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Proceedings of the regional peer review of freshwater cage aquaculture: ecosystems impacts from dissolved and particulate waste phosphorus

June 17-19, 2014
Winnipeg, Manitoba

Co-Chairs: Corina Busby and Jay Parsons
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Foreword

The purpose of these Proceedings is to document the activities and key discussions of the meeting. The Proceedings may include research recommendations, uncertainties, and the rationale for decisions made during the meeting. Proceedings may also document when data, analyses or interpretations were reviewed and rejected on scientific grounds, including the reason(s) for rejection. As such, interpretations and opinions presented in this report individually may be factually incorrect or misleading, but are included to record as faithfully as possible what was considered at the meeting. No statements are to be taken as reflecting the conclusions of the meeting unless they are clearly identified as such. Moreover, further review may result in a change of conclusions where additional information was identified as relevant to the topics being considered, but not available in the timeframe of the meeting. In the rare case when there are formal dissenting views, these are also archived as Annexes to the Proceedings.

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SUMMARY

A regional science peer-review meeting was held on June 17-19, 2014, in Winnipeg, Manitoba. The objective of the meeting was to peer review existing information relevant to understanding ecosystems impacts from dissolved and particulate waste phosphorus from freshwater cage aquaculture. Meeting participants included experts from Fisheries and Oceans Canada (DFO), Universities of Guelph, Minnesota-Duluth, Waterloo and Saskatoon, and an independent consulting firm. This Proceedings report summarizes the relevant discussions from the meeting. Publications resulting from the meeting will be published on the Canadian Science Advisory Secretariat (CSAS) website.

Compte rendu de l'examen par les pairs régional de l'aquaculture en cage en eau douce : répercussions écosystémiques des déchets de phosphore dissous et sous forme de particules

SOMMAIRE

Une réunion régionale d'examen scientifique par les pairs s'est tenue du 17 au 19 juin à Winnipeg, au Manitoba. Cette réunion a été convoquée afin que les pairs examinent les renseignements existants qui sont pertinents pour comprendre les répercussions écosystémiques des déchets de phosphore dissous et sous forme de particules issus de l'aquaculture en cage en eau douce. Parmi les participants à la réunion, il y avait des experts de Pêches et Océans Canada, des universités de Guelph, du Minnesota-Duluth, de Waterloo et de Saskatoon, ainsi que de sociétés d'experts-conseils indépendantes. Le présent compte rendu résume les discussions pertinentes de la réunion. Les documents élaborés à la suite de cette réunion seront publiés sur le site Web du Secrétariat canadien de consultation scientifique.

INTRODUCTION

There is public and industry interest in understanding the potential environmental impacts of phosphorus (P) released from freshwater aquaculture operations. Excessive inputs of P into freshwater can lead to increased algal growth and result in decreased oxygen concentrations. As a result, Fisheries and Oceans Canada's (DFO) Fisheries and Aquaculture Management sector requested Science advice on the risks to freshwater lake ecosystems from the release of dissolved and particulate waste phosphorus from freshwater cage aquaculture operations. Although there are other issues which may be associated with freshwater cage aquaculture facilities (e.g., organic enrichment, other nutrients, habitat alteration, genetic and ecological interactions with wild fish populations) this assessment focuses on P as it is often the growth limiting nutrient for primary producers.

Organic waste material from cage finfish aquaculture operations in freshwaters is released directly into aquatic environments. It can be in the form of particulate matter (e.g., uneaten feed and faeces) which typically settles beneath and near the cage arrays, or as dissolved wastes (e.g., carbon (C), nitrogen (N), and P released from feed, faeces and metabolic excretions of fish) released directly into the water column. A sound scientific understanding of potential effects and scale of P released from aquaculture operations in freshwater is required if the industry is to grow in an environmentally sustainable fashion.

The aim of this scientific peer review process was to assess and provide information and scientific advice on the potential impacts that might be associated with P enrichment by the freshwater cage aquaculture industry. It includes a review of the current scientific literature on P in freshwater environments (fate and cycling) as well as information on freshwater aquaculture, particularly P assimilation and release by Rainbow Trout aquaculture operations. The ecosystem response to P loading added as aquaculture waste is not well understood and this review gathers, assesses and synthesizes the available information. The focus of this assessment is on existing industry in Lake Huron, Saskatchewan, British Columbia and work done at the Experimental Lakes Area (ELA) in northwestern Ontario.

DISCUSSION

The chairpersons welcomed participants and presented the objectives of the meeting. A participant provided an overview of the Canadian Science Advisory Secretariat (CSAS) peer review and advisory process. Document authorship was discussed as was the meaning of "consensus". The terms of reference (Appendix 1) were reviewed by the meeting participants (Appendix 2). The meeting generally followed the agenda outlined in Appendix 3.

The specific meeting objectives were as follows:

1. Review importance of phosphorus to the freshwater environment and, in particular, those Canadian ecosystems where cage aquaculture is prevalent.
2. Review what is known of the type and amounts of phosphorus inputs from freshwater cage farms, including a review of estimation methods, and place inputs in context of other natural and anthropogenic sources.
3. Review what is known of cycling and fate of the chemical forms of P in the freshwater environment, focussing on those chemical forms of phosphorus that are associated with cage aquaculture activities.
4. Review what is known of methods to predict, manage and mitigate effects of cage aquaculture phosphorus in the freshwater environment.

5. Assess risk of phosphorus inputs from the cage aquaculture industry to Canadian freshwater environments.
6. Identify important knowledge gaps that affect our ability to assess the risk that phosphorus release from the cage aquaculture industry poses to freshwater environments.

Participants questioned whether other issues related to freshwater cage aquaculture were being discussed here or elsewhere. A second process related to the impacts on wild fish populations is planned for fall 2014. A participant noted that anoxia is a process related to P and should not be avoided. However, other nutrient issues like N and C (e.g., greenhouse gas issues from fish/feed waste) may be too small to consider on their own. The chair suggested that while the scope of this process was to focus on P, there will be opportunity to make recommendations or highlight knowledge gaps that should be considered related to freshwater cage aquaculture.

The working paper, provided to the participants in advance of the meeting, formed the basis for discussion. In addition, written reviews of the working paper were invited from several scientists who participated in the meeting and several who were unable to attend in-person. The written reviews from those unable to attend were read into the record of the meeting (see Appendices 4 and 5).

Participants were encouraged to suggest additions or changes to the material presented in the working paper, as needed, to ensure that the best, most accurate information was included. Participants discussed the information presented and suggested revisions for the working paper.

ESTIMATING AND ASSESSING P INPUTS

Estimation and Assessment of the Risk of Phosphorus Inputs from the Cage Aquaculture Industry to Canadian Freshwater Environments

Authors: Dr. Megan Otu, Dr. Cheryl Podemski, Dr. Dominique Bureau

Presenter: Dr. Megan Otu

Abstract

Open cage finfish aquaculture operations in freshwaters release waste directly into aquatic environments. These wastes contain phosphorus (P) in the form of particulate P (e.g., faeces and uneaten feed) or dissolved P (e.g., soluble P released from feed, faeces and metabolic excretions of the fish). P is the nutrient most often limiting primary production (photosynthetic rates and biomass) in freshwater and, thus, anthropogenic additions of P raise concerns for potential impacts on lake productivity. Assessing and mitigating the adverse effects of P loading is critical to proper management of freshwater resources.

This CSAS review does not constitute a formal risk assessment of P inputs from cage aquaculture operations in Canadian freshwaters. Instead, it synthesizes the current state of science with regards to two key components necessary to understanding the potential for effects of P waste from aquaculture: the estimation of P loads per tonne of Rainbow Trout produced and the lake response to such P loads. Estimation of P release from cage aquaculture has been best accomplished through bioenergetics models and one such model has been validated for commercial Rainbow Trout cage culture operations within Canada. The complex physical, chemical, and biological interactions that may occur within the P cycle mean that impacts of P loading from aquaculture or other anthropogenic sources are challenging to predict. The complexities of the P cycle are particularly well documented in the Laurentian Great Lakes, and we have drawn on this literature. Attempts to better predict the effect of anthropogenic P loads have prompted the development of water quality models to predict P

concentrations; P fractionation techniques to assess bioavailable P fractions in particulate form; whole lake mass balances to quantify the P loss to sediments; and total P loading estimates from the catchment to contextualize P loads in an area of interest.

Comments and questions

Comment: The budget described for Lake Wolsey does not make sense as inputs exceed outputs. The Lake 375 budget lists sedimentation percentages in the 80s and low 90s, but outflow numbers are well below 10%. Therefore, consistently more than 90% of the P is staying within the lake boundaries. So you can have temporal higher or lower amounts of P stored in the waterbody but if the P never escapes the lake it is a different perspective. The same perspective from ELA needs to be applied to the Lake Wolsey data. A very small percentage of P is being assigned to sediment (30%) but there is about 50% of the budget missing somewhere and yet outflow is accounted for. This needs to be resolved.

Comment: In the Lake Wolsey budget presented, it indicates that 1/3 of the P comes from the farm. Yet the budget is missing P, so the P attributed to farms is misleading. The weakness in the budget should be addressed in the report.

Response: In the paper's discussion we have to identify where the problems or gaps are, and point out that the inputs do not equal the outputs, plus sedimentation is underestimated, which generates an enormous gap. There is no way to estimate all the overland flow into the lake, which is difficult to measure even when you have opportunities to weir off and capture flows. Atmospheric deposition is based on one or two meteorological stations extrapolated to a very large area. P concentrations have to be captured from various sources (e.g., cows, cottages). The lake is known to have great deal of groundwater movement. There is also a sill in the lake (around 30 m deep) that restricts flushing to the epilimnion. It was not conducive to developing a tight P budget.

Comment: Manure is spread in the fall and during heavy rains it can be washed into the water elevating P at control stations. Event monitoring needs to be undertaken to captured this.

BIOENERGETICS AND AQUACULTURE WASTE

Estimating Waste Outputs of Fish Culture Operations Using Nutritional Approaches

Author and Presenter: Dr. Dominique Bureau

Summary of presentation

Phosphorus utilization by fish and release of P waste by fish culture operations are relatively well understood and characterized. Fish ingest P as part of various compounds and nutrients in their diets. These ingested P-containing compounds are digested, absorbed, metabolized, partly retained in the body, and partly excreted by the animals. The quantity and digestibility of P in feed and the P requirement of the animal will determine the amount and types of P wastes excreted by fish and, by extension, fish culture operations. Undigested P-containing compounds are egested as faecal material by the animal, more or less as cohesive faecal particles. The amount of particulate P waste output of aquaculture operations is mainly a function of the amount (concentration) and digestibility of various P forms present of the diet consumed by the animal. The digestible fraction of P that exceeds fish P requirements is excreted through urine as orthophosphates and represents most of the dissolved P waste of fish culture operations. In practice, the amount and type of P waste outputs of fish culture operations can be estimated from the amount of feed used, the total P (TP) concentration of the feed fed, the digestibility of P in the feed, the whole body P concentration of the fish and the achieved feed conversion ratio (FCR, feed: gain), as well as feed wastage by the fish culture operation.

Nutritional strategies offer a direct way of managing the release of wastes of fish culture operations. The modification of feed composition has been demonstrated to be a very effective way of reducing waste outputs by fish culture operations. Endogenous factors, such as fish species and size/age, may also have very significant impacts. It is necessary to improve our understanding of the basis and relative contribution of these various determinants in order to develop nutritional and breeding strategies aimed at minimizing waste outputs from fish culture operations.

Questions, comments, discussion and feedback

Q. What does the feed conversion ratio (FCR) of less than one for small fish reflect?

A. The feed is about 95% dry matter and the fish is about 30% dry matter, so the ratio is a dry to wet measurement. On an energy basis it is about 50% (40-60%) efficiency and the same probably holds true for carbon (50%) regardless of fish size. It stays about 50% (45-55%) energy retention.

Q. If the FCR was perfect, what would the ratio be on a dry:wet basis?

A. It would be anywhere between 40-50% depending on the fat content and how efficiently the protein is retained. The 45% would be dry:dry. As is, you are taking 1 kg of feed and in a fish less than 100 g, you would get more than a kg of weight gain. The model shows an FCR of 0.8 to 1.4 in a 2.5 kg trout.

Q. Do differences in FCR between farms reflect differences in feed or husbandry practices?

A. Farms may use different feeds but in terms of both proximate composition (42-43% protein 23-25% fat) and likely ingredients they are very similar. There are two or three types of feed from two different feed suppliers (Martin Mills, Corey Feeds, and Northeast Nutrition) commonly used by Ontario Rainbow Trout Farmers. Differences between farms may be related to the way the fish are fed, management, health status, stress, temperature regime, and final harvest weight (e.g., producing 1.5 kg trout versus 1 kg fish) or errors in records (e.g., estimating starting biomass, final weight). That is why in order to do a proper job of waste estimation you would have to collect production data and feed information systematically from farms – similar to performance reporting for dairy farms.

Q. How does fish production compare with cattle, pig or chicken production?

A. It is a misleading comparison as fish are poikilotherms and the quality of the fish diet is higher. The protein content, the quality of ingredients and the nutrient density are higher so you cannot just compare pound to pound. But just looking at the numbers at comparable size, the Rainbow Trout is about the same or slightly better than the broiler chicken. The chicken metabolism is eight times higher than a fish but they only live six weeks so they save on time. Pigs are worse and beef even worse. Dairy is complicated because milk is a fluid, the feed composition varies greatly but is a very energy efficient production.

Q. A model of phosphorus conversion ratio (PCR) rather than feed conversion ratio might speak more directly to what we are interested in. If you wanted to sell finfish aquaculture as a good way to produce protein for human consumption, is PCR a good comparison?

A. I guess being vegan would beat everything but aquaculture is a value added activity. You are using industrial or agricultural byproducts (grain, oil seed milling, animal processing) and efficiently converting them into marketable products, fish.

We have a good handle on P digestibility in feeds. Fish meal is not a standardized ingredient. There are dozens of species of fish converted into fish meal with different P and ash contents. This is the same for poultry meal and soybean meal. The P content, the phytate content, will be different depending on where it comes from (growing conditions, cultivars, etc.), so this has to be taken into account. We have good information on the P composition of fish. When the fish are small it is about 0.4 % P and goes down (allometric decrease) to 0.3–0.35 for the largest ones. We have a good handle on the evolution of feed conversion ratio as fish age, either from direct observation or through models, so estimating waste P output is easy enough.

Q. You indicated there was variability in the industry. Can we capture that variability, or a range around it, to help us in terms of relative contribution of aquaculture versus other inputs?

A. When we did our benchmarking of different farms, the actual industry values are highly variable but overall the means are not unexpected given that there is an average 14% mortality which has to be captured. So your economical FCR will be, on average, 14% higher than the biological FCR and the biological FCR, the model prediction under control lab conditions, versus the farm FCR is 7-9% higher which is not surprising when you have a fish in an open environment with varying temperature and feed practice. I think we can arrive at a reasonable number for the industry variability.

Q. With all the refining of diets, one of the main criticisms of industry has been to capture fish to feed fish. What are they doing with respect to bone meal now? Is it from bycatch or has there been any change over the years

A. There have been changes. The source of fish meal is different in Ontario as the main supplier is Martin Mills. Martin Mills is in the fish feed and financial business providing short or mid-term credit to farms. They are running a safe operation with one source of meal which is herring meal from Connors Brothers in NB. They have had a stable fish meal supply but the price has been going up so they have been replacing fish with other meals such as high quality poultry by-product meal which is similar in composition to fish meal. We are working on other alternative plant sources (e.g., corn gluten meal, soybean meal, sunflower meal) but poultry meal, blood meal and feather meal are more competitive price-wise, there are plentiful supplies, they are acceptable, and fit with nutritional profiles high in protein, low in fiber, high in fat. In terms of P content, there was a time when we are formulating a low P diet and we thought the fish would be deficient in P but this has not been the case because the fish meal has been replaced by poultry meal and feather meal with high available P levels. So it is changing and is being driven by economics.

