REVIEW OF THE ORGANIC EXTRACTIVE COMPONENT OF INTEGRATED MULTI-TROPHIC AQUACULTURE (IMTA) IN SOUTHWEST NEW BRUNSWICK WITH EMPHASIS ON THE BLUE MUSSEL

Figure 1. Aerial photo of an IMTA site in Southwest New Brunswick. Right two columns are salmon cages, left column consists of mussel rafts, kelp raft (rectangular) is on upper left (courtesy of J.A. Cooper, Fisheries and Oceans Canada (DFO), St. Andrews Biological Station).

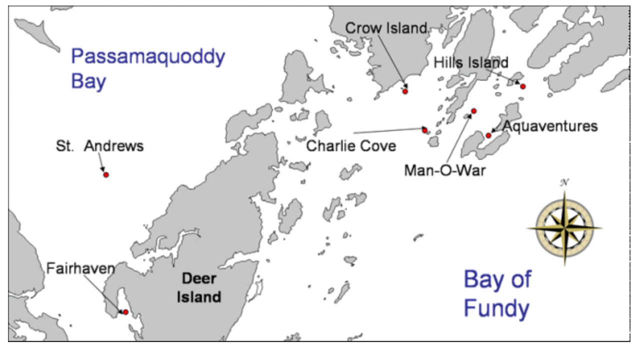

Figure 2. Map of Southwest New Brunswick, showing salmon aquaculture sites where Integrated Multi-Trophic Aquaculture (IMTA) research was conducted.

Context

Integrated Multi-Trophic Aquaculture (IMTA) is an approach to aquaculture in which the by-products (e.g. soluble and particulate wastes) from one aquatic species are partially "recycled" as nutritional inputs for one or more other organisms. Most of the IMTA developmental pilot-scale work in the Maritimes Region has been conducted in the Bliss Harbour and outer Back Bay area of Southwest New Brunswick (SWNB) on a limited scale (Figures 1 and 2). Over the past few years, the number of requests for conversion of traditional salmon sites to IMTA operations has been increasing. DFO Science has been asked to review work on the organic extractive component (e.g. shellfish) of IMTA in SWNB and to address questions related to factors influencing the ecological effects/effectiveness of IMTA, the ability of IMTA to reduce benthic loading, the scale at which impacts of salmon aquaculture might be mitigated, and the scale at which IMTA might have measurable impacts on other aspects of the ecosystem.

This Science Advisory Report is from the October 3-5, 2012, Review of Integrated Multi-Trophic Aquaculture (IMTA) in Southwest New Brunswick. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule *as they become available.*

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SUMMARY

- There are a number of factors that will influence the ecological interactions and effectiveness of an Integrated Multi-Trophic Aquaculture (IMTA) operation, including: the configuration and design of the IMTA site; its species composition; culture scale; the efficiency of selected organisms to capture and assimilate specific wastes from fish net-pens; diet availability; site conditions, such as physical factors (e.g. depth, currents and temperature), background nutrient concentrations and substrate characteristics; and species interactions.
- Physiological model estimates suggest that salmon culture solids (i.e. faeces and waste feed) would have to comprise at least 10-20% of mussel total diet before they would begin to contribute to a net decrease in the site-wide net organic loading from an IMTA site. Based on available data, it is considered very unlikely that IMTA, using only fine particulate filter feeders (mussels) in SWNB, has significantly reduced loading of total particulate matter to the benthos at the sites. Information to-date is insufficient to evaluate the ability of IMTA, with a full complement of species, to reduce organic benthic loading directly and subsequent impacts to the benthos under the site as research is still currently underway.
- At the present scale of IMTA operations, mussels can be used to remove some fine particulates generated by salmon (i.e. small faecal particulates and “fines” from pellet fish feed) and kelp can extract some fraction of soluble inorganic nutrients resulting from salmon metabolic and respiratory processes. Some data suggest that mussels grown very close to the fish farms are capable of ingesting at least 20% of their diet from fish-derived sources. However, it has not been clearly demonstrated that there is a net ecological benefit from the shellfish component of IMTA for reducing benthic organic enrichment to the benthos under the site, as the bulk of the organic load is believed to be comprised of larger particles outside the selection range of the filter feeders. Present site configurations, combined with the lack of a benthic component of IMTA species, are not optimal for achieving such ecological benefits.
- The use of extractive deposit feeders, such as sea urchins and sea cucumbers, has the potential to be more effective at reducing benthic organic deposition beneath salmon aquaculture sites than mussels because they are capable of consuming larger particulates that will typically settle out close to a salmon farm. The design of any future IMTA aquaculture sites will have to evolve both structurally and in terms of complexity in order to accommodate additional species, as well as to ensure that the flow of water is sufficient for salmon respiration and to efficiently connect the various trophic levels.
- IMTA can both add and remove inorganic nutrients at local scales since animal IMTA species produce nitrogen while seaweeds absorb it. No data were presented on the effectiveness of seaweed to absorb inorganic nutrients, but there is no indication in SWNB that inorganic nutrient limitation or eutrophication occurs except at transitory local scales. No data were available to evaluate the potential near or far-field effects of inorganic nutrients from IMTA. The present scale of IMTA is likely to have a minimal effect on the overall ecosystem at the bay level.
- It is not expected that there will be significant changes to the phytoplankton populations on a broad scale due to IMTA, although there may be some local depletion (reduction) around the IMTA sites due to the activities of filter feeders. The increase in nitrogen levels through respiration of the IMTA species is not anticipated to cause any issues since primary production in the Bay of Fundy is thought to be light rather than nutrient limited.

