By I.K. Birtwell, R.C. Degraaf, D.E. Hay, G.R. Peterson

The stimulus for this report was the initiation of beach-cast seaweed harvesting in 2012, close to Deep Bay and Bowser on the east coast of Vancouver Island. This area supports valuable fish habitat, recreational and commercial fisheries, seabirds and eagles and other animals that rely on the shore line and adjacent marine waters. This coastal area provides food, spawning habitats, nursery and rearing habitats, and migration pathways for many species of fish, birds and mammals. The area is adjacent to, and the waters are contiguous with, Baynes Sound which is used for an expanding shellfish aquaculture industry that supplies approximately fifty percent of BC's total shellfish aquaculture production. Seaweeds provide food and cover for many organisms when growing. However, it has been well-documented that when detached and washed ashore they provide readily-available nourishment for organisms at the base of the food chain. In the location of Baynes Sound that food chain includes the organisms that are used for food by fish, birds and mammals aside from that needed to meet the requirements for aquaculture

See petition at https://secure.avaaz.org/en/petition/The_Provincial_Government_of_British_Columbia_An_immediate_moratorium_on_the_harvesting_of_seaweed_for_commercial_use/?tgbQrab

PREFACE

This report provides the opinions of the authors whose careers involved research and the management of aquatic resources in western Canada:

Ramona de Graaf is a "forage fish" research specialist and Executive Director of Emerald Sea

Biological, and the coordinator of the Coastal Conservation Institute of BC – BC Shore Spawners Alliance.

Ross Peterson is a retired government biologist and an environmental consultant who has specialized in resource and environmental management for over 40 years.

Doug Hay and Ian Birtwell are both retired research scientists from Fisheries and Oceans Canada, each has over 40 years experience in the research and management of fish and fish habitat and the effects of human activities upon them.

All the authors are currently involved in research and related activities associated with the management and protection of organisms and their habitat.

The findings, opinions, and conclusions provided in this document are solely those of the authors who voluntarily undertook this review to ascertain if there was a scientific basis for concern over the initiation of seaweed harvesting along the shores on the east coast of Vancouver Island.

This report addresses specific concerns over the harvest of seaweed near Deep Bay and Bowser on the east coast of Vancouver Island but the content and comments have relevance to other coastal areas of BC.

It is hoped that the provision of this science-based report will assist in understanding the ecological issues associated with this new industry and support a cautionary approach and thorough evaluation in support of sound regulatory and managerial decision-making.

May 19 2013

Report citation:

Birtwell, I.K., R.C. de Graaf, D.E. Hay, and G.R. Peterson. 2013. Seaweed harvesting on the east coast of Vancouver Island, BC: a biological review. Unpublished report. 28p.

Cover page: *herring eggs on red algae in the low inter-tidal zone, Bowser, March 2013*.

TABLE OF CONTENTS

APPENDIX 2.

Inter-tidal forage fish spawning habitat and potential impacts

of beach wrack seaweed harvesting 24

SUMMARY

Seaweed harvesting at Deep Bay and Bowser; east coast Vancouver Island

1. The stimulus for this report was the initiation of beach-cast seaweed harvesting in 2012, close to Deep Bay and Bowser on the east coast of Vancouver Island. This area supports valuable fish habitat, recreational and commercial fisheries, seabirds and eagles and other animals that rely on the shore line and adjacent marine waters. This coastal area provides food, spawning habitats, nursery and rearing habitats, and migration pathways for many species of fish, birds and mammals. The area is adjacent to, and the waters are contiguous with, Baynes Sound which is used for an expanding shellfish aquaculture industry that supplies approximately fifty percent of BC’s total shellfish aquaculture production. Seaweeds provide food and cover for many organisms when growing. However, it has been well-documented that when detached and washed ashore they provide readily-available nourishment for organisms at the base of the food chain. In the location of Baynes Sound that food chain includes the organisms that are used for food by fish, birds and mammals aside from that needed to meet the requirements for aquaculture.

1. Wide ranging ecological changes have already occurred throughout Baynes Sound due to extensive commercial aquaculture. The needs of all resources supported by the area require thorough assessment to evaluate impacts on the carrying capacity of the area to meet current and foreseeable requirements.