Q. Where does the 14% mortality come from, is it fingerling mortality?

A. There are different ways to calculate mortality. It depends on the number of fish received from the hatchery. Sometimes you buy 10,000 fish and put them in the cage but you could be putting in anywhere from 9,500 to 11,000 fish as they are sold by weight. So you need the initial numbers, you have to look at harvest plus the reported observed mortality. If it is based on reported mortality or back-calculated mortality, you could have 5% difference between the two estimates. For some farms, the hatchery they were dealing with were not doing such a good job controlling their numbers. You could be sold a number of kg of fingerlings but if you underestimate or overestimate the weight of fingerlings by one gram you throw off your numbers of a 10 gram fish by 10%. There is seasonality to mortality. There is a medium-grade mortality throughout the year regardless of the size and there are two peaks in mortality (e.g., transitioning out of winter).

Q. How good are the nitrogen waste model numbers as the molar ratio from N to P is of substantial interest to the limnological community when looking at P release?

A. If anything it is more reliable than P. The digestibly of N will vary between 80-95% with different feed ingredients so there is less variability than the P digestibility so it is a more stable measure. It matters how you collect faecal material, which system you use, it can vary by 5-6%.

And the protein content of the fish is so stable regardless of the condition of the fish it is always 16% N or protein. It is only amino acid-bound.

Q. Historically for land-based farms, P output was a big economic driver and was impeding farmers from increasing production. It was an impetus for research to minimize waste and meet regulatory point source requirements. From a cage perspective, farmers have been able to take advantage of that work. Are we at an optimal diet now in terms of the amount of bioavailable P in the diet to fish and the ability to minimize, to the extent we can, the P waste?

A. There was a point source regulation that hit land-based farms hard that were trying to conserve water or increase fish density. It resulted in a lot of research and we now have a very good idea of P requirements, low P diets and characterizing the point where the fish become P deficient. In central Canada we are not P deficient, but in Norway and Scotland where they do not have the opportunity to use animal proteins and have been reducing fish meal and relying on soy protein concentrate, pea protein concentrates, sunflower meal, beans, etc., they ran into issues of P deficiency linked to bone deformity in the early life of the fish. We are confident that if we have a regulatory environment limiting P it is feasible to do so, though there would be a cost to it. The technique, ingredients and knowledge is there.

Q. Phytate is the principal storage form of P in many plant tissues. In legumes, it also interferes with the digestibility of proteins which makes legumes unpalatable to insects. Is soy a problem and is it a poor source of protein in fish meal because it has phytate which reduces protein digestibility?

A. There is some research that shows that phytate can impact protein digestibility but the impact is very small (about 1-3%) and basically of the same scale as the error associated with determining digestibility of protein so I am a little bit skeptical. Soybean meal which has been processed (steam cracked, pressed, oil extracted by solvent) will have relatively high protein digestibility at around 90%. There are some factors in soybean meal that may create enteritis (non-jnfectious inflammation of the intestine). But we consistently use a diet with 15% soybean meal, 15% corn gluten meal (also loaded with phytate) and it is perfectly digested. It is not an issue that the fish is unable to digest the plant proteins, it is quite the contrary actually.

Comment. For the growth model work, achieving good or near model FCRs requires that one feeds properly. So you need to use some kind of a model to run for your farm to calculate what to feed the fish tomorrow. If you over feed the fish, you are not going to achieve the FCR that you are trying to achieve and you will have a poor (high) FCR. If you underfeed the fish they will not grow enough which is also undesirable. That knowledge already goes into the farm process. Feeding may cause some of the variability in P waste, but it is relatively small compared to variability in P budgets in lakes from year-to-year. It may not be as big a concern as it might seem when we are focussing on models and FCRs. There is a big economic incentive for farms to achieve good FCR as it is cheaper. It is much better incentive than a goal of low waste output as that does not get them anything. Down the road we may not have to worry as much about the feeding side as we do about the waste output side of the operations.

PRESENTATION OF REVIEW 1

Author and Presenter: Dr. Ray Hesslein

One thing that is very important in assessing the impact of P in lakes is whether there is or is not internal recycling of P. That is a critical feature to understand. In the Experimental Lakes Area (ELA) lakes there is essentially no long-term recycling of P. There are other lakes in the world where there is a lot of internal recycling. If you add P to a lake like one at the ELA, a year after you stop adding P there is no visible impact. That has been shown in Lake 227 but it is not the case in other lakes that have high internal recycling where if you add P, the recycled P keeps building up. You keep increasing your P concentration even at the same loading rate. This is really important to work out when you are assessing potential sites for aquaculture.

With respect to internal cycling, the older literature discusses the differences between the impact of anoxia versus oxic conditions. There is a lot of new literature with a different, more precise view (e.g., Orihel 2013, Gächter and Müller 2003) on P in sediments. The present feeling is that if there is an excess supply of Iron (Fe), then P is tied up in the sediments with Fe whether it is anoxic or not. That is, just because Fe becomes more soluble under anoxic conditions does not mean there is no P binding if there is sufficient excess Fe. Where you run into a problem, the problem being internal P recycling, is when there is not a sufficient supply of Fe relative to P, available either because there is low Fe loading in a particular site or because there is a lot of sulphate and sulphur is being reduced in sediments or in an anoxic zone and the sulphur ties up the available Fe so it is not available for P. Those are the types of conditions that Orihel and Gächter and Müller have addressed in their understanding of this process. This brings to mind an interesting possible treatment to add Fe to fish waste to bind P because typically fish waste has a low Fe:S ratio. So fish waste piles produce a fair bit of reduced sulphur and very little iron. So they are the worst case in terms of P recycling.

Depending on the lake, the depth of the water at which the waste is released, which means usually the distinction between dissolved or particulate release, is very important in terms of how it feeds the algal community. Because waste that is released in dissolved form is generally released in the surface mixed layer, it is immediately available for algal growth throughout the season. Particulate material goes to the bottom and then is released more slowly. Even if particulate P is all ultimately released, in a stratified system it is not released into the euphotic zone, at least in the short-term. So the process is quite different between P released as dissolved P or released from the waste material that settles to the bottom. The uptake efficiency of dissolved P release to algae is very high because it is right there immediately. Efficiency of P release from the waste pile depends on a lot of things but is always going to be slower.

With respect to anoxia, the oxygen demand of the pile is controlled by the area of pile because generally we model diffusive movements in and out of sediment materials based on a boundary layer. So you have a zero concentration of dissolved O_2 on one side and whatever the concentration of O_2 is on the other side of the boundary in the water. If that boundary is a millimeter thick there is a limit on how fast the O_2 can diffuse through the boundary. It does not matter what the demand for O_2 is in the pile, O_2 simply cannot get into the pile any faster than that. So if you have a very localized pile of waste that is very thick, the O_2 demand is very small and we saw this at ELA. If you spread the pile out to make a thin layer so rather than 1 m deep (like it might have been at ELA) it is 1 mm deep, then you will have 1000x O_2 uptake in the short-term. So the spatial extent of waste deposits is a strong factor in estimating O_2 demands. Hopefully we are not siting cage culture where there is a risk of anoxia so maybe this all does not matter. If there is already anoxia at a site, or a high risk of anoxia presumably we would not recommend siting there. The pile area is important. Another aspect of this is if you have a small area but a deep pile, since O_2 cannot get into the pile the decomposition of all that material is anaerobic. That means that 50% of the carbon that is being decomposed is leaving as methane and 50% is leaving as CO_2 (the approximate ratio of anaerobic decomposition). Methane is 25 times more potent than carbon dioxide as a greenhouse gas. Maybe on the scale of fish farms greenhouse gases are not a big issue but it could come up as a public issue. From that perspective, spreading the pile, though it uses more O_2, decreases the production of methane (increases CO_2 production).

If you look at the variability of P loading, independent in a sense of how good the numbers are in specific locations, for some whole lakes we have a pretty good loading estimate. Such is the case for Lake Winnipeg where most of the P is coming in from rivers, which we monitor, and most from the Red River. For big systems you can have pretty good budgets but the variability is high. You can have a year with a spring like this year [2014] where we have huge water loads in the Red River and Winnipeg River, we get big P loads in Lake Winnipeg. In the 1980s we had a drought for ten years we had low loads. So even if you do a very good job monitoring the rivers and the runoff you still can have ± 50% fluctuation in P loads in a natural system. So if you are near a target value, let's say you have set a target value of 10 µg/L for TP, you have to realize there is a lot of variability if the loading is driving that number. It would be foolish to try to refine the understanding of the cage culture well enough that you would try to get close to 10% or 20% of a target number if you are already at or near your target load. So let's say you calculated a natural TP concentration of 9 µg/L you probably would not want to recommend that as an aquaculture cage site because it is going to be 9 ± 5 µg/L in the natural world. So in some years you are going to be at 14 µg/L and would be adding the cage culture on top of that. So the margin has to be pretty wide when dealing with this kind of variability in natural systems. So for systems on the clean side you still would not want to go above say 20% of natural loading. If you had a target of 10 µg/L and your natural system was at 6 µg/L you would not want to push it near 10 µg/L with cage culture. There is not enough room for safety under the precautionary principle.

As we are moving to assessment of nutrient loads on all large systems (we are trying to do it on the Lake Winnipeg Basin), there are lots of contributors to nutrient loads and P loads in particular (e.g., agricultural loads, grain, animal husbandry, industry, city sewage and maybe cage culture) and you have to assess them in the same watershed assessment. You might find that it is easier to reduce the loads coming out of a pig farm than it is to reduce the loads coming out of a cage culture. And because the feeding models are so advanced for the cage culture and can be followed pretty well, fish farms might be doing a very good job in mitigating P loads whereas someone else might not be. We have to stop assessing cage culture as a separate farming issue downstream. Maybe less efficient management upstream has produced P waste and this could include city sewage. We should start from the top, mixing all of the P sources in the decision making process and allocate P loading targets to activities.

Working Paper Author's Response

Q. When you characterized the ELA lakes without longstanding impacts from P, would you characterize these Shield lakes as amenable to P loading because of the high Fe:P molar ratios found naturally there? Are they different from the larger North American temperate sites?

A. ELA lakes and Shield lakes have high Fe inputs and low P inputs in the natural condition. So they are extremely efficient at holding natural P. Even when you load them heavily with P, there is a high enough Fe input to prevent P dissolution. The anoxic/oxic argument is best represented in Lake 227 which has been loaded with P for 45 years, it has been anoxic from 5 m to 10 m since 1969 and probably was before that (prior to the addition of P) and it is still 85+% efficient at holding P in the lake. I do not know the Fe budgets for other lakes though you might be able to get that information.

It is important to look at sulphate. ELA also has very low sulphate concentrations. So production of sulphide (S^{2-}) in sediments to bind O_2 is not an issue at ELA. But if you go to western sites, prairie lakes, they tend to have high sulphate (SO_4^{2-}) concentrations. The lakes D. Orihel studied in Alberta had very high sulphate concentrations and internally recycled a lot of P because the Fe there was tied up as a sulphide (S^{2-}).

Comment: It may be important to capture this information under knowledge gaps especially since there may be the possibility of cage aquaculture at other sites.

Q. Is the reduction of sulphate to sulphide microbially ameliorated?

A. Sulphate is a terminal electron acceptor down the road. First bacteria take O_2 if they can get it, then nitrate and then sulphate if they cannot get those two, and they use the O from the sulphate to oxidize organic matter. However, you would need to know the Fe budgets and sulphate concentrations to evaluate locations which could be looked at.

Comment: Only two of the cage cultures in Ontario would be considered as shield locations (one northern one on the north shore of North Channel and the Parry Sound site). All the rest are on Manitoulin Island which is an extension of the Niagara escarpment and has limestone-based geology.

Comment: There is a publication which lists and compares the various husbandry practices and the ranges of Fe and manganese (Mn) found in manure. In fish waste, Fe is abundant but it would be helpful to know what Fe content would be considered good.

P concentrations in waste are 1-2%, and the Fe concentrations are not that high. Fe concentrations in aquaculture waste were not high at ELA, relative to P.

Q. When you indicate that depth matters for the release of dissolved P from fish cages what do you mean? Some cages are suspended below the thermocline and some are sited at deeper sites than other sites.

A. It is not hydrodynamics that is important but at what depth the fish spend their time. If they are in the top couple of metres of water all the time it does not matter how deep the cage is. Getting this information is not easy unless you have cameras in the cages. Of course when you feed them they are at the surface but the rest of the time you do not know where they are excreting. Evidence from the model (Lake 375) suggests they were in the top few metres. Ancillary evidence of that type of activity comes from Rainbow Trout released outside the cages with sonic tags and they spent all their time in the top five metres. Their temperature preference was around 18-20°C typically in a mixed layer. So even if the cage goes in the hypolimnion, the fish do not go there. In bigger lakes you would not be going into the thermoclines and all the dissolved release is in the euphotic zone.

Q. When you are referring to ELA oxygen demands and estimates, is it chemical oxygen demand (COD) and biochemical oxygen demand (BOD)? How much P will come available during redox related P dissolution relative to surface area of the pile exposed and decomposition rates of the waste pile?

A. The model used for O_2 diffusion into the sediments is a boundary layer model. It essentially says there is a boundary layer at the sediment water interface of calm water that is on the order of 0.3-1.5 mm thick. The thickness of the boundary will depend on the turbulence in the water. In big active lakes it is likely to be thinner while in the deep waters at ELA it is thicker. Basically it does not matter how much you reduce the oxygen concentration on the pile side, it can only go to zero. I assume it is zero at the bottom of the boundary layer and at the top the oxygen concentration is whatever level it is in the water column. So the highest flux you can force into the sediment would be if it was at saturation with equilibrium with the atmosphere (about 300 µmol/L) and zero at the other side and with the boundary being 300 to 1200 microns thick at diffusive rates. That is as fast as O_2 diffuses.

Q. Does the trophic status of a system change the precautionary management structure you referred to? Lake Huron was the example with 6 µg P/L at a site, where 10 µg P/L is the maximum, and you want to give yourself 50% leeway. Is that that because we are dealing with an oligotrophic lake? Would it be different in a reservoir or a situation with typically higher nutrient loads?

A. It depends on how close it is to your target. Variance of loading is not dependent on the level of trophic status. At ELA we have looked at the loading data for Lake 375 and it is high. In 2003, (low water year) the natural P loading to Lake 375 was very low. But in 2002, a high water year, the P loading was high. Variability is high even if the expected concentration is low.

If you have a system that is far from the target, say a system that is a four when your target is a 10 µg P/L, you could load to 50% of the average value and probably not get over 10 µg P/L in maybe one year out of 5 or 10 µg P/L which might be an acceptable value. If you are at eight, you are already going over that value 30% percent of the years so you are going to have to take a different view. You will not get away from the natural loading variability any place very easily. Possibly in eutrophic lakes because the loading is not coming from runoff, it was coming from sewage outflow but you would not be siting aquaculture there.

PRESENTATION OF REVIEW 2

Author and Presenter: Dr. Bob Hecky

The document is comprehensive in how the issue of P in the Great Lakes is scoped, the complexity of P cycling and how aquaculture operations can plan into it.

