing range of this pest highlights the need to identify the factors involved in its post-establishment spread and impacts. The objectives of this case study are to: 1) review the literature concerning the life history and the biological invasion process of *Codium fragile* ssp. *tomentosoides* in the NW Atlantic; 2) evaluate an analytic hierarchy process to census and evaluate expert judgements; 3) contribute to the evaluation of national risk assessment tools, specifically the biological risk assessment framework and associated software, QBRATv2; 4) perform a biological risk assessment for *C. f*. ssp. *tomentosoides* in the Gulf of St. Lawrence; and, 5) include economic and social components using the same framework and survey methods as the biological risk assessment. Although this latter objective is beyond what was requested by CEARA, we decided that it was pertinent within the current exercise (although we admit that the present risk assessments for these latter criteria may not be as robust as that for the environmental components within the biological risk assessment).

2.0 Biological synopsis

2.1 Identity

Codium fragile (Suringar) Hariot 1889 ssp. *tomentosoides* (van Goor) Silva (Chlorophyta, Codiaceae) is a green erect macroalga that originated from Japan. Its thallus may attain a length of 55 to 70 cm and has dichotomously tubular branching (Chapman 1999). There are no native species of the genus *Codium* in the NW Atlantic (Trowbridge 1998). Of the six *C. fragile* subspecies identified around the world, only the subspecies *tomentosoides* appears to have infested NW Atlantic shores (Trowbridge 1998). However, a recent morphological and molecular study suggests that *C. f*. ssp. *atlanticum* may also be present in eastern Canadian waters, suggesting that multiple independent introductions of *Codium fragile* may have occurred in Atlantic Canada (Kusakina *et al*. 2006). For brevity, *C. f*. spp. *tomentosoides* is refered to hereafter as *Codium*.

2.2 Geographical distribution and dispersion

Codium was first reported on the NW Atlantic coast in 1957 in Long Island Sound, New York (Bouck and Morgan 1957). Since then, the species has proliferated and spread both south and north along the coast. In eastern Canada, the species was first observed in 1989 in Nova Scotia (Bird *et al*. 1993). Today, the species is present from North Carolina to the Gulf of St. Lawrence and has been observed in Nova Scotia, New Brunswick, Prince Edward Island and Quebec (Gabary and Jess 2000, Hubbard and

Gabary 2002, Simard *et al*. 2006). The source population of the NW Atlantic invasion appears to come from Europe rather than directly from Asia (Malinowski 1974, Loosanoff 1975, Carlton and Scanlon 1985). Biofouling has been suggested to be the main transoceanic vector of *Codium* in the Atlantic (Loosanoff 1975, Carlton and Scanlon 1985). This conclusion is supported by the ability of *Codium* to settle and grow on poorly protected ship surfaces, withstand strong currents as a large alga or regrow from its holdfast, and to tolerate high ranges of temperature and salinity (Carlton and Scanlon 1985).

Codium may be dispersed by both natural and anthropogenic mechanisms. Natural dispersal mechanisms include reproductive cells (parthenogenesis) and drifting of fragments or whole plants (Coolidge Churchill and Moeller 1972, Dromgoole 1982, Carlton and Scanlon 1985, Bird *et al*. 1993, Trowbridge 1998). Anthropogenic activities that may contribute to its dispersal include: 1) navigation of commercial or recreational boats with fouled hulls or anchors; 2) use of fouled fishing gear; 3) ballast water exchange; 4) stock transfers for bivalve aquaculture; 5) using alga as packaging for the transport of fresh produce; 6) processing of fishery or aquaculture products from outside of the region; and 7) presence of artificial structures or waste materials in the water (Malinowski 1974, Lossanoff 1975, Carlton and Scanlon 1985, Bird *et al*. 1993, Trowbridge 1999, Locke *et al*. 2003, Bulleri and Airoldi 2005). In general, natural mechanisms contribute most to diffuse dispersal of aquatic invasive species from initial establishment points such that colonization of new sites increases over time and decreases with distance from initial invasion sites (MacIsaac *et al*. 2001). In contrast, human-mediated vectors can contribute to dispersal over long distances over a short periods (MacIsaac *et al*. 2001, Johnson *et al*. 2001).

2.3 Habitat

The vertical distribution of *Codium* on shores depends on the severity of the winter season. The alga can form intertidal stands where the intertidal habitat does not freeze during the winter (Trowbridge 1999). Thus, *Codium* mainly occurs in subtidal areas in the NW Atlantic (Carlton and Scanlon 1985, Trowbridge 1999) but may also be observed in intertidal pools (Bégin and Scheibling 2003). In more exposed habitats, thalli may be annual, regrowing from more perennial basal holdfasts (Malinowski and Ramus 1973, Hanisak 1979, Dromgoole 1982, Bégin and Scheibling 2003). In wave-protected bays and lagoons, thalli may survive through the winter in the subtidal zone but with reduced growth and biomass, probably due to reduced temperature and light (Hanisak 1979, Bégin and Scheibling 2003). The lower distribution of *Codium* is at least 13 m (Chapman 1999) but drifting algae may be observed on the bottom in deeper areas (Carlton and Scanlon 1985). In its native range, *Codium* has been found as deep as 22 m (Chavanich *et al*. 2003).

Codium can grow on hard substrates including bedrock, bolders, pebbles, and both living and dead molluscs such as mussels, oysters, scallops and limpets as well as crabs, etc. (Trowbridge 1998, 1999). When growing on small objects, the algae’s buoyancy may result in it being displaced by currents and thus colonizing soft-bottom habitats (Dromgoole 1982). The colonization of soft-bottom habitats can also result from propagules or fragments settling and growing on eelgrass, especially its rhizomes. Indeed, Garbary *et al*. (2004) found that *Codium* is able to display rhizomatous growth along horizontal axes, including the rhizomes of *Zostera marina*. Given its great phenotypic plasticity, *Codium* can inhabit a broad range of habitats.

2.4 Environmental tolerance

Codium tolerates salinities from 12 - 17.5 to 40 - 42 ‰ and temperatures from -2 to 27 - 33˚C and thus may colonize both estuarine and marine habitats (Hanisak 1979, Carlton and Scanlon 1985, Trowbridge

1998). This tolerance to a wide range of environmental conditions is reflected in its invaded range throughout the world: from northern Africa to Norway and throughout the Mediterranean in the eastern Atlantic, in the NW Atlantic, on the western coast of the United States, in Chile, Argentina and South Africa as well as New Zealand and Australia (Trowbridge 1998, Harris and Jones 2005, Provan 2005). *Codium*'s tolerance may vary among life stages and populations as well as with local environmental conditions. Thus caution should be taken when making broad ecological extrapolations based on populations of *Codium* from different geographic regions (Trowbridge 1998).

Hanisak (1979) suggests that reproductive cells may germinate when the salinity is greater than 18 ‰ and the temperature is greater than 12˚C. Codium also shows great resistance to desiccation. Experiments have demonstrated that net photosynthesis was still possible following up to 90 days emersion and total recovery of these algae occurred after rehydration (Schaffelke and Deane 2005).

Trowbridge (1998) reviewed the available literature and suggests that nitrogen may be a limiting factor for *Codium* growth but data are scarce and are not unanimous. *Codium* may be able to utilise nitrate, nitrite, ammonia, and urea as a nitrogen source (Hanisak 1979). Indeed, Malinowski and Ramus (1973) have suggested that *Codium* growth may be limited by the availability of inorganic nitrogen during the summer. Although the spectrum of light absorption by *Codium* is typical of deep-water algae (Yokohama *et al*. 1977), it typically occurs in clear water and shallow habitat. *Codium* demonstrates a good adaptation to various sun and shade conditions. Adult plants do not demonstrate photo-inhibition at high irradiance levels and can utilise accessory pigments at low irradiance levels (Yokohama *et al*. 1977). Although the vaucherioid (pre-juvenile) stage of ssp *tomentosoides* seems to grow best at the greatest light intensity of 6 subspecies of the genus (Yang *et al*. 1997), photo-inhibition can occur on juvenile specimens (Hanisak 1979).