1. The harvest of thousands of tonnes of detached seaweed has occurred as a pilot project on the east coast of Vancouver Island in an area bounded by Deep Bay to Parksville. The project was authorized by the Provincial Government's Ministry of Agriculture and targeted a recently introduced species of red algae *Mazzaella japonica* which grows in shallow sub-tidal waters. Valuable components (carrageenans) may be extracted from the algae for commercial use; 5000 tonnes were permitted for removal by licensees in the 2012 pilot project.

1. Detached, storm-cast *Mazzaella japonica* fronds were collected manually in the late fall and early winter of 2012. The material was gathered by rakes and placed into large bags on the beach. At a number of locations large all-terrain vehicles moved along beaches collecting the bagged algae for transport to drying and processing locations. Some of these same beaches are spawning habitats of importance to "forage fish" species whose embryos incubate in the inter-tidal and sub-tidal areas placing habitats and fish embryos at risk from the present seaweed harvesting methods.

1. There is substantial scientific literature on the role of seaweeds in marine ecosystems. This body of knowledge supports concerns that this new seaweed fishery, as it is currently practised, could be detrimental to habitats of species supporting existing commercial aquaculture ventures as well those existing commercial, recreational, and Aboriginal fisheries. This concern is based on the documented significant role that seaweeds play in the near shore aquatic environment and the ecological effects that will accrue due to its removal. There are particular concerns about the physical and mechanical impacts of collection process. Previous studies have identified key knowledge and research gaps related to the removal of beach-cast seaweeds from the coastal environment. These gaps include: (i) inadequate quantitative data on the distribution of beach-cast seaweeds; (ii) the relationship between beach-cast seaweed and off-shore algal stands; (iii) the residence time of the seaweed on the beach; (iv) the ecological fate of beach-cast seaweeds; (v) the ecological role of floating seaweeds; (vi) the effects of seaweed removals on coastal ecosystem and fisheries resources. These aspects are also of relevance in relation to the seaweed harvest along the east coast of Vancouver Island.

Conclusions and recommendations

- There is a scientific basis for concern about the implementation of a potential new industry that would harvest seaweed along the east coast of Vancouver Island, and perhaps other areas in British Columbia **.**

- The seaweed fishery, as a potentially new sustainable resource extraction activity, should be subject to the Fisheries and Oceans regulations for "new fisheries". The criteria for such are to be found at the web site defining emerging fishery policy:

http://www.dfo-mpo.gc.ca/fm-gp/policies-politiques/efp-pnp-eng.htm#sec6a

- A scientific and ecological review of the *Mazzaella japonica* fishery is required; equivalent to reviews usually conducted through a Fisheries and Oceans Canadian Science Advisory Secretariat evaluation and reporting process.

- A thorough evaluation of the effects of seaweed harvesting should be undertaken in relation to the requirements of the impacted areas affected to support continued aquaculture activities and their future growth, and maintain the supporting habitat for other highly valuable components of the local ecosystem. This is a prerequisite so that appropriate, sensible, and sound decisions may be made based on pertinent factual information.

- The recommendations of Jamieson et al. (2001) regarding Baynes Sound are endorsed and should be reviewed and reconsidered in light of this new proposed industry, as follows:

1. Establish a multi-agency initiative to identify existing and potential future impacts;

2. Develop a network of protected areas in Baynes Sound that includes sensitive habitats, key bird habitats and which exclude shellfish culture;

3. Identify potential adverse impacts from inter-tidal shellfish aquaculture and implement mitigation where appropriate. Consider inter-tidal aquaculture both as an economic asset and as an ecological disturbance;

4. Investigate the overall carrying capacity of the Baynes Sound ecosystem with respect to phytoplankton production and its removal by filter feeders.

- Restrictions should be specified to protect certain ecologically valuable areas from any future harvesting (e.g. inter-tidal pool and lagoon areas within 3 km of Deep Bay, unconsolidated-sediment areas comprising spawning beaches for “forage fish”, and marine riparian habitats).

- A moratorium on seaweed harvesting and licensing should be imposed until such time as the ecological impacts of the *Mazzaella* fishery have been identified and assessed.

SEAWEED HARVESTING: ITS REGULATION AND ECOLOGICAL SIGNIFICANCE

Report objective

The stimulus for this report was the initiation of a seaweed harvesting pilot program in 2012, close to Deep Bay and Bowser on the east coast of Vancouver Island. This area supports valuable fish habitat, recreational and commercial fisheries, seabirds and eagles and other animals that rely on the shore line and adjacent marine waters. This coastal area provides food, spawning habitats, nursery and rearing habitats, marine riparian habitats, and migration pathways for many species of fish, birds and mammals. The area is adjacent to, and the waters are contiguous with, Baynes Sound which is used for an expanding shellfish aquaculture industry that supplies approximately 50 percent of BC’s total shellfish aquaculture production.