My experience comes from two graduate students working in Lake Malawi and I am struck by some of the differences I am hearing about. For example, pile has been used several times to describe what is observed under the cages. In Malawi, we never saw a pile under cages raising 20 tonnes of fish per year which were 12 m in diameter and 6 m deep based on North Sea cages. The areas were very well flushed with currents of 10 cm/s. They were in open water, a kilometer off shore, only partially exposed to the waves of Lake Malawi. When we went looking for P outside the cage, we could not find it. We initially thought this might result from flushing but we had lots of fishes around the cages so we thought that they might be helping to process and carry away the P, although this latter hypothesis did not stand up.

Flushing is important. Siting of aquaculture operations is the number one challenge. People do not want to look at them and will not be happy if they see them. Areas that are well flushed should be sought and ideally you put the operations offshore somewhere. In the report you indicate P concentrations have been falling in Lake Huron, in general, over the last 15 years. It is now compared to Lake Superior in its P concentrations. In general, it is hard to say there is a P problem in Lake Huron right now. But there is concern that the fish are starving out there. The fish communities in the lake are changing. Lake trout are coming back but everything else is going down the tube. Round Goby were now 30-40% of the prey consumption by all predator fishes in the lake. What is going on in Lake Huron is going on wherever we look in the Great Lakes (except Lake Erie). When you think about P, everyone gets excited and worried about it. We understand well what the loading is, and the presentation on aquaculture waste output shows we have a good handle on that. Where we have a problem is once P is outside the cage as waste material, dissolved or particulate. The key to managing P loads is good siting which means good flushing and ideally you would have a hydrodynamic model to determine how much flushing there is and where that particulate and dissolved matter would end up. Is the site so poorly flushed to cause P waste to accumulate into a pile or is there enough current movement in the area that P waste will flush out. P will still be in the environment, it is just highly dispersed. Then you are worrying about it at a different scale i.e., at the nutrient budget of the lake.

You have to manage the waste (how much you feed, when, if you have culture at all) as you cannot manage the hydrodynamics.

In the Great Lakes, nitrate is in abundance and provides protection, along with high dissolved oxygen concentrations, from the extreme reduction processes that can solubilize P and promote nuisance N fixing algae. If we were talking about Lake Malawi, we would talk a lot more about the N:P ratio. The ratio from the earlier presentation was a 7:1 weight ratio in terms of waste material N to P. That is close to a boundary where we would worry about the possibility of inducing cyanobacterial blooms, if nitrate were a problem in the system. In the Great Lakes, nitrate is in excess all the time so we have a protection factor there because of our lack of management of N in the environment. It is worth emphasizing some of those points in the review paper.

I like the emphasis on the offshore and nearshore zones in the report. In the Great Lakes we are struggling with how to deal with nearshore problems. We thought they would go away when we treated the offshore problem. Most aquaculture facilities appear to be sited close to shore. So they are put in very complex areas where there is a lot going on and they will likely be immersed in controversy as long as they are in those nearshore areas. The aesthetic aspect is driving the question more than the threat of P loading. We can deal with the P waste from aquaculture cages, but once P waste is out of the cage it is difficult to understand what can happen. This was well laid out in the report.

Currents are important regardless of source. If you are seeing fine grain material collecting on bottom then there is not much current to move that material away. Hydrodynamics needs to be considered when assessing the risk to lakes from aquaculture P waste. People do not want to see the cages so the long-term solution is to get them out of site.

Comment: There is a difference between surface water flows and currents at the bottom that you see in these lakes. Even though we are in the nearshore area and flushing is ideal, we are not getting the internal seiches like Lake Malawi that moves large volumes of water. We have measured current in several sites using bottom deployed Acoustic Doppler Current Profiler (ADCP). We typically do not see current in excess of 4 cm/s except briefly when you get towards the bottom and it is not enough to move the pile. One site that is really energetic still has a pile though it is offset. The waste material is sticky and it takes a lot of movement to re-suspend it so re-suspension is not a big factor. We are working on dispersion models and setting out sediment traps to map the material .There is an exponential decline in C deposition off the edges of the cages. Offshore is probably the best place to put farms but the technology to withstand the enormous fetch on Lake Huron is problematic. Economics of maintaining cages offshore is also an issue although robotic feeding is being looked at as a way to expand.

Historically, aquaculture siting was based on identifying locations that were good for the cage sites (i.e., water was deep enough, had good water quality, was cold enough to grow fish and was sheltered) so farmers did not have to worry about destruction of the cage systems. They did not necessarily consider location based on waste discharge and they were not bringing limnological criteria to siting. Even now the siting documents encourage a well flushed site but they do not provide details on what one should be looking for. What kind of data would be used to recognize a well flushed site?

Comment: With respect to the hydrodynamic issues, settling velocities of faecal material are very fast especially compared to algae. Depth of water is important. If you are in shallow water there is little time to move the material laterally before it hits the bottom. You have to look at the characteristics or type of dynamics in the system. Sometimes because of bottom friction, you can have lower velocity along bottom. In other situations you can have higher velocities near the bottom. It is site specific. With high settling velocity and low velocities along the bottom due to friction, particles will not move very far before they get sequestered.

Response: That was why I asked about substratum. If you are in areas of rocky shore and complex bottom, you can have coarse sand in area with fine particles moving through it. I suggest adding bottom characteristics to the siting criteria. As a guideline you want fairly good velocity and substratum indicative of continuous fairly natural high velocity. Lake Malawi had sand down to a water depth of 50 m. You mentioned limits of 4 cm/s but at Lake Malawi we were averaging 10 cm/s. Originally they were told to put cages offshore but due to security issues they moved them in close to shore, although they are still 1 km offshore.

Comment: With respect to the N:P ratios, the dissolved release of N in the water column from urine and mucus through the gills, is proportionately higher than P. This mediates the N:P ratios for the direct release in the water. Subsequently, the waste material that falls to the bottom and is decomposed, is releasing N more efficiently than P, and that mediates the N:P ratios. We are starting with high N:P in Lake Huron so things work in the right direction to prevent harmful cyanobacterial blooms.

Q. What is the seasonality of sedimenting material? In Lake Malawi there is decomposition all year long. Does feeding, growth and waste remove P faster when growing in the summer? Do the waste piles increase over the winter?

A. Farms tend to have higher biomass on site and higher feed rates in the fall, leading to the greatest loading of organic matter to the lake bottom. In winter, farmers feed less, 1% of the fish body weight per week. In spring you often see mats of fungus that start to grow on the lake bottom. Over the summer and by the fall decomposition cannot keep up and the lake bottom gets buried by fish waste. In Diefenbaker they have periods, e.g., late July to early August, when you have lots of fish on site to feed, but water temperatures are high (22-24°C), so farmers stop feeding or reduce feed. Feed usage and sedimentation rates in Lake Diefenbaker decline in August and then in September begin to increase again. In the fall, farmers increase feed to fish to get the maximum feeding rates. It depends to some extent on the farms. Some farms historically put all fish in at same age class and grow to harvest size. Some farms have multiple age classes on site. Bigger fish in spring means that, with optimal temperatures, more feed is used. At ELA small fish went in in the spring so fish waste was low in spring.

Comment: It may be not as important whether the solid material is well distributed by currents because if there is a pile (even a somewhat distributed pile) that is decomposing, what is important is how fast the dissolved components that are leaving the pile get distributed in the lake. We do not care about the P (or N) as long as it stays in the pile. It is not effective at eutrophying the system. It is only once nutrients N and P escape as a dissolved components that fish wastes are a threat to water quality. Once P is dissolved, the currents can move it more easily through the water column. The distribution of the solid material may not be that important. The same thing holds true for the resupply of oxygen to an area. If there is oxygen depletion by the pile that depletion will be swept away by the water movement above it.

With respect to the decomposition rates of the waste piles, they were on the order of months+. At ELA (Lake 375), the fish waste deposition ended in October and there was still substantial pile depth in spring. At 4°C temperatures, the piles are relatively persistent. If you spread the pile out, organic matter may decompose much faster and decomposition is faster in warm water (at least a factor of 2+ per 10°C).

PRESENTATION OF REVIEW 3

Author and Presenter: Dr. Rebecca North

This was a very comprehensive and complete synthesis. It incorporates a lot of different disciplines. There needs to be further synthesis and distillation of the information presented to tell the narrative, (e.g. using the “and, but, therefore” principle of designing a narrative), followed by recommendations for management..

Most of what we know about freshwater aquaculture comes from oligotrophic environments. Lake Diefenbaker, Saskatchewan is a mesotrophic (prairie-based) system. Lake Diefenbaker has the largest freshwater aquaculture facility (Wild West Steelhead Inc.) in North America. It is important to start looking at the other aquatic environments when considering effects of P waste from aquaculture. A British Columbia location was mentioned but the majority of the information summarized is based on facilities in Lake Huron and ELA. Characterization of the different sites (substrate, Fe, sulphate concentrations) in different areas would be informative for future management perspectives.

Lake Diefenbaker was formed by damming the South Saskatchewan River. There is a monitoring program underway over the past four years. It is meant to characterize the reservoir. Located in several embayments is the aquaculture facility, Wild West Steelhead. Research results are planned for a Journal of Great Lakes Research: Special issue on Lake Diefenbaker in 2015. It will cover a range of topics including the following:

- Phytoplankton community composition
- Nutrient limitation
- Internal P loading
- Paleolimnological approaches to reconstructing temporal trends in reservoir productivity and trophic status
- Nitrogen sources and processing in a large dynamic reservoir
- Nutrient loading from cage aquaculture
- Distribution of solid wastes from a cage aquaculture farm and resulting patterns in sediment chemistry
- The infaunal invertebrate community and inorganic and organic nutrient sources to Lake Diefenbaker (C. Prestie, M.Sc. Thesis)

There were two assumptions in the aquaculture review paper. The first is that the loss of P from fish mortality represents a small fraction of P in biomass. In Saskatchewan, they have fish mortalities that are not leaving the watershed. Based on anecdotal evidence, there are tens of thousands of mortalities annually, particularly in the winter where the fish are kept higher in the water column than they typically would be found naturally so they are exposed to lower water temperatures resulting in mortalities. They are disposed of into an open pit (about 1 km from the embayment). There are ways for P from the fish biomass to make its way into the reservoir. It is not clear if this is a widespread practice.

The second is that most of the P from aquaculture ends up in the sediments. This leads to the issue of P re-mobilization from the sediments. If we know that most of the P waste falls beneath the cages, the real question is what controls the P returning to the water column and what is the risk of this happening? What controls internal P loading? Hypolimnetic O_2 concentrations (dealt with in the Ontario perspective and risk of anoxia). It depends on metacomplexes including Fe, Mn and sulphate concentrations (Orihel and others work at ELA). The sulphur story: once a lake becomes stratified (even in oxygenated hypolimnions), if sulphate is present in high concentrations then it will bind to Fe, which will cause the dissolution of P that was bound to the Fe and increase the chance of internal P loading within these systems. We are working on this in Lake Diefenbaker. We know that sulphate concentrations are high and the Fe concentrations are also high, but because of sulphate predominating, we have a high rate of internal P loading occurring. The work was done in the open water main channel of Lake Diefenbaker, not in the embayments and not directly under the aquaculture cages. If we were to assume similar sediment processes are occurring then there is this high risk of internal P loading on these prairie reservoirs and prairie soils. It was puzzling initially because oxygen concentrations do not get that low (>2 mg/L) related to the loading from the South Saskatchewan River. Lake Diefenbaker has high rates of internal P loading throughout the reservoir, which we now postulate is related to the sulphur/Fe complex. Internal P loading will cause an increase in water column P concentrations, and after the lake turns over and mixes, the P is available for photosynthesis in the upper water layers.

From a management perspective we might be able to assess the risk for internal P loading. How do we prevent internal P loading from occurring or can we site facilities in areas where there is less risk of this occurring, such as in Canadian Shield areas (and ELA type areas)? The criteria are already set up to avoid hypolimnetic anoxia but perhaps we could categorize systems by their sulphate concentrations. Typically that is something done by every government monitoring agency. We should be able to get some sulphate number for most systems. Some categorization of the risk associated with some sulphate concentrations could help as a step forward. This also relates back to the time scale, internal P loading occurs over a long time period. So at ELA, internal P loading and sequestration equalize over a couple of years, but in these larger systems internal P loading would occur over longer time periods. We also know that with climate change effects we would have more risk of low oxygen conditions and potential for more sulphate reduction, so we would expect a longer time scale would have a big role in whether or not this P gets remobilized up into the water column. So perhaps the next step or knowledge gap is to identify specific regions in Canada that are most susceptible to these processes. Currently what we know about the prairie soils they would be one of the areas very susceptible to this internal P loading, whereas Canadian Shield lakes such as ELA would perhaps be less.

Comment: In regard to the first issue about mortalities, in the aquaculture farms in ON most, if not all, mortalities are collected and are being used, along with the viscera (waste) of processed fish to create “Meeker’s Magic Mix” compost as another “value added” product for the area.

On Diefenbaker there is an estimate of about 260 tonnes of waste (dead fish and fish parts) per year. Less than 50 tonnes of this are fish mortalities. The mortalities are buried while the remainder goes for the production of hog feed and biodiesel (fuel).

Wild West Steelhead is the only operation with a processing plant right onshore. They harvest fish under normal operations almost every week of the year. Their slaughter (processing) waste is going into the production of hog feed. The high fat from the viscera goes to the production of biodiesel used to run some of the farm trucks. It is just the mortalities that are collected during the winter. They do not get out to the cages as frequently in the winter as they would like so the condition of the mortalities precludes their use and they are buried.

On other farms in Ontario, fish mortalities were discarded on land in the past, but that is not the case any longer. They are now all being collected in tubs for MTM Aquaculture (Mike Meeker’s facility), where the waste is mixed with sawdust and is composted in old cement trucks. Canada geese do not like the compost so it has been used by some as a deterrent. It is also used with other amendments to raise pH levels and rehabilitate [terrestrial] areas damaged by acid rain in Sudbury.

Q. In the literature there are a few reports of an aquaculture site that required a re-evaluation because of deepwater anoxia. The response to this was to continue monitoring the site. When we are doing the P budgets and when we are talking about internal P loading, do the models have a capacity to deal with short term localized internal P loads? Does this need to be incorporated into a risk assessment?

A. The one site you are referring to is in the LaCloche Channel near Manitoulin Island, ON. It had been operating there for about 10 years. In 1997, there were complaints about algae blooms in the channel. The company had been doing their required monitoring under the conditions of their licence, but monitoring did not include dissolved O_2 measures. When the Ministry of the Environment (MOE) and Ministry of Natural Resources went to do some audit sampling following the complaints, they found severe anoxia up into epilimnion. This precipitated quite an extensive advancement of the scientific research on aquaculture effects. The site was phased out within a year and was monitored for several years following closure. There was very quick recovery of TP and slower recovery (within a couple of years) of dissolved O_2 concentration, which had gone back to what was determined to be pre-existing conditions. The Channel is a couple of kilometres long and is a series of deep bathtubs. The aquaculture site was in the last bathtub which was 40 m deep, where water discharged into the North Channel. The sill was less than 1 m deep (under low water conditions) and about 1.5 m deep on the upstream side. There was another aquaculture site situated upstream, and that was a historical aquaculture site that MOE ran. MOE did some modelling of the LaCloche system after this event. They determined that about 5% of the bottom waters were naturally anaerobic. That resulted in the “though shalt not establish aquaculture in a type 1 site” rule.

Q. Tens of thousands of fish dying in winter does not sound sustainable. Is this accurate?

A. To put the tens of thousands of dead fish in context, looking at the number of cages on Lake Diefenbaker, size of these cages and average number of fish in cages of this size, this farm has about a million fish on site, so 10,000 fish is only 1% mortality.

Q. Are you doing a whole N budget on Diefenbaker like what was done on Lake Wolsey as it is a reservoir that is flushing?