2.5 Growth and reproduction

Growth is positively correlated with water temperature. Temperatures must be over 10˚C for good growth, but limited growth has been recorded at 6˚C (Hanisak 1979) and adult thalli from Maine grew best at only 4˚C (Malinowski 1974, cited in Trowbridge 1999). That being said, most juvenile plants and adult thalli from both coasts of the north Atlantic were observed to grow best at 24˚C (Malinowski 1974, cited in Trowbridge 1999). The vaucherioid stage also seems to grow best at 25˚C but will also grow between 10 and 30˚C (the entire temperature range studied by Yang et al. 1997). Growth rates may increase significantly at temperatures greater than 16˚C and when salinities are greater than 27 ‰ (Malinowki and Ramus 1973, Malinowski 1974). Optimal growth conditions seem to be around 24˚C and at a salinity of 24-30 ‰ (Hanisak 1979). At the beginning of the summer season (May-June), growth rates can vary between 2.6-2.9 cm $month^{-1}$ and reach 5.6 to 9.2 cm $month^{-1}$ in August, depending on the habitat (Fralick and Mathieson 1973, Bégin and Scheibling 2003).

Codium reproduction is thought to be asexual in eastern North America (Coolidge Churchill and Moeller 1972, Ramus 1972, Fralick and Mathieson 1973, Malinowki and Ramus 1973), thus explaining the low genetic variation among populations (Malinowski 1974, Goff *et al*. 1982). However, Malinowski (1974) and Kusakina *et al*. (2006) suggest that *Codium* may alter reproductive strategies under less suitable environments and reproduce sexually. This hypothesis could explain the possible hybridizing between ssp. *tomentosoides* and ssp. *atlanticum* (Kusakina *et al*. 2006). Nevertheless, sexual reproduction has never been observed in either *in situ* or *in vivo* experiments (Trowbridge 1998, 1999). Likewise, a recent study suggests that *Codium* does not produce male gametes (Prince and Trowbridge 2004).

Reproduction by parthenogenesis may occur at the end of the summer season, when water temperatures are optimal for cell growth (Fralick and Mathieson 1973, Malinkowski and Ramus 1973, Malinowski 1974, Hanisak 1979). Female gametes (propagules) are liberated that develop without fertilization. These have low mobility and may swim for about 30 minutes after they have been released (Coolidge Churchill and Moeller 1972). Once settled, the propagules may germinate quickly and form an undifferentiated stage, also called primary thallus (Trowbridge 1998). Differentiation of the primary thallus into macroscopic alga is stimulated by wave action or current flow (Ramus 1972). According to Steele (1975), thallus differentiation may also be restricted by eutrophication and the presence of trace metals.

Vegetative propagation can arise from isolated utricles, vegetative buds and thallus fragmentation (Chapman 1999, Nanba *et al*. 2002, Garbary *et al*. 2004). These may drift and, if they settle on an appropriate substrate, form a basal holdfast from which dichotomous thalli may grow (Fralick and Mathieson 1972, Malinowski 1974, Hanisak 1979, Garbary *et al*. 2004). Thallus fragmentation has been observed to result from wave exposure, which may be an adaptive mechanism to reduce drag and thus increase local survivorship of adult plants (Bégin and Sheibling 2003, D'Amours and Scheibling in press). Fragmentation of plants in intertidal and subtidal habitats during spring and fall storms may help promote the spread of the species (Bégin and Sheibling 2003, D'amours and Scheibling in press). Although fragmentation also occurs in the winter (Fralick and Mathieson 1972), Hanisak (1979) suggests that this may not increase the dispersal of the species as environmental conditions at this time are too severe for fragments to thrive.

2.6 Ecological impacts

The establishment of *Codium* may affect various habitat characteristics. For example, water circulation may be decreased and sedimentation rates increased as *Codium* creates more dense beds than do native algae (Chapman 1999). Consequently, shade and turbidity may affect benthic faunal communities and reduce the establishment of native seaweeds. *Codium* morphology may also alter benthic habitats as its bushy thallus differs markedly from kelp blades and eelgrass. Thus Levin *et al*. (2002) suggest that recruitment of cunner (*Tautogalabrus adspersus*) is greater in native kelp beds than in *Codium* beds. The presence of *Codium* may also alter the recruitment of benthic invertebrates (e.g. barnacles, tunicates, bryozoans), since it may be toxic for some larvae (C.D. Trowbridge, Oregon State University, Newport, United States, pers. com.). A reduction of small and sedentary species has been observed under *Codium* canopies, suggesting that this invasive species may contribute to biodiversity loss (Scheibling 2001). In contrast, Harris and Jones (2005) propose that *Codium* community might be more diverse and complex than native kelp beds. Indeed, Bulleri et al (2006) have shown that the presence of *Codium* may enhance the recruitment of mussels in Italy. Likewise, there are also some suggestions that *Codium* may provide shelter to a variety of small fish and invertebrates from predators (A. Drouin, pers. obs.).

In Nova Scotia, *Codium* establishment has changed the ecological cycling between sea urchin barrens and kelp forests described by Scheibling (1986). Historically the presence of dense kelp populations increases the abundance of sea urchins (*Strongylocentrotus droebachiensis*). Excessive grazing by urchins creates barrens and the lack of food and/or disease increases their mortality, allowing the kelp to dominate once more. The temporary absence of kelp during this cycle now allows for the establishment of *Codium*, which reduces kelp recruitment and gradually replaces this community (Elner and Vadas 1990, Chapman 1999, Scheibling *et al*. 1999, Scheibling 2001, Chapman *et al*. 2002). The appearance of *Codium* in this natural cycle has led to changes in species composition (Harris and Tyrrell 2001) and ten years after the start of the invasion, *Codium* has replaced kelp in some habitats along 900 km of coastline (Scheibling 2001). The arrival of the invasive bryozoans *Membranipora membranacea* may have facilitated the establishment of *Codium* by increasing kelp mortality (Scheibling *et al*. 1999, Levin *et al*. 2002). More recently, *Codium* has also been observed to affect eelgrass habitat. *Codium* may develop filaments that permit it to attach to and grow on *Z. marina* rhizomes (Garbary *et al*. 2004). Laboratory experiments have shown that rhizomatous growth by *Codium* induced 90% mortality of *Z. marina* in four months (Garbary *et al*. 2004). This particular type of growth may be an adaptation to environmental pressure when developing on soft bottom habitat.

Altered algal community composition may also modify various biotic interactions. Some authors have highlighted the great affinity of *Codium* for nitrogen, which might result in competition between this species and phytoplankton and other macroalga (Hanisak and Harlin 1978, Chapman 1999). Native grazers feed less on *Codium* than on native alga. Chavanich and Harris (2004) have observed that the abundance of the snail *Lacuna vincta* decreased in habitat dominated by *Codium* and that individuals that fed on the invasive alga were smaller. *Codium* tissues contain chemical compounds that may act as a protection from certain grazers. Experiments on the feeding behaviour of sea urchins have demonstrated that although *Codium* chemical defences did not inhibit grazing by sea urchins although they did limit how often *Codium* was grazed upon (Lyons *et al*. 2006). What's more, growth of sea urchins was reduced when feeding solely on *Codium*. Thus, when sea urchins may choose, they avoid feeding on *Codium*, but they can eat it if they have no choice. Although few species graze on *Codium* to any extent, some, such as sea slugs (*Placida dendritica* and *Elysia maoria*), may do so (Freeman and Smith 1999, Trowbridge and Todd 2001, Trowbridge 2002, Bégin and Scheibling 2003) and may even be responsible for a local decrease in *Codium* populations when occurring at unusually high densities (Trowbridge 2002, Harris and Jones 2005). That being said, none of the published literature has demonstrated that herbivory can act as a significant factor in the control of *Codium* invasion. Changes in (for example) grazer populations related to the establishment of *Codium* may also affect higher trophic levels but no data is available to quantify this.