The objective of this document is to comment on the ecological importance of seaweeds to coastal near shore areas and explain the rationale for concerns about the proposed harvesting of an introduced species of red algae (*Mazzaella japonica*). The information in this report relies on published scientific literature and personal knowledge of the authors and others they have contacted. The scientific literature on the ecology of near shore environments is extensive and varied but a fundamental aspect that is universally accepted is the significant role of near shore habitats in coastal food webs. Seaweed plays a significant role in this process and accordingly its removal can be problematic to sustaining the integrity of aquatic communities.

Commercial versus ecological values

The commercial interest in the seaweed is based on substances (carrageenans) that can be extracted from red algae. Phycocolloids are the major polysaccharides found in algae (alginates, carrageenans, agars, fucanes, laminarans, ulvans, and floridean starch). The annual global production of phycocolloids is just less than 100,000 tonnes, with a gross market value of $1 billion (US) annually; 80% of the global agar and carrageenan production and 30% of the global alginate production is used in the food industry (refer to Jaspers and Folmar 2013).They are valuable, and widely used in the food industry for their gelling, thickening and stabilizing properties (Jaspers and Folmar 2013). In 1995 annual carrageenan sales were over $200 million (US) or about 15% of the world use of hydrocolloids (Bixler, 1996). Carrageenan markets grew exponentially at 5% per year between 1970 and 1995: 5,500 metric tons in 1970, and over 20,000 metric tons were expected in 1995 (Bixler, 1996).

In contrast, seaweeds are, fundamentally, of high ecological importance (Harley et al. 2012) and accordingly their removal whether while living, or dead, will have an ecological impact. The scale of the impact depends on the location and nature of the harvest, its timing, the methods used to harvest the seaweed, the organisms impacted directly and indirectly, and their role in the ecosystem productivity.

Background: seaweeds, ecology, mariculture and Baynes Sound

Seaweeds are essential valued ecosystem components that sustain other aquatic organisms, including those that support valuable commercial, recreational, and Aboriginal finfish and shellfish fisheries. Seaweeds also maintain the local primary and secondary productivity. Seaweeds are, therefore, a basic and vital component of the marine ecosystem. Seaweeds are of fundamental importance to the protection of fish and their habitat as required under the *Fisheries Act* (Government of Canada 2012).

Jamieson et al. (2001) wrote a comprehensive ecological review of environmental impacts of inter-tidal shellfish aquaculture in Baynes Sound. At that time (2001) seaweed harvesting was not undertaken so potential impacts were not addressed. Also the timing of, and occurrence of, spawning by important “forage fish” (i.e. surf smelt and Pacific sand lance) in Baynes Sound had not been investigated. However, the report made recommendations pertaining to shellfish aquaculture practices that had significantly modified Bayne Sound’s fish habitat, especially the inter-tidal areas. The planned expansion rates (10% per year) of farmed areas generated concern over the sustainability of the industry in the area.

The concerns of Jamieson et al. (2001) were not just restricted to future shellfish production but also included comments on deleterious impacts on biodiversity and productivity. Such impacts are known to have occurred in other areas including: changes in species composition of benthic communities; exclusion of some species from foraging activity; reduced size of some fish spawning, nursery and rearing habitats; and altered the natural coastal hydrography (Simenstad and Fresh 1995, cited by Jamieson et al. 2001). The authors suggested that such impacts in Baynes Sound could affect growth and survival of transient fish and seabirds including juvenile salmonids (chinook, coho, chum, pink and steelhead), herring and migratory waterfowl and local shorebirds.

Scientific data gaps exist on impacts of shellfish aquaculture in BC and accordingly this hampers evaluation of potential adverse effects of existing practices and of new aquaculture proposals (Jamieson et al. 2001). To rectify some deficiencies Jamieson et al. (2001) proposed recommendations which we endorse because seaweed harvesting has the potential to become another constraint and concern regarding the productivity in Baynes Sound and adjacent local coastal waters.