- The effects on secondary productivity through interactions with intertidal species are less certain. Depending on the hydrographic conditions of the intertidal zone, it is possible there could be interactions with the increased nutrients and epiphytic algae that, under very specific conditions (e.g. an enclosed cove with limited flushing), could create negative consequences for intertidal organisms. This interaction is not limited to IMTA, but could occur with any form of aquaculture or other anthropogenic activity.
- It is possible that a significant proportion of the total mussel larval supply in the Passamaquoddy/Fundy Iles area could be generated from IMTA sources at projected maximum production. This may have impacts on fisheries activities at a small scale, but is not expected to be sufficient to overwhelm wild populations or change settlement patterns on beaches at a large scale. Information is insufficient to determine the actual likelihood of this occurring.
- More work on larger scale ecosystem effects is recommended.

INTRODUCTION

Integrated Multi-Trophic Aquaculture (IMTA) is an ecological approach to food production. It is based on the principle of recycling nutrients (solid organic such as faeces and waste feed or soluble inorganic forms such as carbon dioxide, ammonia and phosphate) that are released from aquaculture activities through a series of organisms at different trophic levels that effectively convert a particular nutrient from an organic to an inorganic form (or vice versa) while recovering some of the nutrients in harvested biomass. Portions of the captured energy and nutrients, recovered in this way, have the potential to decrease net nutrient loading to the ecosystem, increase the profitability of the aquaculture operation (through diversification and augmented growth) and provide ecosystem managers with an active rather than a passive tool for potentially managing anthropogenic loading to the environment. The concept is applicable not only to open water net cage salmon culture, but can be used in offshore systems, closed containment systems, freshwater and either intensive or extensive-based approaches.

Most of the IMTA development research in the Maritimes Region has been completed in the Bliss Harbour and outer Back Bay area of the Bay of Fundy in Southwest New Brunswick (SWNB) on a limited scale (Figures 1 and 2). However, over the past few years, the number of requests for conversion of traditional salmon sites to IMTA operations has been increasing, and some commercial fisheries and nongovernmental organizations have expressed concerns about possible environmental impacts such as negative effects on coastal benthic habitats and phytoplankton depletion. As a result, DFO Science has been asked to review research that has been completed on the fine particulate organic extractive component (i.e. shellfish) of IMTA in SWNB, and to address questions related to factors influencing the environmental effects of IMTA, the ability of IMTA to reduce benthic loading, the scale at which such impacts might be mitigated, and the scale at which IMTA might have measureable impacts on other aspects of the ecosystem.

Presently, the fed trophic level on IMTA sites in SWNB is Atlantic salmon (*Salmo salar*). This type of aquaculture was chosen because salmon is by far the largest aquaculture biomass presently produced in Atlantic waters and, as such, readily enables the development and testing of IMTA techniques. However, the fed trophic level could be any species, such as trout, charr, cod, halibut or shrimp, etc. where additional energy is being added to the local environment through the feeding operations. The extractive species presently used in IMTA operations in SWNB include mussels and kelp, although pilot studies have also investigated the use of sea cucumbers, sea urchins and scallops. Much of the data used to address the questions posed at this meeting were based on results using the present IMTA configuration (mussels/salmon), which is still in pilot-scale development. Thus, IMTA throughout this document refers primarily to the shellfish organic extractive component of IMTA.

Advice developed through this meeting will be used to inform the potential for sustainable expansion of IMTA on existing salmon aquaculture sites.

ASSESSMENT

Factors Influencing the Effect of IMTA

DFO Science was asked, “What are the factors influencing the effects of IMTA?”

There are a number of factors that will influence the ecological effects and effectiveness of a open-water net pen IMTA operation, including: configuration and design of the IMTA site, its species composition, the efficiency of selected organisms to capture and assimilate specific wastes from fish net-pens, diet availability, site conditions, such as physical factors (e.g. depth, currents, and temperature), background nutrient concentrations, and substrate characteristics; and species interactions.

Configuration and Design of the IMTA Operation

The configuration and design of an IMTA operation, particularly its scale (intensity and extent), plays a role in its ecological effects and effectiveness. For example, in Canada there are presently two types of open water marine net pen IMTA systems. On the west coast, one site has been designed around square steel cage systems specifically for IMTA, to optimize species culture ratios, species diversification, current flow direction, and access to nutrients. The operation is currently quite small in terms of production capacity. Sablefish act as the fed trophic level because of their high market demand and price. On Canada’s East Coast, co-cultured species are being added to existing full-scale commercial salmon farms using polar circle technology. Such sites have been selected to optimize salmon culture operations, so lease area available and physical parameters such as current flow may not always be optimal for additional co-cultured species. However, since most existing fish culture in Canada occurs with salmon, for the short-term, an add-on approach to IMTA will be required if the aim is to significantly reduce industry-wide nutrient loading. Some reorganization of the physical design of cage location in existing sites will be required to optimize nutrient recovery.

Species Composition of the IMTA Operation

A key factor influencing the effect of IMTA is the species composition of the operation. At least three broad extractive trophic groups or niches are required if all ‘nutrient streams’ are to be targeted. These nutrient streams and associated niches are as follows:

1) *dissolved inorganic nutrients* that can be absorbed by inorganic extractive species, such as seaweeds and aquatic plants;
2) *small suspended or slow sinking organic particulates* that are generated from feed waste or faeces and can be ‘captured’ by organic extractive suspension-feeders, such as shellfish and some grazers; and
3) *heavier settleable organic solids* that are also generated from feed waste or faeces and that can be consumed by benthic deposit-feeders, such as sea urchins, sea cucumbers, and polychaetes.

The species selected should be able to efficiently capture and convert consumed or absorbed nutrients into body tissue or metabolic waste. The organism should be able to be produced at high enough volumes to sequester significant quantities of available aquaculture nutrients (i.e. grown on commercial scale), and would ideally have some value in terms of the economics of the operation. Societal, ecological and regulatory interactions also require consideration.