2.7 Economic and social impacts

The establishment of *Codium* may have important effects on the bivalve aquaculture industry (Trowbridge 1999). The alga can settle on oysters, mussels and scallops, dislodge them because of its buoyant thalli, and then drift them away from the aquaculture sites with the currents (Loosanoff 1975, Dromgoole 1982, Campbell 1999, Trowbridge 1999). The settlement of *Codium* on bivalves may also inhibit their filtering capacity, thus affecting their growth and the survival (Fralick 1970). *Codium* may also settle on cage structures, clogging them, decrease water circulation, and thus impact the growth of bivalves in culture sites (Bird *et al*. 1993). As an important biofouler, it may incur additional costs for cleaning (Carlton and Scanlon 1985). Although mechanical, biological and chemical methods to remove the alga from shellfish have been tested, none have proven effective (see Trowbridge 1999). *Codium* may also colonise docks, pontoons, buoys, fishing gear, *etc*. (Dromgoole 1982, Carlton and Scanlon 1985, Campbell 1999) which may also incur additional cleaning costs.

On the eastern coast of the United States, *Codium* set on slipper limpets and other small hard substrates can drift and lead to massive accumulations of the alga on beaches (A. Locke, DFO, Gulf Fisheries Centre, Moncton, Canada, pers. com.). This situation requires mechanical removal of the algae, resulting in a large disturbance that can obstruct recreational beach activities. The establishment of extensive populations of *Codium* may also affect commercial species. Scheibling (2003) suggests that the morphology of the alga may reduce the movement of fishes and lobsters through the canopy and potentially reduce their abundance. Nonetheless, more studies are necessary to better test this hypothesis.

In summary, although *Codium* invasion can potentially cause serious negative effect on local ecosystem and commercial and social activities, few studies have focused on its potential impacts. Moreover, the potential impacts can vary among populations and with environmental factors.

3.0 Expert interview

Codium has been established in the southern Gulf of St. Lawrence for more than a decade. As such, this is a case study for a post-introduction assessment and focuses on the potential of dispersal and impact rather than the probability of introduction. In order to consolidate the information about various steps in biological invasion and best address knowledge gaps, the advice of several experts on *Codium* invasion was solicited. The specific objectives of this process were 1) to evaluate the relative importance of various vectors and environmental factors to arrival and establishment to identify areas at risk to invasion and 2) to predict invasion-related impacts on environmental, commercial and social components.

3.1 Analytic Hierarchy Process

An Analytic Hierarchy Process (AHP) was used to interview experts about dispersal vectors and habitat suitability. This method uses mathematical matrices to allow the quantification and the classification of selected criteria (Saaty 1977). The criteria are weighted by comparing them in pairs and assigning them relative measures of importance. This process allows the consistency of the experts' judgements to be evaluated and compared as well as verifying if the weights accorded to all criteria relative to each other follow a logical structure or have been attributed more haphazardly (i.e., evaluated as a "consistency index", CI). The comparison matrix was constructed using the answers from successive questions of the style "What is the importance of criteria A relative to criteria B?" Qualitative answers for compared criteria may range from of "equal importance" through "extremely more important". These are entered as qualitative values ranging from 1 to 9 into the matrix (Table 1). If the inverse is judged to be true (i.e., that B criteria is judged to be more important than criteria A), the inverse values are entered into the data matrix (see Appendix 1 for an example).

Table 1: Scale and description used in the comparison of criteria.

Intensity of importance*	Definition
1	Equal importance
3	Moderately more important
5	Much more important
7	Considerably more important
9	Extremely more important

* Ratings of 2, 4, 6, and 8 can also be used to fine-tune judgements

Experts received a questionnaire with 2 matrices to complete to compare (1) pathways involved in *Codium* dispersal, and (2) environmental conditions involved in habitat suitability (see Appendix 1 for the questionnaire used). The criteria to be compared were selected following the literature review used for the biological synopsis. Once completed, standardized weights for each criterion within the matrices were calculated as their geometric means. The coherence of relative rankings within matrices was then calculated using the method outlined by Saaty (1977) based on the weight accorded to each criterion, the number of criterion and then compared to a "random consistency index, RI". The ratio CI:RI yields the "consistency ratio, CR". The closer this value is to zero, the more the results matrix is logically structured. Saaty (1977) suggests that CR values < 10% indicate informed judgement. We consider this to be far too conservative and have excluded matrices with CRs > 15% from the calculation of criteria means.

Twenty-one experts were solicited to complete the questionnaire. Of these, 11 have done so at the time of writing, 4 declined, saying that it was outside their domain of expertise or else did not have the time to complete it, and 6 did not respond. We consider that the resulting participation success (52%) was reasonable given the short delay between the time when the surveys were sent out and the analyses were started (2 weeks).

3.1.1 AHP on dispersal pathways

The following eight dispersal pathways were compared and given relative weights:

- Fragments (whole or parts of plants)
- Propagules (sexual and/or asexual)
- Ballast water
- Ship biofouling
- Recreational boat activities
- Commercial boat activities (e.g., fishing)
- Translocation of objects (e.g., aquaculture)
- Presence of artificial structures or waste material

Analysis of expert responses showed that the most important mechanisms involved in *Codium* dispersal are fragmentation of the algae and translocation of fouled objects (Table 2). The contribution of ballast water, pleasure craft, and commercial boat activities were described as less important mechanisms (Table 2). The variability between expert judgements was high. As the number of experts was small, the mean weight of criteria could have been influenced by the judgement of individual experts.

Table 2. Expert judgements as to the importance of various vectors involved in the dispersion of *Codium*.

Criteria	**Expert**											**Mean weight**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	
Fragments (whole or parts of plants)	0.34	0.04	0.29	0.40	0.30	0.07	0.19	0.30	0.07	0.06	0.18	0.21
Propagules (sexual and/or asexual)	0.15	0.02	0.03	0.03	0.11	0.04	0.04	0.19	0.16	0.33	0.18	0.13
Ballast water	0.17	0.06	0.07	0.02	0.02	0.02	0.02	0.17	0.09	0.03	0.03	0.06
Ship biofouling	0.17	0.09	0.04	0.15	0.19	0.25	0.19	0.03	0.18	0.03	0.14	0.13
Recreational boat activities	0.04	0.08	0.11	0.05	0.11	0.09	0.19	0.03	0.05	0.03	0.08	0.07
Commercial boat activities (e.g., fishing)	0.04	0.35	0.15	0.09	0.06	0.09	0.10	0.09	0.08	0.03	0.04	0.08
Translocation of objects (e.g., aquaculture)	0.09	0.31	0.29	0.15	0.17	0.19	0.13	0.08	0.28	0.14	0.18	0.19
Presence of artificial structures or waste material	0.12	0.04	0.01	0.10	0.04	0.25	0.13	0.10	0.09	0.36	0.18	0.14
Consistency ratio (%)*	19.56	36.36	11.12	10.01	2.14	5.25	19.31	7.94	5.79	6.45	1.47	

* Expert judgements with consistency ratios > 15 % were not included in calculations of the means

Fragmentation is a natural process that may be involved in the spread of *Codium* over spatial scales ranging from several metres to kilometres (Carlton and Scanlon 1985). Natural dispersal of invasive species can contribute to a diffuse spread of invasive species from initial sites of establishment (MacIsaac *et al*. 2001). Thus the risk of colonization of new sites increases with time and decreases with distance from sites of initial establishment (MacIsaac *et al*. 2001). The direction of spread by this mechanism is clearly tightly associated with current and wind patterns. The other natural method of dispersal considered in this study, dispersal by propagules, was considered to be much less important to the spread of the species (although still one of the most important overall). This is likely related to the short lifespan of this stage (under an hour), which would implicate this mechanism in only very short-distance dispersal. However, as the species may reproduce parthenogenically, dispersal by propagules may be very important in the establishment of founder populations and spread at a very local scale. Indeed, some studies have suggested that only female plants are found in some areas and that this is the main method of reproduction and spread within a site.