A. That work is part of a M.Sc. thesis that should be coming out in the Journal of Great Lakes special issue. It is a mass balance of N and P in the reservoir but only in the main channel, and not the embayments where the aquaculture operation is located. This was being done for the reservoir as a whole.

Q. Is there any way to track or monitor where the source of P is coming from? Thinking of Lake Diefenbaker, there is lots of agriculture around it. When there are high rain events, you would expect that is where the P loading is coming from rather than the soil type.

A. There are approaches to address this, for example, experimental work looking at stable isotopes of phosphate but this has not been done on Lake Diefenbaker yet. We do know that overland flow is minimal. The majority of the loading (95%) comes in from the South Saskatchewan River. That was why the sampling was set up to include the embayments along the length of the reservoir. It was trying to isolate inputs from anthropogenic sources (e.g., marinas, human populations (although low in the area), agriculture, cattle). The P inputs are not quantified but we do not see a lot of changes along the length of the reservoir.

Q. When looking at phytoplankton population in the Diefenbaker Channel, if you are not right beside a cage you are not going to see changes in water column P concentrations. Although it is a mesotrophic reservoir and there is internal P loading, you have a high flushing rate that means you do not have concentration changes that are really measureable in our water quality monitoring data. There are P loading relationships but it is better to look at the algal community composition and population dynamics. Phytoplankton have seasonal changes and in a wet year, it looks as though there is a quantifiable response. I wonder if that is going to be the same situations when you are looking at sulphate. When you have P coming and you are not seeing it I wondered if the sulphur would have the same sort of response.

A. That is why I suggested sulphate measures, as it is actually a conservative molecule and you have would not have analytical issues like you have with Fe and trace metal contamination. I would not expect to see the seasonality in sulphate concentrations that you find in P (things that are taken up). Right now we do not see a large impact from the aquaculture facility in comparison between embayments upstream and downstream of it. We do not see significant differences in phytoplankton community composition, P or N concentrations.

PRESENTATION OF REVIEW 4

Author and Presenter: Dr. Bill Taylor

The review, as we received it, has lot of background information on the P cycle. I have provided comments in my written review that was sent to the authors and I will not go through that here. I would like to speak about the current situation in Lake Huron and the context for the farms on Manitoulin.

What is really intriguing about what is going on in the Great Lakes, Lake Huron and to some extent lakes in Ontario and Michigan, is that the biggest eutrophication concern right now (forgetting about western Lake Erie and its algal blooms) is nearshore fouling. The fouling of the shorelines with *Cladophora*, in many locations diatoms and *Cara*, and in parts of Lake Huron with what is colloquially called “muck” washing up on the beaches. We have this going on and at the same time in the offshore zone we have concerns about oligotrophication. The working paper mentions the targets set for TP, in the various Great Lakes. We have essentially gone to TP below those water column P targets and that is in part because the P loading targets were conservatively set to achieve TP concentrations that are below target. To make the old P load models that were used to set the TP concentrations work, (as in Dolan and Chapra 2012a, 2012b), they’ve had to make the apparent sedimentation velocity for P in the lakes about 50% higher to make the models fit monitoring data. So there has been an apparent change in sedimentation velocities. There is offshore oligotrophication and nearshore eutrophication going on at same time, which creates a certain amount of uncertainty in how we manage these systems. It is not just Lake Huron, similar things are going on in lakes Michigan and Ontario. Lake Huron is the least understood of the Great Lakes. Lake Huron and Lake Superior are the lakes nobody works on as there are no big population centres or government labs nearby, so they are relatively poorly studied.

Offshore Oligotrophication

Looking at this issue alone you would wonder: Why are we worried about P getting into the lakes? Some people are calling the fishery situation a trophic collapse; others say this is an over statement. The index netting essentially fails to catch any forage fishes. Forage fish have become so rare that on a graph they have gone to zero. At the same time the condition of larger fishes (e.g., Chinook Salmon) have fallen precipitously and so has the population. The positive side is that some of the native species are doing well (e.g., Lake Trout) and are actually reproducing again. It has been suggested offshore oligotrophication is a symptom of the new Dreissenid mussels that have invaded the lakes. Although blamed for a lot, I am skeptical that Dreissenid mussels are the reason for the offshore trophic collapse. At a recent International Great Lakes Association meeting there was a talk showing that the water currents are weak in the deep waters. Dreissenid mussels can have great impacts around the shoreline including eutrophication-like symptoms, but offshore it is hard to imagine in 100–200 m water that small mussels on the bottom are clearing the water column. The physics is now showing at the current water velocities, those mussels are clearing a boundary layer just over the lake bottom and there is not the physical mixing necessary to provide mussels the access to the whole water column to contribute to the offshore oligotrophication.

My own perspective is that most deep oligotrophic or deep stratified lakes have TP concentrations in the summer of around 4 or 5 µg TP/L. One of my least favorite graphs in the whole limnological literature is the chlorophyll–TP graph in this morning's presentation (i.e., the Dillon and Rigler graph). Although really useful it gives the impression that lakes form a continuum of TP concentration from very low to very high and lakes are scattered along that continuum. In fact, if you look at the lakes of the world and plot them on a frequency histogram, lakes that are high in TP are quite rare. There is a huge mode around 4–5 µg TP/L like all the Great Lakes and for lakes that are more impacted by human activity they tend to start high in the spring (10–20 µg TP/L) then fall towards 4–5 µg TP/L by late summer. This is an almost natural order of things. In big lakes and stratified lakes, TP concentrations tend to be driven by biological cycles and processes rather than loading.

Although I am skeptical of Dreissenid mussels being the cause, what I think could be a cause is the aggressive stocking of exotic fishes into the Great Lakes. For example, in Lake Michigan the Chinook Salmon stocking depleted the forage fish populations, and large daphnia, so other efficient gazers among the zooplankton community became abundant and then the water became clear. It happened again in Lake Ontario waters. In response, the fishery managers in cut back the stocking practices in time to save the Alewife. We might also have seen effects of stocking to some extent in Lake Erie and now in Lake Huron. The forage fishes become depleted, the Chinook Salmon condition becomes poorer, then stocking has been reduced, and we have seen a resurgence in big zooplankton. My suggestion is that food web effects may be driving the offshore oligotrophication. If it has anything to do with Zebra Mussels it is because they make shells, unlike the previous native deepwater species in the Great Lakes like *Pontoporeia*. Zebra Mussels are long-lived, they have a lot of P content, some of it is in their shell material and once the shell is created it probably does not get re-mineralized except on geological time scales.

Nearshore Eutrophication

Eutrophication is an issue nearshore, which is where fish farms are located at the present time. Sedimentation velocities in the Great Lakes have apparently increased, but in the sort of models that are used to predict P loading effects, sedimentation velocity does not just measure sedimentation. It summarizes the process of sedimentation, the difference between sediment coming down and sediment going back into the water (net sedimentation). Plus P in the water column is moving up to the food web. It could be that sedimentation velocity has changed. The literature on how top-down trophic effects can affect sediment velocity in lakes would support that this kind of change in sedimentation velocity is possible and in fact likely.

It is worth remembering, TP as limnologists measure it in lakes is not really TP. It is the amount of P in the dissolved pool plus the little particles that get into water samples. So zooplankton are not included, and in other Ontario lakes, half the TP can be in zooplankton. And it does not include the fishes and sometime fish P can equal the TP. So when we are talking about low TP and how much TP is out there, it is really not something you want to mass balance because it is really not a complete measure of the mass you are trying to balance. When you say a lake TP is down, by measuring TP in the water column and small particles, have you really measured the TP and has it really declined or is TP just excluded from what you are measuring? MOE for example screens their TP samples with an 80 micron screen and that, based on my experience with other lakes, throws away about half of the TP.

Nearshore fouling

There has been a lot of head-scratching about why nearshore fouling is happening even though we have met our P loading targets and P concentration objectives. There are two ideas identified in the working paper as follows:

1. Zebra mussel have concentrated P near the shore, i.e., “nearshore shunt”, they are recycling P right at the substrate, creating a good nutrient environment for *Cladophora* growth. I tend to think this may be correct.
2. P Loading to the Great Lakes has changed, particularly that the nature of the P loading has changed. Evidence supports that TP loading is down. US datasets show increased dissolved P relative to particulate P. On the Ontario side stream data, both soluble reactive phosphorus (SRP) and TP, are trending downward in both agricultural and other streams. It is a puzzle to me why this is the case, but empirically that seems to be the case.

What I think this review is working towards is a box modelling kind of approach to assessing, or trying to put in context, what aquaculture P contribution might be compared to other loading. Thereby giving the public or decision makers some context for the how important it is to the environment or the aesthetics for the environment. However, right now that is just not an issue for the Great Lakes. TP is lower than what we want and we still have the nearshore fouling issues. Unless you can put loading of fish farms into the context of how it might affect the nearshore zone and the algal fouling problems that people living around the lake see, it will not be very useful. I think that is really what we need to do. Making a prediction of how much it will change the chlorophyll concentration of Lake Huron overall or even the North Channel overall is not useful.

A couple of points that the report makes and I want to reiterate are that the Net P loads for the whole basin do not adequately present the spatial heterogeneity of P sources and regional responses. That is key. P loadings to the Great Lakes might help you predict what overall TP in the lake might be. If it is low we do not need to worry about it. All over the Great Lakes there are local problems caused by local pollution. That is where we are right now. So we have to think locally. I would support Bob Hecky’s suggestion to get fish farms offshore. But I do not think working on those big scale P models is going to do much for understanding nearshore effects.

The other point is that not all P is the same. We have heard about how bioavailable aquaculture P is and a lot of trying to resolve how bioavailable aquaculture P is. But I want to point out that I do not see much evidence that it is any less available than any other kind of P that we measure except for phosphate itself. It is always relative to phosphate. If the issue is how much we discount aquaculture loading by comparing the availability of aquaculture P waste to phosphate – we do not do that for tributary waste or even sewage plant waste. Do we really want to do it for aquaculture waste? I do not see logic in that.

Another thing that needs to be explored, and I do not think the point is made in the report, is timing of when nutrients are loaded, which is very important in the Great Lakes context. So in natural lakes, most of the loading comes in the spring with snow melt. A high spring TP load comes in when the water is not stratified that results in a spring bloom of diatoms with high sedimentation velocities, which quickly sink to the bottom. TP concentrations fall throughout the stratified season, feeding the benthic food web that is important for fishes. But the trouble for sewage treatment plants and aquaculture facilities and other point sources is that P comes in throughout the summer. I think these sources of P are what grows blue-green algae and *Cladophora*. You have to treat different sources of P waste differently, not based on how bioavailable the P is, but when the P is added to the system and how locally concentrated the P is perhaps.

I have been involved with the International Joint Commission (IJC) on their Science advisory board in the past. I agree with how important the IJC has been in managing eutrophication in the Great Lakes, and coming up with these water quality guidelines and TP targets for loading. Without them we would be in a sorry state. But in the big picture I am thinking they have failed.

We have targets we have met with a lot of economic cost, but we still have lots of eutrophication problems. Basically, I think that setting target loads and meeting them has been an approach that has not been entirely successful in the Great Lakes. I do not think we can rely on it to keep us out of trouble in the future.

Comment: What you said is an interesting perspective. You mention that the farms are inshore and the impact of eutrophication being inshore. However the farms are very localized in some areas. Some of them have been operating since 1982. They have been pumping P in "nearshore" though it is pretty deep and I am not sure I would characterize it as being nearshore. But the P is not moving, has not moved, there is no sign of eutrophication. And although we do hear about blue-green algae being an issue, I do not know of any occurrences of blue-green algae associated with the farms since 1982.

Response: That is an important point. If you are going to convince me that aquaculture is not an issue, I would like to see evidence for the lack of fouling problem in the areas where there are aquaculture cages. That would go a long way to convince me they are not an issue. I am less swayed by an accounting of how much P it is coming into the North Channel compared to all the other sources.

Comment: You are not seeing evidence of fouling or algal biomass around cages. Sometimes, in late summer you might get a little algae buildup but I would not characterize it as a huge fouling or eutrophic condition.

Q. Nearshore fouling or eutrophication along the shoreline – is it eutrophication or the presence of filamentous algae blooms? The reason I ask is that in Sudbury lakes we are having many more occurrences of blue-green algae blooms in the city lakes. These are oligotrophic lakes (around 4 or 5 µg/L). They are not eutrophic conditions but they have blue-green algae. So when you are seeing blue-green algae blooms are they in eutrophic systems?

A. The only eutrophic parts of Lake Huron are Severn Sound, Georgian Bay and Saginaw Bay, but I am not talking about those. In Lake Huron from about Sarnia up to Tobermory and now Manitoulin Island there are complaints that a mixture of benthic diatoms and *Cara*, an attached algae (not *Cladophora*) is washing up on the beach and it smells (not cyanobacteria). Algal fouling events are widely distributed. Several years ago in Southern Georgian Bay there was a mass waterfowl mortality, ~5000 diving ducks and loons washing up on shore with botulism. Presumably that was the end result of *Cladophora* or some other benthic algae creating anaerobic micro-environments that were killing gobies and ultimately resulting in the poisoning of ducks. That is not acceptable and that was in the oligotrophic parts of the Great Lakes. I do not understand what is causing these events, but I do not think it is because the TP is too high in Lake Huron. Something else is the issue and I think it is very local and it is very nearshore.

Comment: I have not seen any greater significance of algae around aquaculture operations than there would be any place else. It is very minimal compared to other areas like in southern Ontario – Tobermory to Goderich areas and the occurrences of algal fouling there.

Q. When you are talking about ultra-oligotrophic conditions out in the lake and the effect on fish populations do you think there is any significant to the Spiny Water Flea, an invasive species?

A. It makes sense that the Spiny Water Flea affects oligotrophication, because it adds a trophic level to the food chain. Fish eat the Spiny Water Fleas and apparently they become an important part of their diet. But the fleas eat the zooplankton that the fish used to eat so you would expect the system to have lost part of its trophic efficiency and the production to be down. Invaders may be an issue. There is a whole list of invaders in the Great Lakes. Some of the food web changes and the P cycle changes are likely due to these invaders.

Comment: A session at the International Association for Great Lakes Research (IAGLR) a few weeks ago was about water clarity which is part of the nearshore issue. The Dreissenids are making the nearshore much clearer. Especially in Lake Huron there are diatoms that are able to grow in 25 and 30 m water depth, when they were not able to do so before. It makes sense that it is not related to aquaculture but to Dreissenids in the nearshore

A. That is a tenable hypothesis. I do not know how important Dreissenids are along the Lake Huron shoreline, though I have been told the population is low.

Q. Could the nearshore water clarity be continuation of offshore water clarity without the Dreissenids?

A. That is a tenable hypothesis if there is more benthic production. There is more bottom in the eutrophic zone and therefore more algal fouling. I cannot contradict that. I am not blaming the issue on aquaculture. I am expressing great uncertainty as to what is going on right now, and uncertainty as to whether conditions will get better or worse. Are the Great Lakes going to be understood through a box model of the sort that IJC has applied to set the loading targets?

Comment: In the aquaculture monitoring data I have seen in past 15–18 years, certainly the water clarity is very great and from most of the monitoring the fish farmers are doing, it is increasing. Most of the operations are averaging 10–12 m of water clarity. Over that time period, the thermocline seems to be going a lot deeper too. Now most of the operations will be entirely in the epilimnion by the end of the summer and the thermocline is well below the cages.

Q. What is an acceptable definition of the nearshore zone? Is it based on distance or depth? What is the range of the nearshore?