The recommendations of Jamieson et al. (2001) remain valid today, and they are abbreviated below:

1. A multi-agency research initiative should be established to identify both the nature of existing impacts, potential future impacts and, where necessary, how they can be minimised.

2. An effective network of protected areas in Baynes Sound that exclude shellfish culture should be established. The network should include sensitive habitats and key bird habitat.

3. The significance of Baynes Sound in the Georgia Basin ecosystem appears not to have been recognized by resource managers to date. Potential adverse impacts from inter-tidal shellfish aquaculture in this broader context needs to be identified and mitigation implemented, where appropriate. Ocean management in Baynes Sound should be considering inter-tidal aquaculture both as an economic asset and as an ecological disturbance that may be influencing important ecosystem processes (i.e. productivities of other important species).

4. With increasing bivalve culture in Baynes Sound, the overall carrying capacity of the system with respect to phytoplankton production and its removal by filter feeders needs investigation, both with respect to annual and seasonal fluctuations.

Seaweed harvesting along the east coast of Vancouver Island

The recently introduced species of red algae *Mazzaella japonica* occurs close to the low tide level and in shallow sub-tidal waters in the area around Deep Bay and Bowser on the east coast of Vancouver Island. It is a target species for a proposed commercial harvest venture extending from Deep Bay and Bowser to locations approximately 20 km southwards. A pilot project, initiated by commercial interests but authorized by the Provincial Ministry of Agriculture, was carried out in the late fall and early winter of 2012 with 5000 tonnes licensed for removal. Within this specific permitted area for harvesting the seaweed there is variable and often limited access to the marine foreshore. Harvesters and vehicles were on beaches at a number of locations collecting the algae by pitch forks and rakes, raking along the shore, and then placing the collected material into large bags. In some locations these large bags were collected by all-terrain vehicles on the beaches. The filled bags were then loaded onto large trucks for transport to drying and processing locations.

Location of activities, and concerns related to seaweed and its function

Seaweed harvesting has focussed on particular beaches near Deep Bay and Bowser which often receive substantial accumulations of algae following storms and powerful wave action. Deep Bay is located at the southern extremity of Baynes Sound which supports a vibrant and significant shellfish aquaculture industry. The shellfish production is approximately 50 percent of British Columbia’s total production of native and introduced species (Jamieson et al. 2001) and has been increasing by as much as 10% a year.

The net shoreline movement of materials floating in sea water is into Baynes Sound proper from the Deep Bay/Bowser area. Immediately south of, and within 3 km of Deep Bay are inter-tidal areas with much habitat complexity. The complex shoreline in this area of Bowser directly supports many important organisms of high economic and ecological value especially in the unique and extensive tidal lagoons which are, in part, a legacy from the Qualicum First Nations who modified the shoreline and constructed fish traps and clam gardens (personal communication; M. Racalma, Qualicum First Nations).

Importance of shoreline habitat to food production and feeding

Many organisms derive food from the inter-tidal lagoon areas and the beaches from which seaweed has been harvested in the Deep Bay/Bowser area. Depending on the time of year large numbers of ducks and geese, seals, sea lions and otters, eagles and humans can be found harvesting prey resources reliant upon these areas (Jamieson et al. 2001).These areas also accumulate storm-cast algae in the fall and winter, consequently promoting local productivity.

Marine riparian zones and unconsolidated-sediment beaches provide critical habitat for marine fishes and invertebrates (Levings and Jamieson 2001). Marine riparian vegetation produces terrestrial insects, vital prey for foraging juvenile chinook salmon (Brennan and Culverwell (2005). Sandy/gravel beaches are spawning habitat for surf smelt and Pacific sand lance, “forage fish” species that are critical prey for hundreds of marine predators (Penttila 2007).

Eagles feed in the summer along the BC coast (Elliott et al. 2003). The annual concentration of eagles in the Bowser lagoon areas in early summer often exceeds the published highest numbers recorded during this season on the BC coast. Fifty percent of the eagle’s diet consists of Plainfin midshipman (*Porichthys notatus*) that migrate in May from deep waters to spawn in the inter-tidal areas. They are particularly conspicuous and susceptible to avian predation at this time. The Plainfin Midshipman construct nests, often burrowing beneath the cobbles and boulders found along the shores. In Bowser, the peripheral sand/cobble areas of tidal lagoons, extending up to the mid inter-tidal level, provide much habitat for nests which are occupied by males from May until the middle of August; the males provide parental care. The larval fish hatch from eggs which adhere to the ceilings of the nest. The larval fish remain attached to the nest ceiling until mid August after which time they move to protective vegetated (seaweeds and eelgrass - which occur in the proximal lagoons) nursery habitats (Bass 1995; Sisneros et al. 2009).