Expert judgements suggest that the most important anthropogenic vector for the spread of *Codium* was the translocation of infested objects. The presence of artificial structures and biofouling on ships were considered the next most important anthropogenic vectors. Recreational and commercial boating as well as ballast water in ships were not considered as very important to the spread of *Codium*.

In contrast to natural processes, human-mediated vectors may result in long-distance jump dispersal of organisms over short time periods and in more random directions (although these may be predicted with appropriate modelling) (MacIsaac *et al*. 2001). Overall, the current study found that the total weight accorded to anthropogenic vectors was greater than that accorded to the natural ones. Taken together, these two points may account for the species' disjunct distribution in its current range in the Gulf of St. Lawrence.

3.1.2 AHP on habitat suitability

The following ten physical characteristics on habitat suitability were compared and given relative weights:

- Minimum water temperature
- Mean water temperature
- Salinity
- Nutrient availability
- Depth
- Winter conditions
- Type of substratum
- Area of available suitable habitat
- Wave exposure
- Photoperiod

Relative weightings for habitat suitability indicated that, overall, factors associated with substrate quality (wave exposure, area of available habitat, and substrate type) and mean water temperature were most important in determining the suitability of a habitat for *Codium* establishment and growth (Table 3). Given this and that much of the Gulf of St. Lawrence has fairly equivalent conditions, it seems likely that *Codium* may thus ultimately become fairly widespread in the region until temperatures become limiting. However, the literature review suggests that *Codium* is quite tolerant of cold conditions and thus *Codium*'s ultimate distribution within the gulf remains unknown. Future planned GARP modelling (e.g., Herborg *et al*. in press) will address this issue for *Codium* in the Gulf of St. Lawrence.

Table 3. Expert judgements as to the importance of the various physical characteristics that determine habitat suitability for *Codium*.

Criteria	**Expert**											**Mean weight**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	
Minimum water temperature	0.03	0.07	0.19	0.03	0.03	0.03	0.04	0.12	0.17	0.03	0.04	0.08
Mean water temperature	0.08	0.09	0.01	0.11	0.31	0.27	0.19	0.06	0.17	0.03	0.04	0.13
Salinity	0.03	0.22	0.20	0.06	0.07	0.16	0.07	0.03	0.07	0.03	0.04	0.08
Nutrient availability	0.04	0.02	0.04	0.06	0.05	0.14	0.15	0.09	0.06	0.12	0.20	0.10
Depth	0.05	0.03	0.07	0.22	0.03	0.04	0.04	0.10	0.03	0.03	0.04	0.05
Winter conditions	0.04	0.03	0.25	0.18	0.05	0.08	0.04	0.09	0.10	0.03	0.04	0.08
Type of substratum	0.22	0.23	0.07	0.02	0.22	0.03	0.19	0.09	0.09	0.03	0.31	0.14
Area of available suitable habitat	0.15	0.09	0.03	0.04	0.15	0.18	0.16	0.09	0.13	0.22	0.20	0.15
Wave exposure	0.31	0.19	0.10	0.25	0.05	0.03	0.07	0.24	0.13	0.42	0.04	0.15
Photoperiod	0.05	0.03	0.02	0.04	0.05	0.04	0.06	0.08	0.06	0.03	0.04	0.05
Consistency ratio (%)*	8.03	17.47	9.05	16.46	2.04	13.24	11.15	5.97	6.33	5.62	0.13	

* Expert judgements with consistency ratios > 15 % were not included in calculations of the means

3.2 Qualitative assessment of the risk of impact

Experts were solicited to assess the risk of effects of *Codium* invasion on three sectors (environmental, commercial and economic) using a classification scheme based on that developed by Biosecurity New Zealand (Kluza *et al*. 2006). The likelihood of *Codium* impacting a number of criteria from each sector as well as the magnitude of any such impact were classified as outlined in Table 4. Total risk was estimated from a risk matrix (Table 5). The raw data from each expert and mean rankings for each component are given in Table 6. These means were used to classify the risk of the individual criteria using the risk matrix. Mean probability and magnitude values were thus classified using the table using bins ranging from 1.00-1.49, 1.50-2.49, 2.50-3.49 and 3.50-4.00 for ranks of 1 through 4, respectively. Uncertainty of a classification was assessed as the interval between the minimum and the maximum judgements among experts. Thus the impact was classified as "very certain," "reasonably certain," "reasonably uncertain," and "very uncertain" when judgements were unanimous or varied between 2, 3, or 4 levels of risk, respectively. The qualitative assessments of risk for each of the criteria considered are given in Table 7.

Table 4. Ranking scales to estimate the probability and magnitude of impacts.

Probability			**Magnitude**	
Rank	**Likelihood**	**Description**	**Level**	**Description**
1	Unlikely	Impact will only occur in exceptions or not expected	Insignificant	No measurable impact. Consequences can be absorbed through normal activities. Not requiring management effort.
2	Possible	Impact could occur in some circumstances	Minor	A measurable impact. Disruption to a subcomponent, but reversible and/or limited in time, in space or in severity. May require effort to minimize.
3	Likely	Impact will probably occur in most circumstances	Moderate	A significant impact. Widespread disruption to a subcomponent, but reversible or of limited severity or duration. Can be managed under normal circumstances.
4	Almost certain	Impact is expected to occur in most circumstances	Major	A critical impact. Extensive disruption to a subcomponent that persists over time or is not reversible. Will require proper management or adaptation or may not be manageable.

Table 5. Risk matrix. Letters represent risk level for a given likelihood-magnitude combination: N = negligible, L = Low, M = Moderate, H = High. Adapted from Dufour and Pouillot (2002).

Likelihood	Magnitude			
	Insignificant	Minor	Moderate	Major
Unlikely	N	L	L	M
Possible	N	L	M	M
Likely	N	M	M	H
Almost certain	N	M	H	H

Table 6. Expert judgements as to the probability and magnitude of impacts related to the establishment of *Codium* populations.

	Expert											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**Mean**
Probability												
Biodiversity	4	4	3	3	4	3	4	3	4	4	4	3.64
Habitat	4	3	2	3	4	3	4	3	4	2	4	3.27
Protected species	3	2	2	2	2	2	2	3	3	2	4	2.45
Trophic interactions	3	3	3	3	4	3	4	3	3	4	4	3.36
Aquaculture	3	4	4	3	2	3	4	3	3	3	3	3.18
Commercial fishing	3	4	2	2	2	2	1	3	2	1	3	2.27
Vessels/Moorings	3	3	2	2	2	3	3	2	3	1	3	2.45
Recreational activities	2	3	4	2	2	3	3	3	2	2	3	2.64
Human health	2	1	1	1	1	1	1	1	1	1	1	1.09
Magnitude												
Biodiversity	4	3	3	3	3	3	4	4	4	3	4	3.45
Habitat	4	3	2	3	3	3	4	4	4	2	4	3.27
Protected species	2	3	1	2	3	4	3	4	4	2	4	2.91
Trophic interactions	4	2	3	4	3	3	4	4	4	4	4	3.55
Aquaculture	2	4	3	3	2	3	3	4	4	3	3	3.09
Commercial fishing	3	4	2	1	3	4	1	3	4	1	3	2.64
Vessels/Moorings	1	3	2	1	2	3	3	2	3	1	3	2.18
Recreational activities	2	2	3	2	2	3	3	4	4	3	3	2.82
Human health	2	1	1	1	1	1	1	1	1	1	1	1.09

Table 7. Results of qualitative risk assessments and related uncertainties

Components	**Criteria**	**Qualitative mean**	**Uncertainty (min to max)**
Environmental	Biodiversity	High	Reasonably certain (moderate to high)
	Habitat	Moderate	Reasonably uncertain (low to high)
	Protected species	Moderate	Very uncertain (negligible to high)
	Trophic interactions	High	Reasonably certain (moderate to high)
Economic	Aquaculture	Moderate	Reasonably uncertain (low to high)
	Commercial fishing	Moderate	very uncertain (negligible to high)
	Vessels/Moorings	Low	Reasonably certain (low to moderate)
Social	Recreational activities	Moderate	Reasonably uncertain (low to high)
	Human health	Negligible	Reasonably certain (negligible to low)