A. I am not sure there is an official definition anywhere. From my experience, on Lake Ontario and eastern Lake Erie anything inside of 20 m water depth was nearshore and beyond that was offshore. In Lake Superior, it was 80 m. At other times working on Ontario, nearshore was up to 40 m. It should be set by depth of the thermocline, but that would then vary seasonally and by water clarity.

Comment: Every lake is showing changes in water clarity except western Lake Erie. This can be seen with satellite imagery compared over time. All the lakes are getting more transparent and even the eastern basin of Lake Erie is becoming more transparent. That is attributable to lots of things, the chlorophyll concentration is down and in some of the lakes the mussels are filtering in the nearshore. We can see some of that in Lake Superior, although not at the same magnitude, it is becoming clearer. There is no Zebra Mussel in the main basin of Lake Superior; the mussels are only in the harbours and are very restricted spatially.

The Water Quality Agreement has been renegotiated with specific language in it about the nearshore, developing a nearshore framework, although the IJC has a three year timetable to develop it. So if you are working in the nearshore zone, what the IJC might come back and recommend as new water quality standards and new limits are unknown.

Q. TP is used because, to a large extent, it has much less variability and is more reproducible. Does the form of P (dissolved or particulate forms or reactive or bioavailable forms) matter?

A. It depends whether you are talking about in the lake or about loading. If you want to measure P in the lake you are going to measure TP. I do not see measuring dissolved or SRP in the lake because in the summer time in the epilimnion they are both so small SRP is usually unmeasurable and dissolved P is just a measure of filtration damage. If you filter gently enough you do not see any dissolved P either. So measure TP. Maybe pre-screening water samples is not a bad idea, but everyone should be doing TP sampling the same way. You also should acknowledge it is a pre-screened sample and by screening you are taking out a good fraction of the particulate P. It is really different when you are measuring tributaries and P loading because in a tributary, especially when they are delivering most of their loading in high flow, the dissolved fraction and the SRP fraction can be very high and are bioavailable. On the other hand, the P bound to clay particles and the organic particles that are coming down with the high flow events maybe are less important for eutrophication and are going to quickly settle out. You may also want to measure dissolved P in the tributary loads. In the loads I would measure both dissolved P and TP if given a choice.

Q. We are talking about nutrients, but really we are talking about elements as part of something more complex. Looking at results from the ELA, for example the manure fertilizing the bottom of the lake and stimulating the growth of Chironomids and other benthic invertebrates, we are simplifying reality by saying we have dissolved P and particulate P, when really we are delivering a complete nutrient package (elements, amino acids, fatty acids, trace minerals, vitamins, etc.) which may stimulate the growth of primary organisms through mesotrophy and iterotrophy (zooplankton, etc.). Is there any difference in terms of environmental impact or changes in a trophic chain, based on the work at ELA, delivering the same load of P using an organic or inorganic fertilizer?

A. Algae use inorganic P first and foremost.

Comment. In ELA, prior to the aquaculture experiment there were hardly any forage fish. You install a cage and start a fish farm and right away you get a huge increase in wild forage fish. Something is sustaining this. The change was so fast that it is probably not inorganic fertilizer stimulating the growth of algae, then phytoplankton, then zooplankton, and so on. We tend to look at elemental input but we are looking at nutrient additions that are more complicated.

Response. Some of the increase in the fish population at the ELA aquaculture experiment was, we think, due to direct consumption of fines by minnows. Stable isotopes showed a direct consumption of particulate material by fish and benthic invertebrates living near the cage. If you fertilize with manure, which has a high settling speed, it is not in the epilimnion for very long to fertilize algal growth. At Lake 375, ELA we did see a remarkable response from fish community to the aquaculture site. It started with increased growth rates of forage fish. Then, Lake Trout spawned each year instead of every second year, indicating improvement in their energetic state. We did not see a change in the zooplankton biomass, which may be the result of the nutrient load timing. .

Comment: Fish faecal material is 20–25% protein, 10% fat, loaded with essential fatty acids and all nutrients, minerals and vitamins. It is more than just elements, it is a “complete breakfast”.

Response: We see big increases in biomass and abundance of invertebrates in rings around farms. I have always thought that was because the material that is falling is high quality feed compared to the forms of C that normally hit the lake bottom. Underneath cages we get areas where the biomass is not stimulated because we have excessive deposition rates where conditions are not conducive to invertebrate growth (e.g., too much ammonia). One commercial aquaculture site in Ontario has a very unusual (loose) mooring system and the cages move everywhere. At that site, when you sample sediment cores around it, you see a big increase in invertebrate abundance everywhere. I think the loading rate is dispersed enough that the fish waste acts as a fertilizer.

Comment: There are positive and negative environmental changes from the aquaculture operation and this should be part of the report.

Response: That is true, but the focus has to come back to P. We do not tend to see much in the way of detectible changes in P around cage sites. If you look at water quality monitoring program, a fairly rigorous program done at the sites in Ontario, there are no exceedances. MOE monitors farms by analyzing water samples integrated over the water depth of the cages. Farmer have to sample three times during spring turnover, then they have a series of five samples during the summertime and again three samples during fall turnover, which they have to verify is during turnover, for analysis of nutrients.

There has been the odd exceedance but monitoring also samples up and down-current reference stations. On those occasions when the P concentrations have crept over the target levels the P measures have been the same at both up and down-stream reference stations, and is a basin-wide effect not related to the cage wastes.

Cage sites rarely exceed reference sites when cage sites are plotted against the 95% confidence limits of reference sites. It is possible to measure localized increases in P if you stand right on the cage and take a water sample off the edge, then compare P concentrations with the same depth and date of upstream site samples.

Comment: We worry about P because we worry about stimulating algal growth. Fish waste is more than just P and is a pretty good diet for some organisms, as long as waste is not overloaded. This issue has to be brought up. Given animal nutrition, most upper aquatic food webs (beyond algae) are not P limited. They are limited by energy and carbon. Any time you add an organic compound, it stimulates secondary growth nearby if they can get enough of it. At Malawi, we did not measure increased secondary production (even under the cages), as the area was very well flushed. There is some additional organic production from feeding the fish and there will be some positive responses as a result as invertebrate growth and then fish growth. P alone is not going to affect everything around the cage. In Lake Malawi, we were unable to detect any effects of the cage operations except for some O_2 changes right around the cages. It was a well-ventilated and highly flushed situation. The cages acted as a refuge for wild fishes because nobody was allowed to fish around the cages.

Comment: Even if we have some nutrient enrichment as a result of cage aquaculture that can be detected, that does not necessarily mean that things have gone bad. These are very oligotrophic systems and the fishermen report that the fish are starving on Lake Huron. So we should not automatically assume that a detectible increase in P is a bad situation.

PRESENTATION OF WRITTEN REVIEW 1

Author: Duncan Boyd Ontario MOE

Presenter: Corina Busby

See Appendix 4 for full review.

Discussion

Response: There are a number of intricacies that are part and parcel with aquaculture. We do have to stick to our target of P loads, but hopefully we will get to BOD and COD in the future. Modelling is being worked on to understand the loads and the ability of P to remobilize. In the context of how much organic matter is being added to lakes, a report is in preparation on this issue. That report should be available to support future discussions. In terms of benthic alterations, there are other papers in the works on this topic as well.

The working paper was meant to stimulate discussion rather than being the final risk assessment. Some of that will be captured in the knowledge gaps.

Comment: The review suggests we need to clarify the scope of the paper, whether it is just or primarily the Great Lakes and if there is additional information whether we can elaborate on the other areas. Characterization of uncertainty around our knowledge should be incorporated in terms of the conclusions we reach. We may be able to characterize the level of risk in some summary statements but maybe the uncertainty around that assessment is high.

Q. MOE provided some internal reports with water column profiles and algal assessments. The comments on the assessment risks suggest that the report would benefit from outlining or disclosing that water quality has continually been ok and that ecosystem responses (e.g., Chl-a) are not being seen up- or downstream. Would it be useful to add that there is monitoring and we are not detecting upstream and downstream effects during the monitoring program? Should we use this additional material as support? Participants agreed to both.

Comment: The issues around aquaculture are not just P (e.g., O_2, decomposition, fish impacts). There needs to be something added at the start of the report and in the context of the science advisory report that indicates that although there are other issues that will be considered in the future, the focus of this assessment is P. Participants agreed.

DFO has established a formalized screening level risk assessment process for things like invasive species. You need the likelihood of something occurring and the level of impact if it occurred. We need to decide if we are going to go through a formal risk assessment. You have to lay out how you have evaluated the risk (e.g., Aquaculture P versus all other sources) and document how we established the level of risk. If we are not doing that then we should not call this a risk assessment.

Participants agreed that this is not a formal risk assessment so the title of the research document should be changed. We do want to characterize some of the risk associated with P inputs from freshwater aquaculture.

Comment: I was interested in the comments about adding other factors. Whether the P is flowing alone as an individual nutrient (soluble or dissolved) or whether it is combing with something else may completely change the overall dynamics of the fate of the P. Faeces are a complete package and not P alone. Just P stimulating algae bloom or P as complete package (with complex nutrients) is different from P alone and supports a different food chain. That is maybe why at ELA you can trigger massive algal blooms by adding P yet you can have an aquaculture farm for 40 years without seeing these blooms, because you have a food chain created behind it. We should not discount the fact that there are other components.

If there are factors influencing the P cycle we should recognize and characterize them in terms of biotic or abiotic factors.

Response: That can be worked into the report as there are some papers (e.g., Håkanson and Carlsson 1998) where they indicate aquaculture P is more directly routed into fish rather than going into algae without opening the scope of the paper to include everything. Participants agreed.

Maybe we need to do something on BOD load in the future. But it was noted yesterday that if you spread the manure you would have a much higher BOD load. I do not know that the BOD load from a pile that falls and stays in a very discrete small surface area below the cage is actually larger than a BOD load spread over the entire lake as suggested in the written review. We have to be careful of opening the scope of this.

Comment: I had some thoughts on the idea of risk assessment and what can be achieved or not in this review. The written review spoke to local level modelling. What the report addresses is nutrients coming from aquaculture cages in the context of Lake Huron and perhaps in the context of the North Channel. The intent is to put context into other loads. This is achievable. But the written review also suggests that if we treat an individual site as a point source then you would do the hydrodynamic modeling and determine where the plume will go and what kinds of concentrations would impinge on the shorelines. That is the kind of risk assessment that might be needed but which could not be done in this report. We might be able to scope out what would need to be done for a site that is considering expansion or for a new site. If we could scope out what that kind of local risk assessment would look like it might be useful.

Comment: I agree we may want to have a discussion somewhere about how to improve siting of aquaculture facilities but I do not think it is within the scope of this review. I like the idea of providing information on how would you do a local level risk assessment for P and think it would be a useful addition.

Comment: We need something that would be useful from this process, something that regulators can build on. The focus on P resulted from the IJC setting targets. We focused on P because it is set as targets for other regulatory regimes. However, it is a very holistic question based on the discussions so far. Not all P inputs should be considered equal. Large scale budgeting is difficult and may not be the best or appropriate way to be looking at P inputs. If these can be communicated in the paper, it would be useful. If we describe how to set up a local risk assessment, that would also be useful.

Response: If you start adding recommendations in the paper for background assessments you could be opening up a can of worms. Regulators have established their own requirements in their guidelines for new and expanding sites. It might be possible to provide additional input to what is already existing rather than setting up another whole framework for assessment prior to establishing a site.

Comment: We should stay away from site assessment. That is treading very close to policy. We do not give licences for aquaculture. I was thinking in terms of modelling, that large scale models might not be useful. Because there is nearshore more localized eutrophication, how might we model on a more site-specific basis to predict whether an aquaculture site would be contributing to that or not. It would be a progression of P modelling not a site assessment.

Comment: In the written review there is mention about the focus on Lake Huron and the mention of aquaculture in other areas. The report includes aquaculture across the country in several figures. If information is available about other areas it should be included. If there is no information from elsewhere this should be stated. It should be clear if the advice is meant to apply broadly or if it is only to apply to Ontario.

Comment: There is a need to bring in more commentary in the paper about how P risk from internal loading might be different in different locations. That would require more information about the two cage aquaculture sites in British Columbia, one of which has recently expanded substantially. We also have Saskatchewan. These should be added rather than restricting to Lake Huron. It will also be important to capture this in the science advisory report in terms of how widely this can be applied.

Comment: There was one short-lived site in Lake Ontario as well a number of years ago. With the temperature changes in lakes from global warming, there is potential for sites to establish in the bays in Lake Superior and elsewhere.

There was also a short-lived site in Lake Erie at Nanticoke. They were raising Rainbow Trout in the warm effluent from the power plant for commercial purposes although I do not think it is still operating.

PRESENTATION OF WRITTEN REVIEW 2

Author: M. Maccoux

Presenter: Corina Busby

See Appendix 5 for full review.

Discussion

Response: St. Marys River inputs are incorporated in the “directly monitored municipal loads” from Sault Ste. Marie. Other towns that were not monitored are not included in municipal loads.

Comment: The comparisons with P loading from aquaculture, agriculture and sewage plants needs to put emphasis on the TP related to these other sources. From the public’s perspective, when you say that aquaculture is the same as the city of Sudbury’s discharge there are other connotations beyond P waste, such as faecal coliforms. You really have to stress this is just the P loading. This again brings up the comments from earlier that not all P is equal. The packaging makes a difference and this is needed for context.

Q. Are Dolan and Chapra’s (2012a, 2012b) numbers right about the amount of P loading to the North Channel? There are a lot of assumptions.

A. What we did not bring out well enough is the uncertainty in P loading numbers. They made assumptions in some places about what portion of a tributary went into the North Channel versus what did not. That could have a substantial impact on the actual calculation of the P load going in to the North Channel. I think we need to discuss this in more detail. We need to acknowledge where there is uncertainty.

Comment: It is alarming to know that the monitoring program is so inconsistent that there are some years when it was not monitored. There were 3 of 11 monitored tributaries extrapolated across the system and there were years amongst those three rivers that did not get sampled. Some sites were eliminated in the P budget too because these tributaries, were intermittently monitored.

Response: It is important that the P loading estimates be discussed. If regulators start setting a ceiling on how much more P loading can be allowed in the North Channel from aquaculture or some other activity, it will depend on a reliable estimate of the P loading going in, whether enough tributaries are monitored, and if they monitored frequently enough. Is there accurate estimation of where tributaries load P in the North Channel? For a whole lake budget, it does not matter so much where P is loaded. For the purposes of setting activity limits, it does matter how accurate those P loading sites are and this should be discussed.

Comment: It is surprising that municipal waste water would be on the same level as aquaculture.

Response: Part of the reason monitoring is low is because the population along the north shore is low. This does not include any of the reservations. The loading is only from three cities. P is also measured through the pipe of treatment plants but not from overflow events.

Comment: One of the ones that is not included in there is Sudbury, which actually discharges through the Vermillion and Spanish River systems to the North Channel. It is 100 km upstream but is part of the drainage basin.

Response: That needs to be included otherwise it is misleading when you are making the comparison. You need to say what is missing from the municipal loads and that small municipalities are not included.

Comment: You need to clarify sewage is what has gone through secondary treatment.

OPEN DISCUSSION OF WORKING PAPER AND PRESENTATIONS

One of the participants indicated that the working paper is fine and all the comments presented will improve it. They are concerned about the other problems with P which are beyond the scope of the report. These include the bigger scale things going on in the Great Lakes that still need to be introduced in the paper. Eutrophication from P is not a problem from aquaculture but there is a problem with organic matter coming from the cages from excess feed and faecal material. If the focus is so narrow it may not make people aware of some of the important other issues that are of concern.