Efficiency of Selected Organisms

The potential efficiency of the selected organisms is a factor that will influence the effects of IMTA. Efficiency can be divided into two categories: 1) physiological efficiency, the species assimilation ability for nutrients; and 2) capture efficiency, which relates to the ability of the organism to actually intercept and capture the food.

Most organisms are relatively physiologically inefficient at converting food to biomass, with some of the highest natural ecological efficiencies reaching 30% (i.e. growth per unit of food available). Many of these highest performers are fish. Therefore, it is important to test and choose those species that are the most well suited and capable for assimilating the targeted nutrients. Dietary components that are indigestible (not absorbed) will be repackaged and egested (defecated) as faeces. Consequently, solid waste from fish culture that is indigestible to the receiving species will not be converted or removed from the site.

The physical ability to capture food is a function of both the feeding structures of the animal combined with the physical conditions in which the food is available to the animal. A model was developed (Cranford et al. 2013) for mussel feeding and digestion physiology and used to predict the effectiveness of particulate fish waste capture and absorption by mussels under present and alternative IMTA site scenarios. The capture efficiency of fish waste particles by mussels is limited by the time available to filter the water as it flows past the IMTA mussel structures (this conclusion is also supported by the literature). Present configuration of IMTA systems employing mussels on a few rafts are predicted to be highly inefficient at intercepting wastes from fish net-pens. Model scenarios with intensive (high stocking densities) and spatially extensive mussel culture conditions indicate that it is very unlikely that the mussels are capable of capturing the majority of fish waste at salmon farms in SWNB.

Exposure to the food sources is dependent on the physical conditions at the sites. Currently, mussels are confined mainly to the top 15 m of the water column in relatively small areas around the salmon cages at IMTA sites, often at only one side of the lease site. This arrangement limits exposure to fish nutrient waste during specific tidal periods (e.g. flood or ebb tide) and primarily to “unsettleable” particulate wastes, known as “fines,” that originate from fish pellets or secondarily from faeces. Since the tides in SWNB are bidirectional in nature, it is likely that mussels in the existing configuration are only "downstream" from the nutrient particulate source 50% of the time.

Site Conditions

The physical characteristics of the IMTA site, such as water depth, currents, and temperature, play a major role in determining the flow of nutrients through the system and, therefore, influence the waste capture efficiency of IMTA species. The predicted low waste particle capture efficiency by IMTA mussels in the Cranford model (Cranford et al. 2013) is primarily due to average current speeds in SWNB that transport particles past mussels at a velocity that prevents capture. Flow speed reduction by IMTA structures might increase capture efficiency as current velocities are reduced, but it may also change the particle trajectories and potentially contribute to increasing the deposition of organic waste. There is a small possibility it could also reduce dissolved oxygen to suboptimal levels within fish net-pens under certain conditions of very low flow, low water exchange, warm water temperatures and high biomass, but the data presented do not suggest this is likely. Other factors, such as background nutrient concentrations and substrate characteristics, may also influence the effect of the IMTA operation. An augmented diet available to shellfish, such as fish farm particulates, may have little effect on growth in an already particle rich environment if the amount of high quality natural food (seston) available is greater than the filter feeder's ability to consume it.

Both shellfish and deposit feeders need effective substrates proximally located to access aquaculture based particulates. A well designed and located benthic substrate (e.g. housing structure) can enable some deposit feeders and shellfish to thrive even in highly organically enriched environments.

Species Interactions

As with traditional aquaculture, IMTA operations result in a number of intentional and unintentional biological interactions. Nutrients that are lost from standard mono-culture operations, will ultimately be consumed and absorbed by naturally occurring macro-organisms (e.g. fish, invertebrates, algae), or by micro-organisms (e.g. phytoplankton, bacteria, protozoa), or they may be buried in the sediment. These processes also occur with IMTA systems, except the waste nutrients are targeted by cultured macro-organisms that can be harvested. The availability of resources from aquaculture operations can result in interactions with viruses and parasites, at a small scale, to interactions with feral mobile species and predators, at a larger scale. Understanding the scale and mechanisms of these ecological interactions may help to optimize outcomes and may assist in the development of appropriate management approaches for open-water IMTA.

Ability of the Shellfish Component of IMTA to Reduce Benthic Loading

DFO Science was asked, "Does IMTA help reduce the benthic loading at an aquaculture site?"

Benthic loading from aquaculture or other anthropogenic operations refers to the mass of organic matter (usually organic carbon) that reaches the bottom. Available data were reviewed at this meeting, based on focused studies related to the ability of mussels to capture suspended particles from the water column (fish wastes and natural seston) and subsequently produce faecal pellets.

The published studies reviewed provided information on waste removal and production by mussel organic loading as a means to indirectly assess the potential for benthic deposition. No data for IMTA sites were available to provide a direct evaluation of the impacts of IMTA on benthic loading and, consequently, on the impact on benthic communities. Conclusions on the impacts of IMTA on benthic loading were, therefore, not provided. However, IMTA, as it is currently practiced, may help to reduce the export of some particulate organic matter based on modeling results and growth experiments.

It is recognized that there is organic deposition occurring from salmon farms. The question is whether this organic loading is increased with the addition of extractive IMTA species or reduced. While the IMTA species do consume some of the fish waste nutrients, they are also contributing faeces to the overall organic load. Therefore, an alternative to empirically measuring benthic loading is determining changes in the net organic load produced from the site, with the addition of organic extractive species compared to the monoculture operation through modeling exercises.

Evaluating whether IMTA can reduce Total Particulate Matter (TPM; natural source diets and salmon waste nutrient solids) loading requires an understanding of the various processes that contribute to the loading, including: defining the loading environment including biomass of fish stocked at a site and current velocities that disperse wastes; diet proportions; extraction capabilities; waste absorption and defecation and potential outcomes.