Expert judgements suggest that there is high risk from *Codium* invasion for two of the four environmental criteria considered (biodiversity and trophic interactions, Table 7). What's more, expert judgement on this was fairly unanimous (reasonable certainty). The environmental components that were not at high risk were habitat and protected species and these components were evaluated to be at moderate risk but there was more uncertainty in these evaluations. Thus invasion by *Codium* can be expected to have at least several long-term and significant ecological effects on ecosystem structure and function. Economic criteria were all considered to be at moderate or low risk to *Codium* invasion although the uncertainty associated with these evaluations ranged from very uncertain for commercial fishing through reasonably certain for vessels and moorings. Risks to aquaculture, especially bivalve culture, have been suggested in the past but the impacts have been only limited. To date, no commercial stocks have been identified as at risk from the establishment of *Codium*. That being said, the changing seascape along eastern Canada from hard bottoms being dominated by kelp to *Codium* and eelgrass beds becoming infested by the alga in some places may have an influence of some populations. *Codium* invasion was perceived to have generally lower levels of risk to social criteria (recreational activities and human health criteria). There was reasonable uncertainty associated with moderate risk to recreational activities whereas there was quite reasonable certainty that there was low risk to human health.

4.0 QBRAT Supporting Evidence – A. Biological Risk Assessment

The Quantitative Biological Risk Assessment Tool (QBRAT) was used to evaluate the question "What is the biological risk associated with the invasion of *Codium* in the southern Gulf of St. Lawrence?" Because we consider it relevant to the current study, we also evaluate the question "What are the economic and social risks associated with the invasion of *Codium* in the southern Gulf of St. Lawrence?" A literature review and survey of expert judgements was used to assess the relative importance of various criteria to the arrival, establishment and spread as well as the impact of *Codium* in the Gulf of St. Lawrence.

4.1. Arrival, survival, establishment

Codium was first observed in Canada ca. 1989 (Bird *et al*. 1993). In 1996, *Codium* was detected in the Gulf of St. Lawrence for the fist time, at Caribou Harbour, Nova Scotia (Garbary *et al*. 1997). Since then, *Codium* has spread within the gulf and is now present in several locations on the coasts of New Brunswick, Prince Edward Island, and the Magdalen Islands (Garbary *et al*. 1997, Garbary and Jess 2000, Hubbard and Garbary 2002, Simard *et al*. 2006).

Codium's known northern limit in the Gulf of St. Lawrence to date is the southern side of the baie des Chaleurs in northern New Brunswick. Whether this represents its ultimate northern limit is unknown. It is unlikely that light conditions are limiting the species' northern limit in the gulf as it is found at much higher latitudes in Europe and the consensus of experts placed little importance on this factor as limiting habitat suitability. In contrast, mean water temperature was considered to be very important by many of the experts surveyed (although some considered this factor to be unimportant relative to other factors). *Codium* is usually considered to be a warm temperate species with growth rates being optimal near 24˚C although some strains seem to be much better adapted to cold conditions. Thus *Codium*'s northern limit in the gulf may be set by average temperatures. Again, expert judgements tended to place little importance on minimum water temperatures, reflecting the fact that *Codium* in the gulf is able to survive the winters under ice.

Thus, it is apparent that *Codium* is already present and apparently thriving in the southern Gulf of St. Lawrence. Thus, the **probabilities** of **arrival**, **survival** and **establishment** of *Codium* in the Gulf area were rated as **high** (100%) with a **very certain** (0% uncertainty) level of confidence. It remains unclear as to which pathway or pathways have been involved in its dispersal in the southern gulf but its expanding distribution confirms that at least one vector is operating and that environmental conditions, at least in the southern part of the gulf, are favourable for its survival and establishment.

4.2 Spread

The spread of *Codium* from infested areas in the southern gulf has occurred in the past and is likely ongoing. Scientific studies have yet to evaluate the factors that are important to the spread of this alga in the Maritimes. In terms of natural factors, the general consensus of the surveyed experts is that fragmentation is quite important to the spread of *Codium*. Indeed, the alga is often found washed up on beaches in the southern gulf and seen floating on the surface in areas where it is established. Moreover, Kinlan *et al*. (2005) have suggested that algae that are dispersed by this means may contribute greatly to jump-type dispersal in algae in general. Anthropogenic factors also seem likely to aid the spread of *Codium* in the Gulf of St. Lawrence. Of these, translocation of infested objects is judged by the experts surveyed to be the single greatest vector for spread of the alga. Indeed, proposed aquaculture stock transfers have been prohibited because of this perceived risk. Whatever the mechanism of introduction, when *Codium* arrives in a suitable habitat, establishment and local secondary spread may occur via parthenogenesis. Moreover, the large suite of habitats in which *Codium* seems to be associated with in eastern Canada (semi-exposed rocky coasts, calm lagoons and embayments, eelgrass beds, artificial structures, etc.) suggests that it may be quite successful, at least in terms of general habitat requirements, in the Gulf of St. Lawrence.

Thus, for the current risk analysis using the QBRAT framework, the **probability** of further **spread** of *Codium* within the gulf was set at a (conservative) value of **95%** with a **good certainty** (**10%** uncertainty) level of confidence (Figure 1). A normal distribution of uncertainty was assumed for the framework as the expert judgements for most criteria followed this distribution.

4.3 Impact

Overall, expert judgement suggests that the establishment of *Codium* is likely to impact a variety of criteria from all three sectors (environmental, economic and social). Of the environmental criteria considered, biodiversity and trophic interactions were found to be at high (but not critical) risk to the invasion by *Codium*. As such, some ecological values and processes were assumed by the surveyed experts to be at risk to persistent and irreversible damage. The risk to threatened species and habitat were considered to be moderate. The economic criteria were considered to be at moderate or low risk to *Codium* invasion and thus were not expected to beset by any unmanageable consequences. With respect to social criteria, recreational activities were also considered to be at moderate risk by *Codium* invasions whereas human health was considered to be at negligible risk.

These results were used within the QBRAT framework to evaluate the risk to *Codium* in the Gulf of St. Lawrence. Because there is no clear way to assign meaningful weightings to levels of impacts for the different subcomponents of the model, we used a simple ordinal scale, to indicate that impacts are more or less greater than each other. All uncertainties were assumed to have normal distributions because of the qualitative scale used for the assessment and because expert judgements usually best approximated this type of distribution.

The absence of *Codium* does not seem to cause any biological issues on the environmental, economic or social components, since the *statu quo* in communities is maintained. Thus, impacts associated with this event are rated as **insignificant** (**I1=1**), with a **very certain** (**0%** uncertainty) level of confidence (Figure 1 and 2). At the following two levels within the framework, where *Codium* arrives but dies or survives without establishing, biological impacts on the different components may occur but these will likely be extremely limited in time and space as and likely unmeasurable (other than their presence being noted). Thus, the impact for the presence of *Codium* without establishment is rated as **minor** (**I2=2**, **I3=2**) with a **good certainty** (**10%** uncertainty) level of confidence (Figure 1 and 2). The establishment of a *Codium* population in an area is when biological effects begin to become evident. Thus, the continued presence of a growing population of *Codium* may involve impact on the different examined categories. Mean expert judgements rated the probability of impacts for environmental and economic components as likely (3.18 and 2.63, respectively) with moderate consequences (3.26 and 2.63, respectively)**.** For this reason and for brevity, the QBRAT output for both the biological risk assessment and the economic risk analysis are shown graphically in the same figures (see below). As outlined above, the exact forms these impacts will take are unclear, since few studies have focused on the impact of *Codium* population in the Gulf of St. Lawrence. Most experts believe that significant impacts on habitat and community structure and on aquaculture and commercial stocks will occur. Thus the biological impact associated with establishment without spread from an area was, for these two issues, rated as **moderate** (**I4=3**), with a **poor certainty** (**60%** uncertainty) level of confidence (Figure 1). The mean probability and magnitude of impact for the social components, as assessed by the surveyed experts, was “possible” (1.86) with “minor consequences” (1.95). Until now, no effect on human health has ever been associated with *Codium* invasion and the reported impact on beach activities are known to be occasional and reversible. Thus, the biological impact associated with recreational activities and human health was rated as **minor (I4=2)** with a **reasonably certainty** (**20%** uncertainty) level of confidence (Figure 2).