Forage fish

The term “forage fish” has a variable set of definitions but in general this term usual refers to small, low-trophic level schooling species. Typically, they are abundant species that provide food for other piscivorous animals, especially other fishes, marine mammals and seabirds. In the vicinity of Baynes Sound “forage fish” would include species such as herring (*Clupea pallasi*), surf smelt (*Hypomesus pretiosus*) and sand lance (*Ammodytes hexapterus*). However, there are many other species of fish that are important prey in the near shore marine food web, including species of cottids, gunnels and pricklebacks that reside in shallow, near shore habitats.

Several species of “forage fishes” are of vital importance to key commercial fish species, especially salmonids, rockfish, halibut, and seabirds. These include, but are not limited to, sand lance, juvenile herring, and surf smelt. These three species are of special interest and they all spawn in shallow sub-tidal or inter-tidal habitats. Two of the species, sand lance and surf smelt could be spawning at the same times, and at the same locations as the pilot *Mazzaella* harvest occurred (unpublished report; de Graaf 2012).

Once hatched, the larvae of sand lance and surf smelt can be found in the sand/gravel beaches, then in the adjacent shore line aquatic habitats. These fish are, therefore, directly at risk from human activities on the beach such as raking the substrates and vehicular traffic. A separate report by de Graaf (2012) is appended to this document to provide information on these “forage fish” and their beach spawning habit. It was prepared to highlight the importance of the fish and the need for their protection in the face of seaweed harvesting that is likely detrimental.

The seaweed harvesting areas between Deep Bay and Bowser represent some of the most important herring spawning locations in BC (Hay and McCarter 1999, 2006). The present seaweed regulations preclude harvesting during herring spawning times but these areas also are used by larval and juvenile herring for rearing (herring are an important “forage fish” for salmon and other animals, and other important fish species spawn each year along these shores (Hay and McCarter 1997).

[The progressive demise of kelp beds in Georgia Strait over the last 30 years has been a significant loss to near shore habitat complexity (Birtwell, personal observation; Nile Creek Enhancement Society). The kelp provided habitat for many organisms, food while it was growing and also when it was decomposing. The significant loss of this habitat emphasizes the need to maintain plant material which provides for alternative habitat and supports the aquatic food chains. That is, the other vegetation that currently performs a similar function, such as, the eelgrass and algae of the tidal lagoons and natural beaches in the Deep Bay/Bowser area].

Legislation, and regulation of seaweed harvesting in British Columbia

The BC Ministry of Agriculture is responsible for the management of the commercial harvest of marine plants in British Columbia. Their mandate is to "*ensure that the harvest of marine plants is done in an approved manner, and that the harvest will not compromise habitat or traditional First Nations use of the resource*". In February 2009, however, the B.C. Supreme Court ruled that marine finfish aquaculture on the coast of B.C. is a "*fishery*" and a matter of exclusive federal jurisdiction. In December 2010, the federal government assumed regulation of the finfish and shellfish aquaculture industries in B.C. However, the provincial government continues certain roles under the applicable legislation of the *Fisheries Act* (Government of CanadaRSBC c-149 1996). This includes: licensing marine plant cultivation; issuing tenures where operations take place on Crown land, issuing business licences under the *Fisheries Act*; maintaining the mandate to protect the provincial public interest in sustainable aquaculture development.

Existing Provincial guidelines for the harvest of marine plants are as follows: "Before an application can be considered, the applicant should be able to demonstrate that the product will be used for a viable business. The applicant should provide a comprehensive outline of the proposed harvest operation and processing arrangements. When an application is approved, a licence quota may be set based on the amount of product requested and historical inventories (where they exist) of the marine plant resources in the area. *In all cases, the conditions of licence will stipulate that no more than 20% of the total biomass of a marine plant bed may be harvest. Other conditions related to particular species of marine plants may also be imposed*. These measures ensure the long term sustainability of the resource and minimize the impact to fish and fish habitat." (http://www.agf.gov.bc.ca/fisheries/commercial/commercial_mp.htm).