Physiological model estimates suggest that the dietary proportion of mussel food would have to be at least 10-20% from salmon culture solids (i.e. faeces and waste feed) before there would be a decrease in the site-wide net organic loading from an IMTA site. This was shown to be possible in some cases, based on growth data comparing mussels grown on salmon farms compared to reference areas. However, it is considered very unlikely that IMTA using only fine particulate filter feeders (mussels) in SWNB has significantly reduced the overall TPM loading at the sites since the bulk of the organic load is contained in particles too large for the mussels to consume. Information to-date is insufficient to evaluate the ability of the shellfish component of IMTA to reduce organic benthic loading directly and subsequent impacts to the benthos under the site. Further work on this aspect is continuing using stable isotopes and fatty acids as a tracer to determine the diet component originating from salmon.

The following information/analysis would be useful in addressing the question of whether IMTA (i.e. the inclusion of organic extractive suspension feeders or deposit feeders) can reduce benthic loading of a salmon aquaculture site once the full system has been deveoped:

- information on sulfide concentrations at sites before and after organic extractive suspension feeders or deposit feeders are introduced; and
- comparison of mass-balance and depositional modeling predictions at sites with or without the inclusion of organic extractive suspension feeders or deposit feeders.

Research is continuing on these aspects.

Organic Deposition Potential

Growing large numbers of fed species (e.g. fish) for national and international markets requires large amounts of food, which results in large amounts of organic and inorganic waste due to the physiological efficiency of the different species. The extractive species that feed on the organic waste nutrients (either natural or aquaculture derived) produce their own level of wastes, which can be significant. The organic content of these wastes and their physical characteristics can differ dramatically and can make a large difference to the loading of organic carbon to the bottom. Therefore, understanding the organic carbon available, its utilization by IMTA species, and the mechanisms of delivery to the seabed will determine benthic loading.

Mussel faeces have a lower fraction of organic material and on average, settle more slowly in comparison to salmon faeces. Consequently, there should be less relative carbon deposition potential per unit area from mussel faeces in the near-field. This can be illustrated with a simple simulation. A release of an equal mass of settleable salmon and mussel faeces was simulated along a hypothetical transect, applying current velocities typical in Passamaquoddy Bay, to compare deposition and impact potential of salmon and mussel faeces. Model results indicated that at a water depth of 20 m, near-field deposition was substantially higher for salmon faeces for both organic and inorganic components (Figure 3). Organic fractions of mussel faeces were deposited along the hypothetical transect in relatively smaller amounts dispersed over a greater distance. In reality, linear unidirectional current flow at all depths will not occur, nor is it to be expected that all faecal material will reach the larger distances without some degree of degradation. Nevertheless, the simulation does illustrate how similar masses of mussel and salmon feces will deposit differently under the same conditions. No data are presently available for other species, but similar theoretical calculations can be done once the biophysical properties of their faeces are known. Results from this simulation are not intended to suggest that all benthic organic loading from mussels is benign, but simply to frame impact potential of mussel culture (IMTA or otherwise) in the context of salmon culture, which has well established monitoring protocols. Model results still need to be evaluated against actual field data.

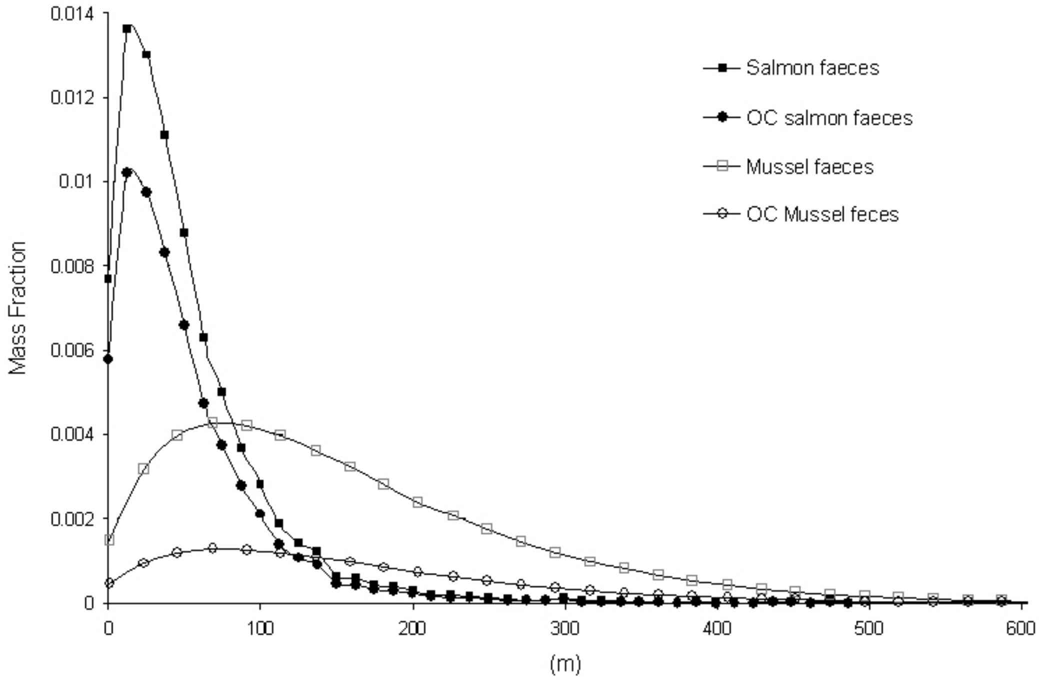

Figure 3. Theoretical deposition of salmon and mussel faeces along a transect in 20 m water depth. The estimated spread is from an equal mass release of salmon and mussel faeces. Mass fraction refers to the percentage of the organic content (OC) load released. Model development is detailed in the scientific paper (Reid et al. 2013).