The more *Codium* can spread, the more establishments beyond the invaded area may occur and then the spatial scale of impact would increase. Both the magnitude and the certainty of impact increase concomitantly with the probability of dispersion. Taken together, evidence from the surveyed experts and observations within the Gulf of St. Lawrence suggest that this species will continue to spread and have impacts in the Gulf and Northwest Atlantic. That being said, it is not possible to determine, with complete certainty, *Codium*’s ultimate effects and distribution in the area. So for the ecological and economic issues, the impact of widespread distribution was rated as **major** (**I5=4**) (Figure 1) and for the social issues as **moderate** (**I5=3)** (Figure 2), with a **reasonably certainty** (**20%** uncertainty).

The Monte Carlo simulation was used with 5000 trials and a 95% confidence interval. Results related to ecological and economical issues are shown in Figure 3. For these two categories, the biological risk associated with *Codium* invasion in the Gulf of St. Lawrence is high based on the qualitative scale used (simulation mean 3.931). The probabilities of arrival, survival, establishment and spread were estimated as high, but the consequences were estimated to be manageable. Significant impacts on ecological criteria will likely occur, but impacts on these and other criteria are not expected to become critical. The correlation between overall risk and the impact of the establishment of *Codium* (I5 in Figure 3b) shows that future impacts will be largely a function of the spread of the species. As *Codium* can establish rapidly once it arrives (Simard *et al*. 2006), controlling this aspect of the invasion process should be a key factor in the management of this species, and limit impact on wild communities and commercial stocks. Similar results were observed for the risk on social components, except for the total biological risk that is smaller with a moderate risk (simulation mean 2.948; Figure 4). Here again, the total biological risk was mainly related to the impact of widespread *Codium* population (I5 in Figure 4b).

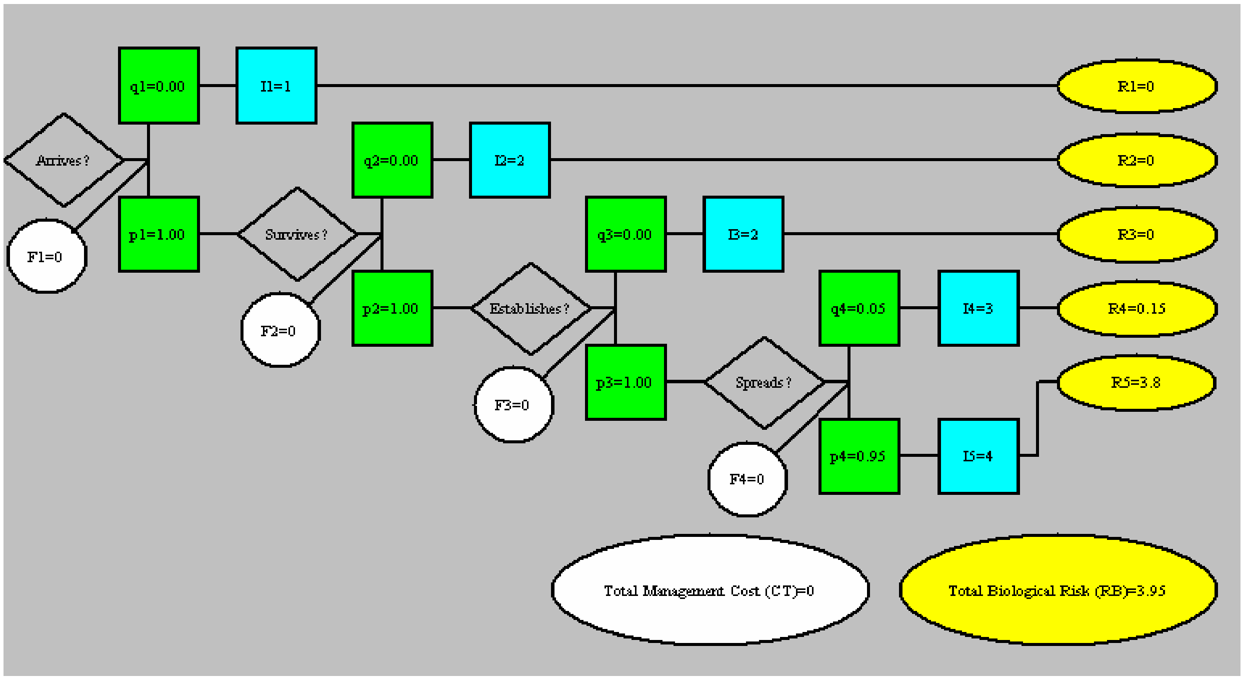

Figure 1: QBRAT v2 framework results for the probability of biological impacts on environmental components due to the invasion of *Codium fragile* ssp. *tomentosoides* in the Gulf of St. Lawrence. For brevity, this figure also represents the probability of economic impacts for economic components due to the invasion of *Codium fragile* ssp. *tomentosoides* in the Gulf of St. Lawrence.

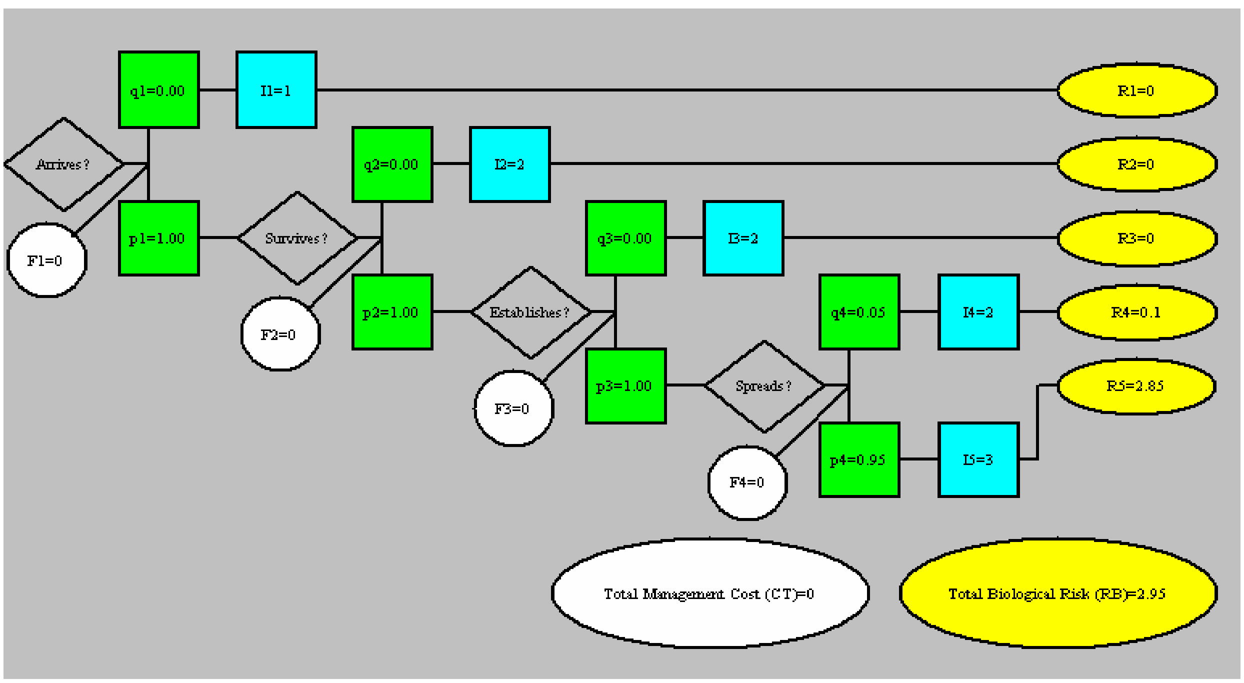

Figure 2: QBRAT v2 framework results for the probabilities and biological impacts on the social components of the invasion of *Codium fragile* ssp. *tomentosoides* in the Gulf of St. Lawrence.