The provincial government's guidance regarding the harvesting stipulates certain requirements and consequences for non-compliance: (http://www.agf.gov.bc.ca/fisheries/Manu

als/Licensing/gt_MarinePlantHarvesting.pdf
)

"(10) In addition to the powers that may be exercised by the minister under section 18, the *minister may suspend, revoke or refuse to issue a licence under this section in the minister's opinion*

(a) the licensee has failed to comply with a condition of a licence, or

(b) the harvesting of kelp or other aquatic plants under the licence would

(i) *tend to impair or destroy a bed or part of a bed on which kelp or other aquatic plants grow*
,

(ii) *tend to impair or destroy the supply of any food for fish, or*

(iii) *be detrimental to fish life.*"

(The underlined and italicized sections shown above relate to the concerns expressed in this document regarding the harvesting of seaweed and the fisheries and ecologically important areas that support them).

The context of this aspect of regulation relates to the federal *Fisheries Act* (Government of Canada 2012 R.S.C., 1985, c. F-14, Last amended on June 29, 2012) wherein the definition of fish also includes (*a*) parts of fish, (*b*) shellfish, crustaceans, marine animals and any parts of shellfish, crustaceans or marine animals, and (*c*) the eggs, sperm, spawn, larvae, spat and juvenile stages of fish, shellfish, crustaceans and marine animals. Also, “fish habitat” which means the spawning grounds and nursery, rearing, food supply and migration areas on which fish depend directly or indirectly in order to carry out their life processes.

Guidance documents from the provincial Ministry of Agriculture that were applicable to the pilot seaweed harvesting project are appended to this document (Appendix 1). The draft “guideline” document provided by Fisheries and Oceans Canada staff in 2007 is also in Appendix 1.

Commercial harvest and impacts

The harvesting of seaweed and its artificial production occurs world wide and it was reported that about 13 million tonnes (fresh weight) annually was collected world-wide (Zempke-White et al. 2005 and references therein). Almost all of the seaweed was harvested live or cultured but there was also harvesting of material cast on beaches. Such harvesting can, however, result in adverse effects to aquatic communities (Schmidt et al. 2011; Krumhansi and Scheibling 2012; Seeley and Schlesinger 2012).

In 2009 the European Union declared that the commercial harvest for macroalgae should not be done in any way so as to cause a significant impact on ecosystems (Stagnol et al. 2013). On the east coast of Canada seaweed harvesting, which has occurred for decades, was not sustainable for all species targeted because of the methods used to collect the seaweed while it was growing, when detached, and the escalating quantities taken over time (Chopin and Ugarte 2007). The ecological consequences of harvesting were often considered only in relation to algal communities and re-growth in support of a sustainable harvest of algae (Sharp and Pringle 1990, Chopin and Ugarte 1998); less attention has been given to the ecological effects on the communities impacted by the harvest (Black and Miller 1994; Rangeley 1994; Lorentsen et al. 2010).

Concern over the sustainability of the commercial ventures to harvest seaweed and the potential effects on communities of aquatic organisms has prompted regulations to be formulated to control the timing and modes of harvest, species of algae taken and allowable quotas. In certain circumstances a moratorium has been placed on these activities so that studies may be undertaken to assess impacts (e.g. New Zealand, Zempke-White et al. (2005).

Beach harvest

A thorough review of the beach harvesting of seaweed was carried out by Zempke-White et al. (2005). These authors stated that there are few published studies that have investigated the impacts of harvesting beach-cast seaweeds on the coastal environment. Most studies completed to date indicated an immediate short-term decrease in densities of strandline species extending to fish species in estuaries. While recovery of these species occurred relatively rapidly after single events, long-term harvesting created a beach fauna and flora very similar to beaches that had no input of beach-cast seaweeds. Differences in beach topography and habitat values were also noted between raked and un-raked beaches and, where in use, vehicles in the coastal environment were identified as a source of negative impacts on coastal ecosystems. The review by Zempke-White et al. (2005) identified a number of key research gaps related to the removal of beach-cast seaweeds from the coastal environment. Knowledge gaps include quantitative data on distribution of beach-cast seaweeds, the relationship between beach-cast seaweed and off-shore algal stands, residence time of the seaweed on the beach, the fate of seaweeds when not collected and the communities they support, the role of floating seaweeds, and the effects of removals on the coastal ecosystem and fisheries resources.