Diet Proportions

IMTA shellfish will consume both a natural diet of suspended particulate matter (seston) (i.e. phytoplankton, small zooplankton, detritus) and culture solids originating from the fed trophic level. As described above, whether or not an IMTA extractive organism increases or decreases the net-organic load from the IMTA site depends on the proportion of its diet from a fed trophic level (i.e. fish culture solids). Consumption of digestible organic material results in the conversion of much of the assimilated organic carbon into carbon dioxide through respiration, which dissolves in the water. The remaining indigestible organic carbon from the diet is egested as faeces, some of which will settle to the bottom within the site lease area. Model estimates show that the dietary proportion of blue mussels requires 10 to 20% food from salmon culture solids before the site-wide net organic load is decreased (compared to a mono-culture site of only salmon). Whether an extractive species can accommodate this amount of diet and whether it is a significant decrease in the overall loading, depends on the size classes of diet available, the ability of the trophic level to exploit it, the biomass of extractive organisms compared to the organic load available and the extraction efficiency of the organism with the nutrient.

Extraction Capabilities

The ingestion ability of an organism is primarily dependent on its morphometrics and the contact rates with the food. As long as the dietary proportion of salmon culture solids by an IMTA mussel population is maintained over a particular threshold determined by the organic matter, the amount of TPM consumed will not increase the net organic loading at an IMTA site, assuming minimal pseudo-faeces are produced. However, a number of phenomena can impose limits on the diet proportion of salmon culture solids that can be consumed by a mussel or other IMTA population, including: size classes of salmon culture solids available; amount of salmon culture solids available compared to natural TPM concentrations; direction and depth of particle delivery; and frequency and rates of delivery.

There is very little information available on the proportion of the overall particle load from a fish farm that is within the filtering size range of blue mussels. While measurements can be made of a subset of particle sizes in a volume of water using various instruments (e.g. laser particle counters), and settled solids can be collected in sediment traps, this provides only a snap-shot of what size particle classes are present in that sample, not their frequency of occurrence within the total farm solids loaded over a given time frame. This complicates the assessment of shellfish effectiveness in IMTA systems, as it is unknown how much of the total load is available to them simply based on size requirements. Blue mussels can filter particles from 5 µm to a maximum of 5,000 µm, although it is generally thought they are feeding primarily on the smaller size classes. Particle sizes exiting at salmon cages range from less than 1 µm (e.g. individual particles) to well over 20 mm (e.g. salmon food pellets and faecal casts), a difference of 5 orders of magnitude. It is believed that the bulk of the load (by mass) would exceed the filtration size range of mussels.

Empirical Data

Growth differences and tracers can be used to infer the dietary proportion absorbed (digested) by shellfish, but with some limitations. In two experiments at different IMTA sites in SWNB, blue mussels grown adjacent to salmon cages demonstrated significantly increased growth compared to growth at reference sites away from the cages. This suggests that IMTA mussels had access to higher organic particle concentrations. However, two other studies showed no growth enhancement in mussels cultured at fish cages, indicating that site specific factors can influence the potential for augmented growth. These contradictory results match those in other published studies indicating that it is necessary to understand the flow dynamics of the nutrient dynamics at a site. There are some difficulties in using growth differences to assess response of shellfish in net pen IMTA systems. These include comparisons using reference sites, since it is not possible to have true controls when considering commercial scales. There is also the practical limitation of ensuring that mussel culture capacity at reference sites is the same as at IMTA sites. Some trials are presently underway using stable isotopes and fatty acids as tracers to address some of these limitations, but these data were not available for the review. While stable isotopes can infer the proportion of dietary sources digested and stored as biomass, information on the absorption efficiency of these dietary sources is required before a determination of dietary proportion consumption can be made.

Present and Potential Future Benefits of IMTA

DFO Science was asked, “Does the present scale of IMTA in SWNB reap any ecological benefit? If not, at what operational scale (i.e. spatial scale), species mix, and with which biophysical attributes would be required to result in a net environmental benefit (e.g. a reduction in the rate of carbon deposition)?”

As mentioned previously, present IMTA practices in SWNB have focused on two of the extractive trophic levels, the inorganic extractive level and the fine particulate extractive level. Information reviewed at this meeting was focused on studies related to the investigation of the fine particulate extractive level, primarily mussels. Thus, additional work and analysis would be required to answer the question asked of DFO Science in full.

Present Benefits of IMTA

The present orientation of fish cages is unique to each IMTA site, so there is no uniformity in the cage arrays or number of cages. IMTA structures for either blue mussels or seaweed are generally located where they are convenient to the site manager and where space is available.

Generally, for the blue mussel, there are 2 to 6 rafts on each primary site. Presently, the mussel raft design is a series of concentric circles holding 35-45 t that are stocked with mussels on a continuous socking system to a depth of 15 m.

Mussels are intended to extract fine particulates generated from the salmon component of the farming operation while kelps are employed to extract inorganic nutrients. At the present scale of IMTA operations, mussels can extract fine particulates generated from the salmon component of the operation (i.e. small faecal particulates and "fines" from pellet fish feed) and kelp can extract portions of soluble inorganic nutrients excreted from salmon metabolic and respiratory processes. However, net ecological benefits of IMTA in terms of reducing total benthic organic enrichment to the benthos under the site has not been demonstrated since the bulk of the organic load is comprised of larger particles outside the selection range of the filter feeders. In addition, present site configurations combined with the lack of a benthic component of IMTA species are not optimal for achieving such ecological benefits.

However, there are other potential environmental benefits that may accrue from using IMTA. For example, there are potential synergies that are created in the multi-species environment of an IMTA site. Multi-species complexes are the norm in nature. Some of the most productive areas in the marine environment are reefs where a combination of three-dimensional structure and multiple trophic levels create an ecosystem where nutrients are continuously recycled. These systems can be stable for long periods of time.