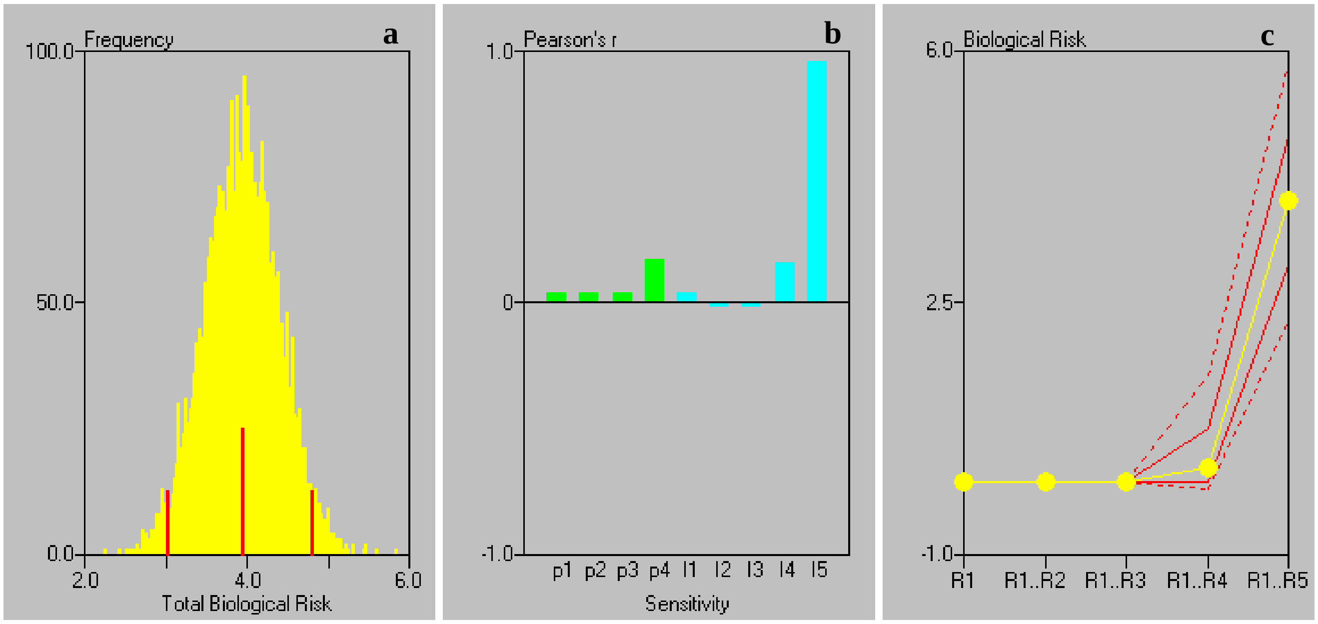

Figure 3: QBRAT v2 output results for the Monte Carlo simulation for environmental impacts: a) the frequency of total biological risk, b) the correlation of the values with the biological risk, and c) the curve of the biological risk related to each risk values. For brevity, this figure also represents the QBRAT v2 output results for the Monte Carlo simulation for economic impacts.

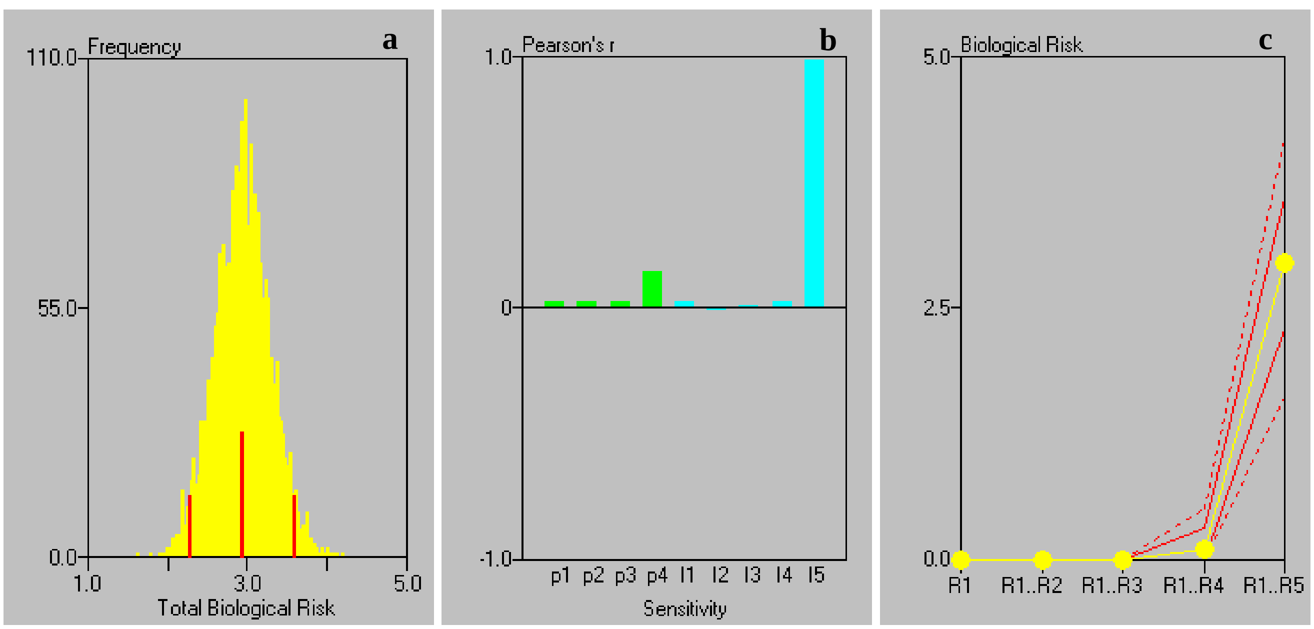

Figure 4: QBRAT v2 output results for the Monte Carlo simulation for social impacts: a) the frequency of total biological risk, b) the correlation of the values with the biological risk, and c) the curve of the biological risk related to each risk values.

5.0 Comments and recommendations on QBRAT

We found that one of the most important benefits of using a structured framework such as QBRATv2 is that it provides novices to the field of risk assessment, such as the authors, a way to focus their research to get all, and only, the information needed to run the risk assessment. The framework sets clear criteria that must be addressed for successive steps in the invasion process. Each of these may then be addressed in turn without confounding the different processes. The use of the framework also forced us to become more objective. For example, in the present assessment, we supplemented information from a literature review with targeted surveys to a number of experts on the species under consideration. We chose to do this because much information about *Codium* is either unknown or contradictory. We also wanted to get a better idea of the error structure associated with the judgements for the different criteria and this seemed to be the best way to do so.

With respect to the associated software, it is very user-friendly and a novice user may start using it quite quickly. The supporting documentation is sufficient to give the user a rudimentary understanding of the logical part of the framework and start using the software. That being said, direct support from the developers was used quite often. Many of the questions were quite specific and not very amenable to inclusion within a user manual. To this end, it is suggested that the questions asked of the different users but put together with the appropriate responses in some sort of technical aid that could be updated as questions arise (perhaps some on-line support). It is further suggested that some generic case studies be included to show examples of how the framework may be followed and how different parameters respond to variation. These examples must be general enough as to show only how the framework works and not bias how they will use it in their own assessments.

One of the most important options within the framework is that it allows the user to specify the error distribution of the different probabilities that best reflect the user's knowledge. It also lets the user decide on the scale used for the weightings of the different parameters used. For instance, we chose an ordinal scale to reflect the fact that we really didn't know how to classify the importance of one variable as compared to another. We (and our polled experts) could say that a given factor was more important than another but we could not assign logical orders of magnitude of importance. In another case, this would probably not be an issue and the user should have the flexibility to use all the information at their disposal.