Role of algae in the food chain and relationships to aquatic productivity

In some locations in the Deep Bay/Bowser area seaweed washed up along shoreline accumulates in dense mats often exceeding a metre deep (Birtwell; personal observation). This visible vegetation along the shore is often referred to as wrack. Wave and tidal actions continuously move this material and large quantities become mixed into the beach substrate. During tidal changes the material can be re-suspended, fractured, decomposed and transported with subsequent wave action.

Living, dead and decomposing algae provide food for many components of food webs. Aside from the physical aspects of algae and the role they play in the structural complexity of waters which constitute fish habitat, this “primary production” has a direct influence on those organisms higher in the food chain (e.g. Levings et al. 1983; re Georgia Strait). Algae and other plant material are part of this primary production which provides nourishment while alive but also when dead and decaying and producing detritus. It has been stated that more energy and materials flow through detrital food webs than through grazer food webs (Mann 1988). This means that, “more is transmitted to other trophic levels from dead decomposing plant tissue than from living tissue consumed by a grazer. Nevertheless, those who manage aquatic systems for high productivity of fish, shellfish, or other invertebrates will be interested not so much in the total flow of energy and materials as in those pathways leading directly to nutrition for species of interest” (Mann 1988).

The nature of primary production influences how detritus may be beneficial to other organisms (Jones and Iwama 1991; Rodhouse and Roden 1987). For example, marsh grasses and other vascular plants require a longer time to be broken down by fungi and bacteria into smaller particles (detritus/particulate organic matter which in turn are consumed by invertebrates that digest the microbial content) than do algae which decompose at faster rates and are more nutritious and available.

Animals can obtain much nourishment directly from algal material (Findlay and Tenore 1982; Tenore 1981, 1988). Thus the importance of particulate macroalgae detritus is documented and emphasized due to its significant and important role in the productivity of invertebrates (e.g. amphipods: Rossi et al. 2010; oysters: Crosby et al. 1989; snails: Smith et al. 1985; fish: Levings et al. 1983; Mann 1988). Some inter-tidal fish have been reported to directly use algae as food such as the cockscomb pricklebacks (Peppar 1965, cited by Levings et al. 1983) which occur in the lagoons at Bowser/Deep Bay. Benthic inter-tidal communities, especially crustaceans, within Georgia Strait have been reported to be important in the diet of many juvenile fish such as salmon (refer to Levings et al. 1983).

<u>Floating and shore cast seaweed (wrack)</u>

Seaweed that washes ashore and becomes stranded is termed wrack. Typically it is a complex mixture of vegetated materials from vascular plants and seaweeds, dead and dying organisms with an associated community of micro and macro organisms.

The onshore deposition of macroalgae and macrophyte wrack provides a potentially significant marine "subsidy" to inter-tidal and supra-tidal herbivore and decomposer communities. Based on the study of daily input loads to beaches, Orr et al. (2005) estimated summer wrack deposition in Barkley Sound, British Columbia. Cobble beaches retained approximately 10 times and 30 times more wrack than did gravel and sand beaches, respectively (Orr et al. 2005): the beaches upon, and in which detached seaweed occurs in the area of Deep Bay and Bowser are primarily of cobble, pebble and coarse sand.

Tyron (2012) provided information on the ecological importance of wrack and emphasized that it supports a diversity of animals and contributes towards nutrient and carbon cycling in marine and terrestrial environments. The comments in this paragraph are attributable to Tyron's assessment. For example, accumulation on sandy beaches provides thermal insulation from temperature extremes, and maintains a humid environment for the organisms that thrive in the wrack and in the substrate below (Columbini and Chelazzi 2003). Nutrients and carbon from beach wrack can be transported via various means to sub-tidal zones (Romanuk and Levings 2006), to interstitial spaces in sandy beaches (Dugan et al. 2011), and to marine riparian systems (Levings and Jamieson 2001; Polis and Hurd 1996). Tyron (2012) also reported that beach wrack is associated with highly diverse infaunal assemblages and their predators, including taltrid amphipods and staphylid beetles (Richards 1984), oligochaetes and nematodes (Sobocinski 2003)and birds (Bradley and Bradley 1993). The diets of commercially important fish, including juvenile salmonids, herring and surf smelt overlap with the invertebrate food items found in beach wrack. In a review of marine riparian systems, epi-benthic crustaceans, including amphipods partially derived from inter-tidal areas of detrital build up, provide important food web connections for salmon in Puget Sound (Brennan and Culverwell 2005)and British Columbia (Levings and Jamieson 2001; Romanuk and Levings 2005). This has important implications for fisheries values in the area; both salmonids and “forage fish”, along with many other species, will consume amphipods, worms, and insects that are dislodged in the inter-tidal zone during the high tide. Many birds also take advantage of the beach wrack communities, and may be affected by the loss of beach wrack to the ecosystem (Bradley and Bradley 1993). As the area is home to a diversity of birds, unintended consequences of beach wrack removal may have localized or larger effects, depending on the extent of the harvest.