When aquaculture structures are placed in the water, the three-dimensional habitat can be colonized by many different species. Several studies have shown that mussel farms increase biodiversity on the growing structures. Studies have also shown that fish farms act as fish aggregating devices and potential nursery areas for some wild commercial species such as cod and haddock. However, depending on the scale involved, these three-dimensional structures also have the potential to alter the local-scale hydrographic conditions around farm sites, which could alter the dispersion and deposition of organic waste if they were not designed properly.

The use of inorganic extractive species (such as kelp) to reduce inorganic nutrient loadings was not evaluated but is also expected to be a potential environmental benefit of IMTA. Kelp can extract aquaculture byproducts such as inorganic nitrogen, phosphates, carbon dioxide, while producing oxygen. Further evaluation is required to determine whether the present use of kelp in SWNB is achieving these types of benefits in a significant way.

Future Potential Benefits of IMTA

The use of extractive deposit feeders, such as sea urchins and sea cucumbers was discussed. They have the potential to be more effective at reducing benthic organic deposition beneath salmon aquaculture sites than mussels, because they are capable of dealing with larger sizes of waste particulate matter that will typically settle out in close proximity to salmon farms. Further studies are needed to fully examine whether this potential can be realized in practice. In the future, the design of IMTA aquaculture sites will have to evolve, both structurally and in terms of complexity, in order to accommodate additional species, as well as to ensure that the flow of water is sufficient for salmon and to efficiently connect the various trophic levels.

Currently, the loading of fine particulates is not clearly understood so the biomass of mussels needed is unclear. It is likely that the filter feeders will fit within the existing site boundaries since they need to be in close proximity to the fish cages. It may also not be necessary to expand the boundaries of existing aquaculture leases to enable addition of deposit feeders. With present lease size, there is a substantial amount of bottom space available for subsurface IMTA structures in close proximity to the salmon cages. There is a mean area of approximately 77,000 m^2 underneath the subsurface grid-work holding the salmon cages in place. Moreover, local studies have shown the bulk of the organic depositional field at present IMTA sites in

SWNB is concentrated within these boundaries. However, to achieve optimal IMTA design, including all trophic components of IMTA, reconfiguration of the lease or cage boundaries may have to be considered.

Salmon are predicted to produce approximately 2,025 kg of organic waste per day at peak production (300,000 fish at 4.5kg feeding at 1% body weight per day). Projections from small-scale trials of growing sea urchins, sea cucumbers and scallops in the lab and field, indicate that if these 3 species were grown on 30% of the available bottom, they could potentially consume double this amount per day. While this is speculative, it does show that the scales of waste production and consumption match and that a significant reduction of organic waste to the sea bottom is theoretically possible.

In order to achieve the numbers and biomass of extractive species needed for the benthic component, the production of new extractive trophic level species will likely require hatchery production to achieve sufficient volumes. Except for a few species where the collection in the field of newly settled larvae is practical (such as blue mussels and perhaps scallops), it would be impractical to institute wild collection for juveniles of commercial species for redistribution on an aquaculture site. In some cases, it would likely impact on commercial fisheries and there would be environmental impact associated with the collection.

There are some studies that suggest growing certain extractive species might help reduce the load of some diseases and parasites, which are now presently being managed in part through the prescribed use of therapeutants and other husbandry practices. Studies have shown several species of shellfish can consume and digest sea lice larvae along with other small zooplankton and that cleaner fish from the wrasse family (e.g. cunners) are capable of consuming adult sea lice. Filter feeders, such as mussels, have been shown to destroy certain viruses (e.g. infectious salmon anemia virus), although other studies have shown that some pathogenic bacteria and viruses can pass through the digestive system of mussels relatively unaffected. How IMTA species fit into the dynamics of overall farm healthcare is still in the early phases of research.

There are other non-biological benefits that are associated with IMTA operations such as increased levels of revenue and employment, but although those were not considered in this review they are not insignificant. This review focussed mainly on the ecological benefits. In order to achieve these additional benefits of IMTA, the construction and organization of future IMTA sites would have to evolve to optimize several different aspects, including: accessibility of IMTA structures; optimizing the flow field around the IMTA site; building on existing element of the aquaculture operation (e.g. grid systems, harvesting equipment); and training specialized teams capable of carrying out these types of operations.

IMTA Impacts on other Aspects of the Ecosystem

DFO Science was asked, “At what scale would IMTA have measureable impacts on other aspects of the ecosystem, such as on phytoplankton and on existing clam beaches?”

Previous CSAS reviews (DFO 2005, DFO 2006, DFO 2010) have reviewed and discussed ecosystem-scale effects of shellfish and finfish aquaculture. This review was focused on potential ecosystem changes related to phytoplankton and intertidal species, such as the softshell clam, if IMTA species are grown on existing salmon aquaculture sites.

Monitoring Ecosystem Change / Bay Management / Cumulative Effects

Understanding changes to the ecosystem within SWNB due to the contribution of IMTA species on commercial salmon aquaculture sites is a formidable challenge. There is the potential for IMTA operations to contribute to stressors of the ecosystem through the potential addition of waste nutrients in some scenarios and species addition to the local environment. However, detecting small changes in the ecosystem due to IMTA outside of the salmon aquaculture site is difficult. It is complicated because measures of what constitutes a stable state in the local ecosystem or what suite of baseline metrics is best suited to make an assessment of changes over time are poorly known. However, despite the complexity of the system, there are some basic approaches that can be used to perhaps detect changes over time, (e.g. examination of habitats for major long-term shifts in populations that are more dramatic than those due to inter-annual variability).