One aspect of the framework that is a bit odd is that ultimate modelled biological risk may have a variance associated with it that extends greatly beyond the maximum or, presumably, lower limits set by the user. Although this should not influence interpretation greatly, it may indicate some glitch that should be considered.

In the present risk assessment, we evaluated the risk associated with environmental, economic and social criteria. We believe that this method can help qualify the total biological risk and provide further information for managers. We recommend that the criteria that account for the greatest portion of the biological (and other) risks be well identified and discussed within the risk assessment, as appropriate management decisions depend on such accuracy.

6.0 Conclusion

This study found that the risk of spread of *Codium* in the Gulf of St. Lawrence is considerable. The species is already well-established in the gulf and is expected to continue its spread. The literature review and expert survey done within the current study suggest that *Codium* will have, overall, a considerable effect on the ecosystem but less of an effect on economic and social sectors. This general impression was supported by the more structured risk analysis done within the QBRATv2 framework.

Consultation with experts served to reduce assessor bias as it brings together the diverse knowledge and expertise from many scientists. Based on our results, it seems that judgements can greatly vary between the researchers, suggesting that each person can interpret the literature differently and/or have different experiences with one or more given criteria. The variance among expert judgements further highlights the need to use a highly qualified assessor combined with peer review to enhance the quality of risk assessments. Survey questions must be as clear and neutral as possible to avoid bias due to misinterpretation.

The use of a structured framework such as QBRATv2 can greatly enhance the objectiveness and overall quality of a risk assessment. Specifically with respect to QBRATv2, the flexibility of the framework to define variance structures that reflect the data and use a variety of quantitative or semi-quantitative classification schemes greatly increases the assessor's ability to reflect the accuracy of the data that is being used in the model. One other positive outcome of using such an approach is that it forces the assessor to structure their thought process to come up with the questions needed to answer specific questions.

Notwithstanding the discussions at the National Risk Assessment Methods workshop held in Burlington in June 2006, we suggest that the number of levels used to classify different levels of impacts be increased from the 4 we used to 5 as outlined in Hewitt *et al*. (2006) and Kluza *et al*. (2006). We do not believe that the four levels provide enough latitude for the experts to make fine enough judgements. This may have led to too critical judgements on the impacts of *Codium* in some cases.

7.0 Acknowledgements

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Appendix 1. Survey used to solicit expert judgements

<u>Instructions for Sections 1 and 2</u>

The method used in the first two sections is based on the analytic hierarchy process (AHP) developed by Saaty (1977). This method allows for the comparison of criteria as successive questions using a numerical scale: *What is the importance of criterion A in comparison to criterion B?* Five general answers are available:

Equal importance	1
Moderately more important	3
Much more important	5
Considerably more important	7
Extremely more important	9

* Ratings of 2, 4, 6, and 8 can also be used to fine-tune judgements.

Expert answers are compiled in a matrix (see example). The matrix should be filled in row by row. The entered value is a measure of the importance of the criterion noted in that row relative to the criterion in the corresponding column. If the criterion in row is judged less important than criterion in column, fill the corresponding space in the matrix with the reciprocal value. You only have to fill in white spaces. Note that each criterion compared to itself is given the value 1.

<u>Example:</u>

Comparison matrix of each criterion pairs

X \ ***Y***	***A***	***B***	***C***
A	*1*	*5*	*1/9*
B		*1*	*3*
C			*1*

1- What is the importance of criterion ***A*** *relative to criterion* ***B****?*
Criterion A is judged to be much more important than criterion B, so the value 5 is assigned.

2- What is the importance of criterion ***A*** *relative to criterion* ***C****?*
Criterion C is judged to be extremely more important than criterion A, so the value 1/9 is assigned (i.e., the reciprocal of 9).

3- What is the importance of criterion ***B*** *relative to criterion* ***C****?*
Criterion B is judged to be moderately more important than criterion C, so the value 3 is assigned.

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Section 1: Vectors and Pathways

Based on your expertise, which of the following factors are the most important in the dispersion of *Codium fragile* ssp. *tomentosoides* in the NW Atlantic?

- Fragments (whole or parts of plants)
- Propagules (sexual and/or asexual)
- Ballast water
- Ship biofouling
- Recreational boat activities
- Commercial boat activities (e.g., fishing)
- Translocation of objects (e.g., aquaculture)
- Presence of artificial structures or waste material

First three questions:

1. How important are fragments relative to propagules to the spread and introduction of *Codium*?
2. How important are fragments relative to ballast water to the spread and introduction of *Codium*?
3. How important are fragments relative to ship biofouling to the spread and introduction of *Codium*?
4. etc…

Comparison matrix for vectors/pathways involved in *Codium* dispersion.

X \ Y	Fragment	Propagule	Ballast water	Biofouling	Recreational boats	Commercial boats	Translocation	Artificial structure
Fragment	1							
Propagule		1						
Ballast water			1					
Fouling				1				
Recreational boats					1			
Commercial boats						1		
Translocation							1	
Artificial structure								1

Section 2: Environmental suitability

Based on your expertise, which of the following environmental factors are most important to the survival of *Codium fragile* ssp. *tomentosoides* in the NW Atlantic?

- Minimum water temperature
- Mean water temperature
- Salinity
- Nutrient availability
- Depth
- Winter conditions
- Type of substratum
- Area of available suitable habitat
- Wave exposure
- Photoperiod

First three questions:

1. How important is minimum water temperature relative to mean water temperature to the survival of *Codium*?
2. How important is minimum water temperature relative to salinity to the survival of *Codium?*
3. How important is minimum water temperature relative to nutrient availability to the survival of *Codium*
4. *etc…*

Comparison matrix for environmental criterion involved in *Codium* survival.

X \ Y	Minimum temperature	Mean temperature	Salinity	Nutrients	Depth	Winter conditions	Substratum type	Suitable habitat area	Wave exposure	Photoperiod
Minimum temperatur	1									
Mean temperatur		1								
Salinity			1							
Nutrients				1						
Depth					1					
Winter conditions						1				
Substratum type							1			
Suitable habitat area								1		
Wave exposure									1	
Photoperiod										1

Instructions for Section 3

The impact assessment classification used is based on outcomes outlined in the Organism Impact Assessment for *Styela clava* for Biosecurity New Zealand (Kluza *et al*. 2006). For each of the following components, use your best judgement to estimate the probability and magnitude of potential impacts. Use the ranking scores described in probabilities and magnitude grids to complete the impact table.

Section 3: Impacts

Table for probabilities and magnitude of impacts (to be completed by experts)

Components	Probability	Magnitude
Biodiversity Flora and fauna that exist in a given area		
Habitat Biotic and abiotic structures that provide habitat for flora and fauna		
Protected species Marine wildlife: seabirds, fish, mammals		
Trophic interactions Energy flow within an ecosystem; food webs, predator-prey relationships		
Recreational activities Public fishing, aquatic and beach activities		
Commercial fishing		
Aquaculture Shellfish and fish farming		
Human health Personal injury, toxicity, allergy		
Vessels/Moorings Maintenance and cleaning costs		

Probabilities that an impact will occur for each component

Rank	Likelihood	Description
1	Unlikely	Impact will only occur in exceptions or is not expected
2	Possible	Impact could occur in some circumstances
3	Likely	Impact will probably occur in most circumstances
4	Almost certain	Impact is expected to occur in most circumstances

Magnitudes of impact for each component

Rank	Level	Description
1	Insignificant	No measurable impact. Consequences can be absorbed through normal activities. Not requiring management effort.
2	Minor	A measurable impact. Disruption to a subcomponent, but reversible and/or limited in time, in space or in severity. May require effort to minimize.
3	Moderate	A significant impact. Widespread disruption to a subcomponent, but reversible or of limited severity or duration. Can be managed under normal circumstances.
4	Major	A critical impact. Extensive disruption to a subcomponent that persists over time or is not reversible. Will require proper management or adaptation or may not be manageable.