How would we best do this in the structure of the paper? Should it be added at the beginning or the end? We could add some discussion of the larger context of aquaculture impacts and acknowledge that their concern is related to fish escapes, the rather substantial BOD load. Provide general information about those and then add because of the historical eutrophication issues in the Great Lakes we are focussing on P.

There are two things that need to be brought up in the introduction so people know what to expect:

1. Other impacts of aquaculture, BOD, escapees, etc.
2. Mentioned of the other things going on with P that you are not dealing with. In the Great Lakes, Bill [Taylor] summarized those issues. In other lakes maybe we do not know. You need to put the P questions in context. There are some huge scale issues with P and some we understand and some we do not.

Another participant indicated that the paper did a really good job of discussing P with respect to cage culture especially the work on P cycling through the fish, through the feed and into the environment. It needs an expanded section on monitoring included in paper. From a public perspective they do not know that these farms have been monitored since their inception and continue to be monitored this relates to the impacts that are being discussed and how aquaculture is having a minimal impact. The first cages were established in 1982 and there was slow growth in the industry. There is a review done for EC in 2001 that reviews the history of the industry and monitoring results to 1999 or 2000. There is a paper copy that can be provided. Subsequent to the incident of O_2 depletion in 1988–1999 in the LaCloche Channel, there were significant studies by MOE in Ontario doing extensive water quality characterization around cages which resulted in one or two papers on a comprehensive look at broader issues. From that it got narrowed down to TP and dissolved O_2, the things requiring monitoring. That was incorporated into the licences. There is a brief section in the report saying that in Ontario these are the requirements. That work is reported annually. These monitoring data are around as well. You have to show that these are all the potentials impacts and as well as the work done to monitor them.

How should we deal with this in the report? We could lay out the current monitoring program. We could add the Clerk et al. (2004) to indicate there have not been historical exceedances. We should recognize that the way the monitoring is done is to look for evidence of whether you have exceeded a particular value. I am not sure we want to go through the history of the LaCloche Channel (O_2 depletion) as it sets off alarm bell. The important thing is that we learned you should not be putting sites in those types of areas. Can we just put in information on the monitoring and an overview of the results rather than full history?

That approach would be acceptable but that is only from the Ontario perspective although Ontario has the bulk of the operations. What about Lake Diefenbaker?

There is a lot of monitoring for Diefenbaker as it has been done by DFO Science. The monitoring there is more extensive than in Ontario. The licensing structure is different there as well. Should we be including similar data for Saskatchewan and British Columbia given we have indicated the scope of the report should acknowledged that there is aquaculture in Saskatchewan and British Columbia?

We need to recognize if there have been monitoring programs in place and capture this for sure. Ideally we reference existing reports and their conclusions and identify any exceedances. This addresses objective four and should tie in monitoring in all areas. Ideally you would not need to dig up raw data and undertake analyses. Hopefully water quality data are available and you can reference it. You may need to find out the state of these data. Just state what monitoring has been undertaken and that they have been operating within conditions of licenses.

Some of this might be captured in the knowledge gaps and maybe there should be a recommendation that those data get centrally reported so that we can begin to have a comprehensive Canadian picture of results of monitoring. Most of the data is submitted to MOE annually but it is not publically available. So we should identify what current monitoring plans look like, generally what they have found and whether there have been exceedances. We could then point out that making everything public would be a good step forward including for the industry.

DFO has a Sustainable Aquaculture Initiative. When it was being developed, we proposed a reporting system. Maybe in this report we should add a paragraph or two about how monitoring could be done to increase the certainty of the estimates of waste output and how it is done in other industries.

It would be good to mention the Sustainable Aquaculture Initiative section on reporting. Looking at the report it appears that placement of sites is extremely important for mitigating impacts from the farms. Can we build more into the directions about siting? Is there an ability to understand hydrological processes so you would know if the site flushes out to the deep water? Can information be added around siting to give more directions? Details about the First Nation's aquaculture sites needed to be worded carefully in the report.

The wording in the report about First Nation's sites needs to be changed. It should say they do not obtain Provincial Licences. They get a band and council license before putting a site in the water. However, what we want to bring up in the report is that there is a risk in terms of the ability to manage cumulative impact from farms because these First Nation's licensed sites do not report to anyone except the band and council how many fish, cages, feed they have in the water which makes it relatively difficult to understand what kind of P load they may be adding into an area which impacts the amount of freeboard there is for Provincially licensed aquaculture sites. This is increasingly becoming a problem as in the last year alone the capacity (number of cages) of the Ontario Production has gone up rapidly. The capacity of Ontario's entire (including First Nations) industry has increased by 17%. Of the 17% increase, only 25% of it is reported. It is a management risk in the future and over the long term. C&A is the only region that currently has this issue with First Nation's sites.

Adding to that are the newly proposed aquaculture regulations under Section 35 of the *Fisheries Act*. It could put the First Nations aquaculture sites out of compliance with the *Fisheries Act*. The new regulations will require monitoring and reporting so this is another risk or gap.

We discussed flushing yesterday and it is an important concept to include. This could be tied to the local risk assessment. This would be a way to mitigate with what we should know about local areas. If you are in the business of a site assessment you would want to know the footprint which involves knowing the hydrodynamics in the area, what would be the expected concentration of P around the area, how often this area sees 2 µg SRP/L in the water impinging on that rocky shoreline, which way is the plume going to go, who might be affected, how quickly is it advected offshore. That kind of hydrodynamics study combined with an ecological model that would include how fast phosphate is assimilated would be part of the site assessment to feed into the decision if it is an acceptable site or whether the site could expand. That is the sort of information that would feed into something like a Cladophoran growth model. Such models exist and would indicate how much more *Cladophora* will this shore grow with a fish farm.

We just need to be careful not to provide advice on where to site or not to site as this is a management or policy decision. The information does fit under objective 4.

So do we indicate there is merit in putting sites in areas with higher flushing with higher dispersion to minimize local loading of P or would we rather have it localized?

Given the situation in Lake Huron we could say that dilution is the solution to pollution since P in the offshore is so low. You just have to be very specific throughout if you are talking about the Great Lakes or elsewhere. We could work in prediction of effects and the fact that the large scale models might miss the localized nearshore effects in the Great Lakes area. We might need to move to the nearshore mixing models and modelling the small area.

There is some wording on the recommendations for monitoring put out by MOE in 2001 around siting. It indicates avoiding the type 1 situation (e.g., LaCloche Channel) based on a dissolved O_2 concern not TP.

Knowing that Type 1 is insufficient is important. A tool might include *Cladophora* growth and circulation models, assessing the footprint in terms of how far it goes or how quickly it assimilates, plume movement and speed combined into a cohesive model.

Currently in the licensing program in Ontario there is a recommendation for a well flushed site but there are no numbers around it. In marine jurisdictions, the proponent has to provide inputs to a dispersion model and that model is used to predict where the solid load goes. A way to potentially mitigate is that this information is also used in a model to predict dispersion of dissolved load. Ontario does not require this. None of that modelling is currently required in freshwater facilities.

The new Aquaculture Activity Regulations (AAR) for marine aquaculture does require that for new sites. We will, over the next number of years, be trying to set some monitoring standards and criteria for freshwater. It would be nice to be starting down the path of recommending something that is similar or consistent with this for freshwater.

The challenge I see in all of this is the application in areas where we do not have this information (e.g., Lake Diefenbaker, smaller reservoirs). It would take a lot of structure, knowledge and know how to collect that kind of data to make informed decisions.

There are two mass balance models for aquaculture in the paper, the ELA work and Lake Wolsey. For the ELA work we have the published reports. Have we captured enough of an understanding of potential applicability to the Great Lakes systems? Are there considerations or assumptions that need to be stated?

The mass balance modelling for ELA is tight. They are useful for understanding where things are ending up. They are not necessarily useful for managing aquaculture. I am not sure you want to continually do mass balances for other sites. They can be very expensive and it depends on how tight you need them to be. In some systems like Lake Wolsey it was a challenge.

The mass balances serves as the framework: Have we captured everything? Are they balancing? When it is balancing is there internal loading? Is there going to be trophic changes and in what forms? For an embayment in Lake Huron area with exchange between it and the larger waterbody, how much P is going to the nearshore and how much is going out? In some of our larger budgets settling velocities are increased to compensate for the nearshore effect. Is that really what is happening? Is the mass balance leading us to believe that dilution is going to be playing a larger role and it is not a nearshore effect? You would need fairly conservative limits if you were using a mass balance approach for general management.

In the Lake Wolsey description, what further work is needed to describe the gaps? Do we need to elaborate more on that? There were challenges with the study and there are questions about some of the assumptions and calculations, and there is uncertainty in what is reported. How do we characterize the uncertainty?

We need to be more critical in discussion of that budget. There were technical issues, in terms of the frequency and how inputs were quantified. We need to mention the limitations. We can point out the gaping hole in P budget. The budget comes from a thesis which has not yet been published.

MOE is working within that framework. They suggest 11 µg/L with an upper target of 18 µg/L with their license agreement. They are working within an appropriate window. For Lake Wolsey the provincial water quality objective, an interim objective, is 20 µg/L not 10 µg/L (10 µg/L is for the protection of oligotrophic or sensitive areas). When the cage culture was established in Lake Wolsey in 1986 it was called a level 2 lake, as springtime TP was in the 15–16 µg/L range. It has decreased since then and is now <10 µg/L. Under the license it is still held to 18.5 µg/L. Lake Wolsey is an oddball in the whole group of farms from the North Channel perspective so is there merit in including it? Is it used for the mass balance and not as an example of inputs?

It was used because it is one of very few attempts at mass balancing in aquaculture. We probably could acknowledge that it is unusual in terms of aquaculture that occurs in the area. But because it is a much more enclosed basin it lends itself better for mass balancing.

There is also mass balance literature from Europe that could be included although the farms are often sited in challenging locations, have had fouling at times and they have differences in their industry because of sources of feed from what we have in Canada. Should they be included?

We have to distinguish studies where people have mass balanced farms versus mass balancing the ecosystem where a farm occurs. They are very different things. There are a lot of papers on mass balancing farms, many of which are marine. When you are talking about the P cycle including aquaculture you need to balance the ecosystem to the growth limiting nutrients.

It is useful to use these lake mass balances, maybe not so much in the North Channel context, to apply to the other lakes in Canada. If someone wanted to put an aquaculture facility on a small lake I think it is the way to go. It is the way Ontario decides lakeshore capacity, how many cottages you can put on a lake. You can predict the effects on the TP based on an estimate of the point source addition. Decisions can then be made based on what is acceptable or not. The ELA study is a very good study. Lake Wolsey is difficult and not as tight because one is a hard water lake and one is a soft water lake they are both valuable. It would be nice to get some more mass balances where aquaculture is the source. It is the best way to apply decision making to small lakes.

The mass balance is the starting point. We still do not have good P response model so you might know the loads but you would want to know how much P ends up in the epilimnion and that is a gap.

Information was provided on the significant reductions from the 1980s to 2000s. I want to understand that context a bit more. Was it in 2000? Is there information available, additional context for 2000–2014, have there been further reductions that we could characterize?

This depends on the context. For the global salmonid aquaculture overview, yes there have been improvements. For Ontario there has not been any change since 2000. There have been some changes but they cancel out because of the use of poultry and feather meals. The level of soy and corn gluten meal has not changed much. The level of fish meal has been reduced and they have been compensated by something with very similar elemental composition. Feed formulation evolved in the early 2000s with introduction of lower phosphorus diet (e.g., Skretting Orient LP) for land-based fish culture operations (feeding of relative small fish for stocking or food purpose). These feeds are formulated with highly digestible fish meal and animal protein ingredients (e.g., blood meal, low ash poultry by-products meal) with lower mineral content that allowed reduction in total P level of the feeds, higher digestible nutrient densities and better feed efficiency. A small number of land-based farms (mostly in Quebec) having to operate under very strict licensing conditions that have been forced to adopt these low P feeds. However, demand/volume has been limited due to the very limited size of the market (very small production volume of fish produced by land-based fish operations).

It would be useful to address what drove the pre-2000 and post-2000 changes to the industry.

The comparison was between the 1980s versus the early 2000s. There was not a change that occurred in 2000, the changes have been progressive. Over the past three decades, there have been improvements made to feed formulations used by the majority of cage culture operations in Ontario (e.g., Martin Mills Profishent). However, overall changes made to these feeds in recent years have been relatively limited (at least less important than those made to hatchery fish feed formulations) mainly due to economic reasons (high cost of producing feed with lower P levels and greater risk of having fish develop nutritional deficiencies).

In the larger context there have been changes even since 2013 with a significant shift in the salmon feed in Norway and Scotland. There has been a shift in the diet formulation because of the introduction of new additives.

Participants discussed the information presented on fish feed and whether it should be included in the research document and what parts were needed as context to understand the rest of the report. The history presented was useful. The key piece we need in terms of the context is the P in faeces. It is important for people to understand it is possible to estimate the P in faeces and the estimates are very good. If you are going to do this the information on production and feed is necessary in the future. The nutritional model was not dealt with in detail in the report or how superior it is to sampling. You always need samples but there are biases in the sampling.

A participant noted that they appreciated how well the model worked. There is value in knowing that the start and end samples are needed but the model can predict in-between. The farms still have to report on a relatively fine-scale feed usage, water temperature, inventories and send in carcasses.

In the working paper there is a lot of mixing between what comes out from farm and what happens to the waste. For example, what happens with the leaching of P from the faeces and feed and the different rates. The report should be stronger in laying out how much the farm is putting out, the independent variable, the waste output from the farm. Whatever happens to the limnological waste components should be addressed as part of the biological transformation (leaching, etc.).

One thing that was not covered in the bioenergetics and aquaculture waste presentation but was included in the other presentation was the estimate of the apatite organic P coming out from the feed. This is one use of the model that has been validated. Our goal was estimating the digestible P level in the feed. You can flip that around to look at the waste output. It does not mean that the apatite P that came in passed across the stomach, intestine and was solubilized, neutralized by the pancreas or intestinal secretions. The model is suggesting that apatite is solubilized and precipitates with calcium and becomes a dibasic calcium phosphate. There is 60% of the apatite P is digestible 40% is not and what is coming out the other end may be very different from what model is predicting. Obviously the phytate P is zero percent digestible but the rest is taken care of after that if it is solubilized.

This was not included as it takes preliminary results from the sediment analysis. Fe bound (redox bound) P is the most rapidly mobilized and sulphate reduction helps to facilitate it. In the literature there are ways to digest phytate. The phytate in solids is still very mobile but the mobility of the other forms of P were not discussed. Is it part of a risk assessment?

As a source of P, it was clear from the bioenergetics and aquaculture waste presentation that we understand it better than any other potential source of P (e.g., cottage, industry, sewage treatment plant). It is a well-defined and characterized effluent. There are still some issues about bioavailability. Phytate is not well understood. It is apparently available and when it gets in the environment it is hydrolyzed by free-living bacteria. The other issue is apatite and in the environment it is not well understood. It could be identified as a knowledge gap. Trout digest and reduce apatite by pH in their gut. I am guessing that when it gets out in environment in relatively high quality faeces and if there is still apatite in them it gets further reworked and becomes available. So I think the simple story is that all P in aquaculture waste is available. If it is not, in the grand scheme of things we are talking small differences. I am not sure from a management point of view it is worth chasing that down.

The faeces settle very rapidly into a pile and based on the work to-date it does not seem to come out from the pile. The physical characteristics and what happens to the pile of manure is Important.

In the Great Lakes you have an aquaculture cage in 20 m of water, and there is a pile under the cage, that material is probably ultimately going to get transported if it is a high energy site and not an embayment. Whereas in a small lake 20 m of the cage depth is in the hypolimnion and it may stay there forever without being mobilized.