Phytoplankton Interactions

In the Passamaquoddy Bay area, for example, there will be inorganic loading from the feeding activities of the salmon and various invertebrate species such as the mussels, sea cucumbers and sea urchins. Inorganic loading can be calculated based on biomass of the organism and temperature. Salmon have been shown in the past to be major contributors to the nitrogen nutrient pools in the water column for the Limekiln area of New Brunswick and gradients of ammonia have been observed in the water in close proximity to the salmon cages with several studies. The nutrients were observed to quickly reduce to background levels further away from the cages by several studies in the Bay of Fundy and the Gulf Maine so that no major concentration gradients remained for nitrates or silicates. To-date, no far-field effects of the nutrients have been observed.

IMTA can both add and remove inorganic nutrients at local scales since animal IMTA species produce nitrogen while seaweeds absorb it. There is no indication in SWNB that inorganic nutrient limitation or eutrophication occurs except at transitory local scales. This is thought to be a result of the large volumes of water exchange that comes in to the coastal area from the Bay of Fundy. While no data were presented to evaluate the potential far-field effects of IMTA, the present scale of IMTA is likely to have only a minimal effect on the overall system. Results from the literature suggest that primary production in the Bay of Fundy is light rather than nutrient-limited (Harrison et al. 2005). Therefore, it is not expected that there will be changes to the phytoplankton (including the regular occurrence of blooms) on a broad scale due to IMTA, although there may be some local depletion (reduction) around IMTA sites due to the activities of filter feeders.

Intertidal Interactions

The effects on secondary productivity through interactions with intertidal species are less certain. Depending on the hydrographic conditions of the intertidal zone, nutrients could be retained for longer periods of time in shallow water with good light penetration. It is possible there could be interactions with the increased nutrients and epiphytic algae that could create negative consequences for intertidal organisms under very specific conditions (e.g. an enclosed cove with limited flushing).

Increasing the number of IMTA extractive species (e.g. mussels) will have the consequence of augmenting the reproductive output of these species in the Passamaquoddy Bay/Fundy Iles areas, adding to the existing larval supply. Recently, there have been observations by clam fishers that there have been increasing numbers of juvenile mussels settling on the subtidal areas of a few beaches, with concerns that this could impact fisheries. Questions have been raised as to whether such an increase could result from cultured mussels being grown on the IMTA sites. It is probable that mussels contained within an IMTA site will spawn since they will be held for up to two years and will experience one or more spawning seasons. Ultimately, the question revolves around the mixture of larvae from those from IMTA sites and those from their wild conspecifics. In the general Passamaquoddy/Fundy Iles area, there is approximately 730 km of shoreline. If the average stretch of shoreline supported a mussel population of 500 animals per meter (from high tide to low tide), that would equate to a total population size of almost 365,000,000 mussels. If 20 IMTA sites each grew 4 rafts of cultured mussels, the total number of mussels would be 90 million, or about 25% of the predicted wild population. Thus, it is possible that a significant proportion of the total mussel larval supply in the Passamaquoddy/Fundy Iles area could be generated from IMTA sources at projected full production. This may have impacts on fisheries activities at a small scale, but it is not expected to be sufficient to influence the population size, abundance, and distribution, or change settlement patterns on beaches at a large scale since mussel populations are not considered to be limited by the number of larvae in the system. Information is insufficient to determine the actual likelihood of this occurring. However, given observations that have been made about changes in mussel densities on beaches in this area, further investigation is warranted on the cause and effect of these changes.

To date, most of the research conducted to assess the impacts of aquaculture on the environment has been done near-field close to the aquaculture sites. Results have shown that the benthic organic loading is highest under or close to cage arrays, but benthic enrichment effects decrease rapidly with distance from a farm. Levels of organic deposition over a certain threshold result in higher levels of sulfides and potential changes to biodiversity. There is much less information available on the far-field effects of nutrients on the natural ecosystem and associated species, including commercial ones. Some studies using tracers have shown that in some cases waste particulate matter can be consumed by wild populations, but the effects of these transfers at the population level are unknown. More work on larger ecosystem-scale effects is warranted.

Sources of Uncertainty

There is a lack of empirical data or information from the literature that are suitable for evaluation of the potential for IMTA to reduce the benthic loading of organic carbon under salmon aquaculture sites. Since most IMTA operations have been sporadic additions to existing sites, there are very few data sets which measure benthic levels pre and post-IMTA. The current biomass scales of the extractive species are small in comparison to the biomass of fish being cultured and, to-date, the species that are being cultured (fine particulate feeders such as the blue mussel) are not capable of feeding on the large sized particles that contain most of the organic matter.

The degree to which benthic deposition is influenced by IMTA will depend on the distribution of particle sizes and relative densities coming from the aquaculture activities. To date, there has not been a good description of the full particle size field. Some studies are underway to document this with the Canadian IMTA network program (CIMTAN).

The implications of the release of additional nutrients into the natural environment from aquaculture fish farming operations have been studied primarily at the near field level. The movement of nutrients away from fish farms and how they interact with wild populations is much less known. There are some programs developing to look at this, but they have just been initiated.

The majority of the work done on IMTA to date has focused on seaweeds and filter feeding shellfish, mostly blue mussels. There is a large benthic component that still needs to be developed in order to address the full suite of nutrients available, particularly those that cause benthic organic loading. This benthic component of IMTA is just beginning to be addressed.

In both monoculture and IMTA operations there is a degree of interaction between wild populations at both the micro and macro scales. At the smaller scales, changes in diseases and parasites are some of the notable and potential interactions that could occur (either positive or negative). It is not clear at the present time what the overall impact of interactions caused by

IMTA practices will be. In some cases, it appears positive, however, the concerns about reservoirs of pathogens being created. More research needs to be done on this subject.

CONCLUSIONS AND ADVICE

There are a number of factors that will influence the ecological effects and effectiveness of an IMTA operation, including: the configuration and design of the IMTA site; its species composition; culture scale; the efficiency of selected organisms to capture and assimilate specific wastes from fish net-pens; diet availability; site conditions, such as physical factors (e.g. depth, currents and temperature), background nutrient concentrations and substrate characteristics; and species interactions.