The wrack is an important nitrogen and carbon source for coastal waters due to the relatively rapid release of nutrients during breakdown, which facilitate primary productivity (benthic algae and phytoplankton) and on up the food chain (refer to Zempke-White et al. 2005; Mews et al. 2006).

The seaweeds that become detached from substrates where they grew may form floating masses of organic material. These floating masses, which may or may not impinge on the shore, provide habitat for a variety of organisms e.g. invertebrates and fish. Hence the material is of functional significance even though it has been removed from its benthic attachment site. Zempke-White et al. (2005) provided a review of the effects of beach harvesting of seaweed in New Zealand. They concluded that “the floating component of the drift algae may also play a significant role in the dispersal of beach invertebrate species and also appears to play a role in the dispersal of juvenile fish”. Furthermore, “the sources of energy and nutrients that may wash back into the sea include whole seaweed, inhabitants of the wrack, and dissolved and particulate organic matter. When whole seaweed washes back into the sea it can form an important habitat for juvenile fishes, can be eaten by herbivores, or can be further decomposed and used by detritivores and filter feeders, or the dissolved nutrients be taken up by primary producers” (Zempke-White et al. 2005; Shaffer et al. 1995).

Rossi et al. (2010) documented the importance of seaweed wrack derived from an invasive species of algae (*Sargassum muticum*) which is present in the inter-tidal areas of Deep Bay and Bowser, to sustain part of the benthic food web. Similarly, McGwynne et al. (1988) and Olabarria et al. (2010) comment on the relationship of buried and decaying seaweed wrack to beach organisms and the role it plays in influencing the composition and structure of meiofaunal and macrofaunal assemblages respectively. Lastra et al. (2008) also report the importance of beach cast materials to invertebrate populations and community structure in the inter-tidal zone, and Pennings et al. (2000) commented that invertebrate “consumers” (an isopod, and rocky and sandy-shore amphipods) tended to prefer wrack (aged, stranded seaweeds) over fresh seaweeds of the same species. Romanuk and Levings (2003) documented the increased importance of such vegetated material to organisms that dwell in the transitional supra-littoral zone between the terrestrial and aquatic environment.

Zempke-White et al. (2005) concluded that most studies of seaweed harvesting indicated an immediate short-term decrease in densities of strandline species extending to fish species in estuaries. But, although the recovery of these species occurred relatively rapidly after single events, “long-term harvesting created a beach fauna and flora very similar to beaches that had no input of beach-cast seaweeds. Differences in beach topography and habitat values have also been noted between raked and un-raked beaches. Where in use vehicles in the coastal environment have also been identified as a source of negative impacts on coastal ecosystems” (Zempke-White et al. 2005).

<u>Multi-species effects of seaweed harvesting</u>

There is little research on the effects of *M. japonica* harvesting, but given the stated importance of algal species in beach wrack in marine ecosystems, one must conclude that its removal in any significant proportion will have profound effects on adjacent marine and inter-tidal ecosystems.

An example of the ramifications of seaweed removal practices on higher members of coastal food chains is exemplified by Lorentsen et al. (2010) in Norway. They stated that “coastal kelp forest ecosystems provide important habitats for a diverse assemblage of invertebrates, fish and marine top-predators such as seabirds and sea mammals” and that little is known about the multi-trophic consequences of this habitat removal. The authors investigated how kelp fisheries, which remove feeding and nursery grounds of coastal fish, influence local food webs and the availability of food to a marine top predator, the great cormorant (*Phalacrocorax carbo*). Their results demonstrated that cormorants preferentially foraged within kelp-forested areas and performed significantly more dives when feeding in harvested versus un-harvested areas suggesting lower foraging yield in the former case. In kelp areas that were newly harvested the number of small (