That is the heart of the paper. That faeces particle will settle into a pile and will either be remobilize or stay there and become permanently buried.

More research is needed. In terms of transport, all farms but one in Ontario were sampled. When you look at P in the sediment around farms it is elevated above background levels around cages but it is only elevated to about 30 m away from the cages. The material falls very rapidly. The movement of the cages may be why it is elevated out to 30 m. We set a large number of sediment traps around a farm (over 100 in a random pattern). It is very clearly an exponential decline off the edge of the cages. It does not disperse in the water column very far. And when you look at the sediment chemistry (longer term accumulation) we are still not seeing a lot of evidence that it is being moved. One commercial fish farm site in Ontario has higher water currents and you can see the pile is offset a bit but it is still not spreading long distances.

A useful exercise which would further our knowledge of this is to take that footprint and calculate how much P is in pile. Then compare that to the age of the farm. Is it still all there? You know what comes down. Is there a 10 or 20 year accumulation of P still there? If there is not you would be able to estimate a residence time for the P.

Currently we typically only take surface sediment samples (top 2 cm). At ELA it is a little different. Up until this year we went out each winter and characterized the pile by taking slices all the way down and essentially mass balancing the pile to see how long it was going to take for it to go. We could think about including some of that information in this report if it would be helpful.

This information needs to be presented in perspective. An elevated P concentration, up to 30 m from the cage can be taken out of context and this is what gets picked up. It is elevated but if it is compared to the area of the bay it gives a better perspective for the public.

I do not think that this sort of information is currently included in the report about how far away from the farm we see sediment elevated P. Is it important? Participants agreed that it was important to add. There are deeper cores at ELA. There are a few cores in Diefenbaker but they are not around the farms. This should also be identified as a knowledge gap. Such cores could be used to compare availability from burial versus dispersion.

There is a report in the inland water special issue where sediment cores from Lake Winnipeg, Hamilton Harbour and Lake Simcoe are compared for release rates and internal loading of P. The conclusions were basically that all three systems are different. Cores would be needed in a variety of places to see if the processes were different given the different sediment types especially between Prairie and Shield.

For aquaculture farms it is within and away from the piles of manure irrespective of the areas of the lake or the sediment. It would help with a P budget for remobilization from the waste pile.

Has anyone looked at the old North Wind site that was decommissioned? What happened to the leftover manure there?

It has been sampled several times but how available the data are is unknown but we can check. We had proposed research to check several sites but it was not funded. The modelling of P in Lake 375 is being modelled and all the downcore data will be included in that modelling.

There has been discussion around spreading the manure (dispersal) versus keeping it in a pile (buried) so that is contained. Is one option better than the other? There is a recommendation related to high flushing areas. What if we have research that shows it is better to keep it in a pile and when it is dispersed back into the environment it is going directly into an enhanced fisheries food chain? If that were the conclusion, we would have a very different management approach or mitigation or even select sites differently because we want to contain the piles.

To some extent that depends on the size of the lakes but right now we do not have sites in Ontario that are in areas energetic enough to disperse the piles. The only way we could have dispersal of the material is to adopt a fallowing approach at farms. This is done in marine environment where they operate for a growth cycle at a specific anchorage after which they check their sediments. There are limits on sulphide concentrations, etc. If they have exceeded the limits indicating a carbon load still on the bottom that the assimilation is not keeping up with then they cannot restock the site and they move to a different site. You cannot move back to the first site until it is back below a threshold. We do not have that kind of system in Ontario. The sites there have operated for several decades on a specific location. That kind of approach has been discussed and some farmers were amenable to trying the practice at same site but we do not have science to support it (i.e., how long would you have to fallow for, what are the kind of bio or geochemical indicators you might use to indicate whether it is time to fallow or it is ok to restock on the site. It is a big Science gap. If there was concern about BOD it would be better not to spread the pile. It is also complicated because spreading the pile requires visible aquaculture structures showing up in more places (i.e., multiple anchorages) with a larger footprint which impacts acceptability.

If the reports can identify benefits to keeping the pile piled up or contained this should be stated. Then, when making management decisions or communicating to the public, it would help to be able to say that farms are loading some P but we can see and understand that it is staying right here and when it does get released it is does so over a number of years and is incorporated into the food web.

You are still going to end up with a problem with MOE’s mandate to not allow toxic sediments. From a P or BOD perspective you can say perhaps it is better to contain the pile to a smaller area. The only way to do that is to allow an accumulation of material. It will reach a point where benthic life is not interested in inhabiting the area and that triggers the idea that you have “toxic” sediment. So the advice is difficult to provide. It has been discussed and there are solutions (e.g., do not sample directly under the cages but go 10 m out). What is the best way to manage P from aquaculture? Is it to flush and spread it around and put it into the larger loading system or is it to contain it?

That is the goal in the risk assessment when we talk about designing a hydrodynamic model which will both assess whether a site is going to have P remobilization and aerobic or anaerobic decomposition. So right now you have two different goals, if you do not want P to be released, then you want to restrict anaerobic conditions. If conditions may become anaerobic at a site, then spatially you want to keep organic matter deposition small, so that the probability of internal P loading is small. If it is going to be aerobic decomposition, you are going to have P binding with high Redox potentials and other things so if you have the right Fe availability you could probably spread the organic matter waste around and encourage aerobic decomposition and removal of organic matter and P will remain sequestered in the sediments. Should the aquaculture site ever go anoxic and you have just spread organic matter across an enormous surface area, you will have P in abundance ready to be released. You are giving yourself a situation of internal P loading that is still site specific.

You would hope that you have an appropriate hydrodynamics model to know that you are dealing with a small embayment. Then the science advice is fine and both situations are plausible, aerobic and anaerobic conditions. If you need to assess BOD in future, you need to consider P first. You are going to have a bigger BOD problem if you are putting P back into that water column and algae are blooming. There are two things to consider, BOD and P release here. The same thing two issues need to be addressed when going to offshore aquaculture. How will P release be in deepwater? You do not want a deepwater anoxic pit like Lake Erie where climate warming is starting to allow for deepwater anoxia to be persistent. It needs to be within the context of a model.

DEVELOPMENT OF SCIENCE ADVISORY REPORT (SAR)

The report, and the advice contained in it, is directed to our client Fisheries and Aquaculture Management. The report should be understandable by a broad suite of people who might be interested in the topic.

Sections of the science advisory report were developed by all participants. The context and introduction sections used the terms of reference as a starting point. The objectives from the meeting were used as the framework for the assessment section of the report. All changes were made directly to the report. Following the meeting the report was completed with material from the research document then redistributed to participants for their review.

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APPENDIX 1. TERMS OF REFERENCE

Freshwater Cage Aquaculture: Ecosystems Impacts From Dissolved And Particulate Waste Phosphorus

Regional Peer Review – Central and Arctic Region

June 17-19, 2014
Winnipeg, MB

Co-Chairs: Jay Parsons and Corina Busby

Context

Organic waste material from open net pen finfish aquaculture operations in freshwaters is released directly into aquatic environments. These wastes may be in the form of particulate matter (e.g., uneaten feed and feces) which typically settle to the benthic environment beneath and near the cage arrays, or they may be in the form of dissolved wastes (e.g., carbon, nitrogen, phosphorus released from feed, feces and metabolic excretions of fish) which are released directly into the water column. Fish size, water temperature and aquaculture practices (e.g., feed composition, ration, and feeding methods) are some of the factors that can affect the level of waste production. The release of phosphorus in the freshwater environment is of particular concern because it is generally the most limiting nutrient for plant growth in freshwater ecosystems. Excessive inputs of phosphorus into freshwater can lead to increased algal growth and result in decreased oxygen concentrations.

There has been little research into the cycling of phosphorus between aquaculture waste accumulations and the water column and it is not known what proportion of phosphorus released from aquaculture operations is will eventually be available for primary production. Research at the Experimental Lakes Area was undertaken to determine the ecological consequences of freshwater cage aquaculture by evaluating how phosphorus, nitrogen and carbon from aquaculture facilities cycle in the freshwater environment.

The lack of tested tools for predictive modelling and a thorough understanding of the long term fate of phosphorus released from freshwater aquaculture operations generate apprehension for the public and industry about potential environmental damage and create reliance on a precautionary rather than a science-based approach to regulation of the industry. A sound scientific understanding of potential effects and scale of phosphorous release from aquaculture operations in freshwater is required if the industry is to grow in an environmentally sustainable fashion.

Based on a review of the current scientific knowledge of the release of phosphorous (dissolved and particulate) from freshwater cage aquaculture operations, this scientific review process will aim to provide advice on the potential impacts that might be associated with phosphorous enrichment by the freshwater cage aquaculture industry.

Objectives

1. Review importance of phosphorus to the freshwater environment and in particular those Canadian ecosystems where cage aquaculture is prevalent.
2. Review what is known of the type and amounts of phosphorus inputs from freshwater cage farms, including a review of estimation methods, and place inputs in context of other natural and anthropogenic sources.

3. Review what is known of cycling and fate of the chemical forms of in the freshwater environment, focussing on those chemical forms of phosphorus that are associated with cage aquaculture activities.
4. Review what is known of methods to predict, manage and mitigate effects of cage aquaculture phosphorus in the freshwater environment.
5. Assess risk of phosphorus inputs from the cage aquaculture industry to Canadian freshwater environments.
6. Identify important knowledge gaps that affect our ability to assess the risk that phosphorus release from the cage aquaculture industry poses to freshwater environments.

Expected Publications

- Science Advisory Report
- Proceedings
- Research Document

Participation

- Fisheries and Oceans Canada (DFO) (Ecosystems and Oceans Science, and Ecosystems and Fisheries Management sectors)
- Environment Canada
- Ontario Ministry of the Environment
- Academia
- Aquaculture Industry
- Other invited experts

APPENDIX 2. MEETING PARTICIPANTS

Name	Affiliation
Chris Baron	Fisheries and Oceans, Science
Duncan Boyd[†]	Ontario Ministry of Environment
Dr. Dominique Bureau	University of Guelph
Corina Busby (Co-Chair)	Fisheries and Oceans, Science
Dr. Stephanie Guildford	University of Minnesota Duluth, Emeritus
Dr. Bob Hecky[‡]	University of Minnesota Duluth, Emeritus
Dr. Ray Hesslein[‡]	Fisheries and Oceans, Science, Emeritus
Dr. Todd Howell[†]	Ontario Ministry of Environment
Janice Linquist	N.A.R. Environmental Consultants Inc.
Matt Maccoux[†]	Milwaukee Metropolitan Sewerage District
Kathleen Martin	Fisheries and Oceans, Science
Dr. Rebecca North	University of Saskatchewan
Dr. Megan Otu	Fisheries and Oceans, Science
Dr. Jay Parsons (Co-Chair)	Fisheries and Oceans, Science
Adrienne Paylor	Fisheries and Oceans, Fisheries and Aquaculture Management
Dr. Cheryl Podemski	Fisheries and Oceans, Science
Dr. Patricia Ramlal	Fisheries and Oceans, Science
Dr. Bill Taylor	University of Waterloo, Emeritus

[†] Did not attend, review comments provided for consideration during the meeting
[‡] Attended June 17, 2014 only

APPENDIX 3. AGENDA

Day 1 – Tuesday, June 17th, 2014

Presentation of Working Paper and Formal Reviews

09:00–09:15	Welcome and Introductions (Jay Parsons (JP) / Corina Busby (CB))
09:15–09:30	CSAS Overview and Meeting Procedures (Kathleen Martin)
09:30–09:45	Review of draft Agenda (JP/CB)
09:45–10:00	Review Terms of Reference (JP/CB)
10:00–10:45	Presentation of Working Paper: **Estimation and Assessment of the Risk of Phosphorus Inputs from the Cage Aquaculture Industry to Canadian Freshwater Environments** (Authors: Dr. Megan Otu, Dr. Cheryl Podemski, Dr. Dominique Bureau)
10:45–11:05	***Health Break***
11:05–11:35	Presentation of bioenergetics and aquaculture waste output (Dr. Dom Bureau)
11:35–11:50	Working Paper feedback (JP/CB)
11:50–1:00	***Lunch (on own)***
1:00–1:15	Presentation of Review (Dr. Ray Hesslein)
1:15–1:30	Author Response
1:30–2:00	Presentation of Review (Dr. Bob Hecky)
2:00–2:15	Author Response
2:15–2:45	Presentation of Review (Dr. Rebecca North)
2:45–3:00	Author Response
3:00–3:20	***Health Break***
3:20–3:35	Presentation of Review (Dr. Bill Taylor)
3:35–4:45	Author Response and Discussion
4:45	Day 1 – Adjournment (JP/CB)

Day 2 – Wednesday, June 18th, 2014

Discussion and Development of Science Advisory Report (SAR)

9:00–9:30	Review of Day 1 (JP/CB)
9:30–10:00	Presentation of Written Review by Ontario MOE (JP/CB)
10:00–10:30	Presentation of any additional written reviews received (JP/CB)
10:30–10:50	***Health Break***
10:50–12:00	Facilitated Discussion of Working Paper (JP/CB)
12:00–1:15	***Lunch (on own)***
1:15–3:00	Facilitated Discussion of Working Paper (JP/CB)
3:00–3:20	***Health Break***
3:20–4:35	Development of SAR (JP/CB)
4:35–4:50	Day 2 – Summary and Adjournment (JP/CB)

Day 3 – Thursday, June 19th, 2014

Development of Science Advisory Report (SAR)

9:00–9:30	Review of Day 2 (JP/CB)
9:30–10:30	Development of SAR (JP/CB)
10:30–10:50	***Health Break***
10:50–12:00	Development of SAR (JP/CB)
12:00–1:15	***Lunch (Public Service BBQ in Cafeteria)***
1:15–3:00	Development of SAR (JP/CB)
3:00–3:20	***Health Break***
3:20–4:20	Development of SAR (JP/CB)
4:20–4:30	Day 3 – Summary and Adjournment (JP/CB)

APPENDIX 4. INVITED WRITTEN COMMENTS – D. BOYD

Review of "Estimation and Assessment of the Risk of Phosphorus Inputs from the Cage Aquaculture Industry to Canadian Freshwater Environments"

Thank you for the opportunity to review the draft working paper. Although the current draft is still a work in progress (I have not worried about the smattering of typographical errors) it contains much useful information and has great potential to be used as an up-to-date source of information for all interested parties including industry operators, regulators, and the public.

I have provided some general comments pertaining to the purpose, scope and structure of the paper followed by a few specific, page-by-page comments. I would have liked to check references and independently verify some of the statements contained in the draft, but time did not permit this so I will have to provide supplementary comments when the opportunity arises if these would still be helpful.

GENERAL COMMENTS

Who is the intended audience and what are the primary objectives?

After reading the paper I am not entirely clear as to its intended audience or purpose. There is much emphasis on evaluating the environmental risks associated with the relatively large commercial operations in the Great Lakes, specifically Lake Huron/North Channel, but there are also hints that the intent is to include a broader evaluation of risk associated with all freshwater cage aquaculture sites across Canada. The Great Lakes context is unlike any other freshwater setting in terms of size, trophic status, and sensitivity so if the goal is to cover all freshwater settings it might be worth separating (re-formatting) the discussion to clarify the differing approaches to risk assessment that would be entailed. Environmental risks in reservoirs, or small lakes, will not resemble those in deep offshore settings in the North Channel and will dictate a different set of potential concerns and approaches. This would make it easier for potential audiences to find the material that is of the greatest relevance to their situation.