Physiological model estimates suggest that the dietary proportion of mussels would have to consist of at least 10-20% food from salmon culture solids (i.e. faeces and waste feed) before they would remove more nutrients than they would contribute. This has been found in some cases. However, based on available data regarding the biomass of mussels, the probable contact rates and the available particles, it is considered unlikely that IMTA, using only fine particulate filter feeders (mussels) in SWNB, has significantly reduced loading of total particulate matter at the sites. Information to-date is insufficient to evaluate the ability of IMTA to reduce organic benthic loading directly and subsequent impacts to the benthos under the site.

Mussels are intended to extract fine particulates generated from the salmon component of the farming operation and kelps are employed to extract inorganic nutrients. At the present scale of IMTA operations, mussels can extract some of the fine particulates generated from the salmon component of the operation (i.e. small faecal particulates and "fines" from pellet fish feed) and kelp can extract portions of soluble inorganic nutrients excreted from salmon metabolic and respiratory processes. However, net ecological benefits of IMTA in terms of reducing benthic organic enrichment to the benthos under the site has not been demonstrated since the bulk of the organic load is comprised of larger particles outside the selection range of the filter feeders. In addition, present site configurations combined with the lack of a benthic component of IMTA species are not optimal for achieving such ecological benefits.

The use of extractive deposit feeders, such as sea urchins and sea cucumbers, has the potential to be more effective at reducing benthic organic deposition beneath salmon aquaculture sites than mussels because they are capable of dealing with larger particulates that will typically settle out in close proximity to the salmon farm. The design of any future IMTA aquaculture sites will have to evolve both structurally, and in terms of complexity, in order to accommodate additional species, as well as to ensure that the flow of water is sufficient for salmon respiration and to efficiently connect the various trophic levels. This development should be continued.

Detecting small changes in the ecosystem due to IMTA outside of the salmon aquaculture site will be difficult. Ecosystem impacts will likely revolve around eutrophication, sedimentation, and effects on the food web.

IMTA can both add and remove inorganic nutrients at local scales since animal IMTA species produce nitrogen while seaweeds absorb it. There is no indication in SWNB that inorganic nutrient limitation or eutrophication occurs except at transitory local scales. While no empirical data were presented to evaluate the potential near and far-field ecosystem effects of IMTA, the present scale of IMTA is likely to have only a minimal effect on the overall system.

It is not expected that there will be changes to the phytoplankton on a broad scale due to IMTA, although there may be some local depletion (reduction) around the IMTA sites due to the activities of filter feeders. Primary production in the Bay of Fundy is thought to be light limited rather than nutrient limited.

The effects on secondary productivity through interactions with intertidal species are less certain. Depending on the hydrographic conditions of the intertidal zone, it is possible there could be interactions with the increased nutrients and epiphytic algae that could create negative consequences for intertidal organisms under very specific conditions (e.g. an enclosed cove with limited flushing). This interaction is not limited to IMTA, but could occur with any form of aquaculture or other anthropogenic activity that generates excess nutrients.

It is possible that a significant proportion of the total mussel larval supply in the Passamaquoddy/Fundy Iles area could be generated from IMTA sources at projected full production. This may have impacts on fisheries activities at a small scale, but is not expected to be sufficient to influence the population size, abundance, and distribution, or change settlement patterns on beaches at a large scale. Information is insufficient to determine the actual likelihood of this occurring.

More research on cumulative and larger ecosystem- scale effects is recommended.

OTHER CONSIDERATIONS

IMTA has created more complexity within the management sector because it is multi-faceted and actively tries to accommodate several different aspects of ecosystem dynamics. As a result, there are presently ongoing discussions among stakeholders on how best to monitor IMTA sites, and if additional approaches are required beyond existing monitoring protocols at standard salmon farms.

Presently, most aquaculture regulatory structures are based around the concept of monoculture and do not account for interaction terms or non-traditional species that may not be used for human consumption. This is not surprising since IMTA development on marine cage fish farms is relatively recent (12 years from very basic scientific experiments to commercial densities) and Canada is one of the leaders in this field. Given different spatial distribution of mussel waste versus salmon waste, this is one factor that might be considered in the potential spatial configuration of IMTA monitoring. If various containment structures are used on IMTA sites, the impact of these structures on the distribution of benthic impacts (e.g. due to changes in water flow) would need to be considered in monitoring design. If another objective of IMTA is to generate environmental benefits beyond reductions in benthic loading, then consideration of metrics other than sulfides (i.e. water column characteristics, habitat creation) would be required to assess the effectiveness of IMTA at achieving these benefits.

SOURCES OF INFORMATION

This Science Advisory Report is from the October 3-5, 2012, Review of Integrated Multi-Trophic Aquaculture (IMTA) in Southwest New Brunswick. Additional publications from this meeting will be posted on the *Fisheries and Oceans Canada (DFO) Science Advisory Schedule* as they become available.

Cranford, P.J., Reid, G.K. and Robinson, S.M.C. 2013. Open water integrated multi-trophic aquaculture: constraints on the effectiveness of mussels as an organic extractive component. Aqua. Env. Inter. (in press)

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DFO. 2010. Pathways of Effects for Finfish and Shellfish Aquaculture. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2009/071.

Harrison, W.G., T. Perry and W.K.W. Li. 2005. Ecoystem indices of water quality Part 1. Plankton biomass, primary production and nutrient demand, p. 59-82, Hdb. Env. Chem Vol. 5, Part M, Springer, Berlin.

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MPO. 2013. Examen de la composante d'extraction des éléments organiques de l'aquaculture multitrophique intégrée dans le sud-ouest du Nouveau-Brunswick, avec accent sur la moule bleue. Secr. can. de consult. sci. du MPO, Avis sci. 2013/056.