The Introduction states that open cage aquaculture discharges waste containing soluble and particulate P directly into aquatic environments and that this can increase primary productivity, change algal community composition, enhance fisheries, cause nuisance algal production, and lead to hypolimnetic hypoxia and fish kills. It goes on to state that the effects of P from freshwater aquaculture are not well studied and that a sound scientific review of the potential effects and scale of P released by freshwater aquaculture is required to assess environmental risks. Six objectives are listed of which five relate to a review of the current science or to the identification knowledge gaps that affect the ability to assess the risk of P release from aquaculture on freshwater environments. These are all in keeping with the broad premise of this as a state-of-the-science review paper that identifies a need to integrate limnology, nutrition and hydrodynamics and enumerates a lengthy list of research questions (regarding P bioavailability, remobilization, loadings, remediation, and modelling for carrying capacity) that have yet to be answered in sufficient detail to adequately assess the cycling and fate of P inputs from cage aquaculture waste.

All these serve to highlight the other stated objective which, in keeping with the title of the paper, is to actually assess the risk of P inputs from cage aquaculture to Canadian freshwater environments. This is a much more ambitious undertaking that will be of prime interest to a broad spectrum of stakeholders including regulators, operators, and the public. If the title of the paper is to remain as it is, I would suggest that the risk assessment section will need to be considerably expanded and developed. There is a well-developed literature associated with ecological risk assessment (ERA) protocols and the progression from qualitative screening-level assessments through fully quantitative assessments and I think it is reasonable to suppose that the title of the working paper will generate some expectation that an ERA framework is being followed. An alternative would be to stick to the scientific review and research recommendation objectives that dominate the discussion and develop the risk assessment separately.

My final observation on the intended audience pertains to the five pages (8–12) dedicated to the discussion on sources of P and abiotic and biotic factors dictating P concentrations in lakes. Since a specialist audience will already be aware of most of the content in these pages, one assumes that the intent is to convey the complexity of the P cycle to a general audience. If this is the case, then the discussion on pages 10 and supplies an unnecessary level of detail. This contrasts disproportionately with the subsequent three paragraphs on predicting effects of P on lake ecosystems and three paragraphs regarding use of mass balance models. Assuming a general audience, a more balanced summary would be achieved by abbreviating the discussion on pages 8–12 to a similar level of detail as contained on page 13 and 14.

Is this a Risk Assessment or literature review?

The section containing the assessment of risk is only five paragraphs (including one primarily concerned with the potential economic burdens imposed by regulatory monitoring requirements) and starts by concluding that *"…today's aquaculture industry presents little risk"* related to eutrophication and anoxia associated with P from aquaculture waste. It goes on to assert that *"In Ontario the risks of eutrophication are minimized by water and sediment quality [monitoring] conditions attached to licence agreements"* and that although the freshwater industry is currently sustainable in Lake Huron, future expansion will require consideration of P loadings and location.

These may all be defensible statements, but as presented they are not explicitly linked to the preceding scientific review and are contradicted by the subsequent lengthy exposition of knowledge gaps. Either the paper needs to clarify that the need to fill knowledge gaps through additional research is primarily driven by the situation *outside* Ontario where the risk is not yet adequately determined, or the confident conclusion of low risk needs to be qualified and the need for the various research projects needs to be explained more fully.

To be more specific, if this paper intends to function as a screening level risk assessment, the review of the current science and regulatory process needs to be supplemented by documenting explicitly that water quality standards are being met and ecosystem problems are absent at all locations. If this then supports a confident determination that the risk of eutrophication and anoxia related to waste from cage aquaculture in Ontario is low, there appears to be little incentive for environmental managers in Ontario to support research to fill the numerous and specific knowledge gaps catalogued in the final section.

Why limit the scope to P-related Effects?

It is apparent that the authors were charged with focussing on phosphorus (P) cycling and fate and eutrophication issues, but the utility of the working paper would be greatly increased if the scope were expanded to include other factors of equal or greater significance when assessing the environmental impacts of cage aquaculture in oligotrophic environments such as Lake Huron/North Channel. For example, the primary concern with P load sedimentation outlined in the paper appears to be related to remobilization and release to overlying waters, presumably as a possible factor in driving late season algal blooms following fall turnover. A more direct concern that this paper overlooks is the influence of high accumulations of organically enriched waste material on benthic life. By choosing to focus almost entirely on the P content of the waste, this paper ignores the potential significance of direct injection of high BOD waste into the hypolimnion on hypoxia/anoxia, as well as the potential for significant and long-lasting alteration of the benthic ecosystem. Much of the potentially relevant content regarding benthic alteration is already contained in an unpublished technical summary prepared by Podemski and Grapentine (2012) and could be added to the discussion with relatively little additional work. Such an expansion of the scope beyond P cycling and fate would also go a long way to reconciling the conclusion of low risk associated with P from cage aquaculture with the extensive research agenda contained in the final section.

The paper contains a fairly protracted discussion regarding the measurement and estimation of total loads of soluble and particulate P from all sources and comparison with total loads from cage aquaculture. It is worth tabulating TP loadings for the industry in order to provide context, but it would be more relevant to compare aquaculture loads with other regulated and "controllable" sources such as municipal and industrial wastewater. As summarized in Table 9, at ~32 MTA the estimated TP loads from cage aquaculture to Lake Huron/North Channel are approximately the same as from municipal wastewater (~29 MTA) and about 60% of industrial sources (~50 MTA). This is a useful means of confirming that the industry is a significant source from a regulatory perspective, even though it is of limited use when assessing the eutrophication risk associated with P from cage aquaculture waste at the scale Lake Huron/North Channel. It is widely recognized that issues related to excessive inputs of P will be determined at a local scale as the result of the operational scale of the aquaculture facility and site-specific factors which dictate the local assimilative capacity. A small load in an isolated embayment could generate significant eutrophication and anoxia effects whereas a large load at a well-flushed, offshore site could have a negligible impact.

As the paper justifiably suggests, development of local scale models to assess the carrying capacity of individual freshwater sites will be an important step forward. The utility of these models would be greatly increased if they included more than P cycling and fate since the paper has already documented the limitations of applying traditional eutrophication and DO models to predicting the effects of aquaculture waste inputs. There is an obvious need for development of a model to predict oxygen depletion that incorporates oxygen demand directly associated with the input of organically enriched high BOD waste rather than assuming that increased algal productivity is the only source of oxygen demand that needs to be accommodated.

PAGE-SPECIFIC COMMENTS

Page 15, par. 2 and 3

The paragraph on the aim of the paper would be a good fit in the introduction and objectives section. The paragraph on P from aquaculture waste could be moved to the discussion on aquaculture sources of P that currently starts at the bottom of page 16.

Page 15 and 16 "Freshwater Aquaculture Industry in Canada"

It is not clear why this brief history of the aquaculture industry in Ontario and Canada and the summary of economic data are included in the discussion paper since they do not correspond to any of the objectives listed in the introduction. It could be relevant to a scientific review if it provided the basis for a subsequent benefit-cost analysis but there is no such discussion and hence this appears to be out of scope. The reference to the uncertainty for future growth of the industry in Canada due to regulatory and environmental challenges has the look of an editorial comment unrelated to science and also seems out of place.

Page 21, par. 1

There are no Provincial regulations specific to cage aquaculture in Ontario so strictly speaking, there is no regulatory requirement that operations to be sited in adequately flushed sites. This is a recommendation from regulatory agencies that is taken into account when reviewing applications for new or expanding operations.

Page 22, par. 6 (of 7)

Would not the difference between P content in consumed feed and P retained in fish biomass yield total, rather than dissolved, P waste? Perhaps I'm missing something.

Page 23, par. 3 and 5

These two paragraphs are virtually identical and could be merged.

Page 24, par. 2

The message in this paragraph is hard to glean. I think it implies that conditions in Lake 375 were conducive to internal loading of P from the sediment pool and hypolimnion but that this was not observed because the fish waste was confined to a small depositional zone. It does not state whether this situation occurred every year and it is hard to reconcile this interpretation with the statement on the previous page that hypolimnetic P concentrations increased to 25 µg l^{-1} from an unspecified pre-cage background that was presumably less than 10 µg l^{-1}. I note that reference is made to Bristow et al. (2008) and it would seem appropriate to include some additional key findings from this source that are not included in the current draft:

Lake 375 did not equilibrate after three years of aquaculture. To this end, this study should not be used to assess the full impacts of aquaculture on a small Precambrian Shield lake… we should expect to observe the full impact of this cage aquaculture on Lake 375 productivity at some point in time between 2009 and 2014.

Compared with a reference lake, hypolimnetic dissolved oxygen concentrations in the aquaculture lake decreased by 36% and hypolimnetic ammonium and total phosphorus increased by 120% and 35%, respectively.

The discussion of the Lake 375 would be more complete if it also included findings from Paterson et al. (2011)[1] such as:

Following establishment of the cage farm in 2003, densities of Mysis decreased from an annual average of 85 m^{-2} (2002–2005) to 7 m^{-2} in 2007–2008. This decline was strongly correlated with decreasing concentrations of hypolimnetic oxygen.

Our results indicate that declines in hypolimnetic oxygen associated with nutrient enrichment can have severe impacts on populations of Mysis.

Our results also provide a clear indication that careful consideration must be given to the potential effects of cage farms and other sources of nutrients on hypolimnetic O2 conditions. An important goal of future regulations should be to minimize this impact.

Page 24, par. 3

There are numerous problems with this paragraph describing the situation at Lake Wolsey and the report should either greatly expand the discussion or remove it.

The assertion that the mean water column P concentration exceeds 10 µg l^{-1} is not accurate. MOE data show spring concentrations consistently less than 10 µg l^{-1} (although unlike the situation observed in undisturbed lakes, this concentration rise during the summer as the result

[1]Paterson, M.J., Podemski, C.L., Wesson, L.J., and Dupuis, A.P. 2011. The effects of an experimental freshwater cage aquaculture operation on *Mysis diluviana*. J. Plankton Res. 33(1): 25–36.

of external P loads inputs which include a significant component from the aquaculture operation).

It would be helpful to clarify that the estimated internal P load of 186 kg a^{-1} is not a separate source of P such as those associated the aquaculture operation (915 kg a^{-1}) and overland flow (1,120 kg a^{-1}), but a subsequent recycling of these external loads. The inclusion of a trivial estimated load from leaf litter is a rather odd detail since this type of exogenous source would normally be picked up in tributary loads or estimates from the various land use export coefficients. Also, the Milne (2012) estimate of 915 kg a^{-1} is hard to reconcile with the estimate of 8.7 kgP T^{-1} of production endorsed by the report (Table 9). Even assuming that the recent annual production at this operation was equal to the long term average of 250 Ta^{-1} (which appears to underestimate recent production) the resulting load from the aquaculture facility would have been more than twice this at 2,175 kg a^{-1}.

Most significantly, by ignoring the hypoxia/anoxia problem and focusing on solely on the P mass balance work undertaken at the Lake Wolsey site by Milne (2012), the report conveys an incomplete and misleading view of environmental conditions in the embayment. Work undertaken and presented by MOE (Diep et al. 2011)[2] has shown that the water quality of this moderately productive clear-water embayment has deteriorated with increased duration, magnitude and frequency of hypolimnetic DO depletion. The severe hypolimnetic dissolved oxygen depletion observed at this location would not be predicted by traditional P-related eutrophication models since it is not a eutrophic system (moderately low total phosphorus and chlorophyll a concentrations). Despite this, episodic near-bottom anoxia has been observed since 1999 and the magnitude of the DO depletion has increased since 2006 with prolonged near-bottom anoxia observed consistently from 2007 to 2010. This suggests that the DO problem is not driven primarily by a P-related increase in primary productivity, but rather by the large quantities of high BOD waste deposited directly into the hypolimnion.

Page 26, par. 3

The LaCloche Channel site would be characterized as a Type 1 rather than a Type 2 site since it does not have a good epilimnetic flushing rate. A rough estimate based on deployment of current meters by MOE in 1998 yielded a residence time of approximately 160 days (Boyd et al. 1998)[3].

Page 26, par. 5

The description of the current P sampling regime in Ontario refers to a threshold of 10 µg l^{-1} for data evaluation except at Type 2 sites where *"…a site specific P is assigned*". This does not conform to my understanding of the situation – can a more specific reference be supplied?

Page 27, par. 4

A minor point, but I believe it was the Land Use permit (Public Lands Act) rather than the Licence to Culture and Sell Fish (Fish and Wildlife Conservation Act) that was revoked.

[2]Diep, N., Boyd D. and Sein R. 2011. Dissolved Oxygen Dynamics of an embayment of the Great Lakes, presentation at the CAWQ conference, 23 February 2011.

[3]Boyd D., Hobson G., Neary B., McBride J. and Gale P. 1998. Conditions at the LaCloche Channel during June and July 1998. Provisional Data Summary and Interpretation for Discussion.

Page 30, par. 2

This paragraph implies that the binational Great Lakes Water Quality Agreement administered by the IJC is the primary reason that Ontario requires a water quality monitoring program for cage aquaculture facilities in the Great Lakes. This is not an accurate assessment. The Ontario Ministry of the Environment has a responsibility and mandate to regulate any entity that discharges waste into the surface waters of Ontario regardless of any binational commitments or agreements.

I hope these comments are helpful. As I mentioned at the outset, the paper has great potential to provide an up-to-date review of the science that will be a valuable resource for a wide spectrum of interested parties.

APPENDIX 5. INVITED WRITTEN COMMENTS – M.J. MACCOUX

Comments on "Estimation and Assessment of the Risk of Phosphorus Inputs from the Cage Aquaculture Industry to Canadian Freshwater Environments"

I think this paper provides an adequate and informative introduction and assessment of aquaculture in Canada. This is not my area of expertise and I found it easy to understand and I feel it covered all of my questions/concerns regarding the topic. Besides some minor grammatical errors here and there, the citations of the Chapra and Dolan papers are not accurate. The first part (loadings) is Dolan and Chapra (2012), the second part (model) is Chapra and Dolan (2012). Also, the phosphorus limit on effluent discharge from municipal treatment plants should be 1 mg/L, not 1 ug/L (on p. 14).

With respect to the external phosphorus loadings, the idea was to use the same methodology that had been previously used to report to the IJC. The biggest problem, which you mentioned, was the lack of monitoring, both spatially and temporally. In addition to having only three tributaries monitored in general, there were several occurrences where these were not monitored for a given year and we had to estimate loadings by using a previous year and adjusting it based on average flow. These large tributaries were then used to estimate other adjacent tributaries using a unit area load. The unmonitored watersheds were assigned a monitored tributary to use based on a PLUARG (Pollution from Land Use Activities Report Group) report. While this may not be ideal, that's what was done in the past. This was done in the late 1970s (I believe) and this may need to be revised due to land use changes, although it is still predominately forested. This highlights the need for continued support and expansion of long-term monitoring programs.

One thing that I noticed that was not included in Table 9, and I am unsure if it was made available in the supplements in the papers, was the incoming load from the St. Marys River. According to the version of Chapra's model I have, which may not be the final version, the averaged incoming TP load from 2005-2010 is roughly 236 tonnes. He has this load split as 34.3% to main Lake Huron and 65.7% to the North Channel. In addition to this, there is also a loss of 12 tonnes on average to Georgian Bay. If you would like more detail on this part, I would suggest contacting Dr. Chapra.

We also estimated loads for total dissolved P, total nitrates, and chloride in the same level of detail as TP. If you would like the TDP loadings, I can send you some files. Just for comparison, the total North Channel loading for 2008, comparable to Table 9, was 110 tonnes and averaged 1994-2008 was 91 MTA. Input from Superior is about 80 MTA on average, and then split using the above mentioned percentages. TDP is also dominated by tributaries and interannual variability is affected by precipitation. Typically the availability of TDP data is less than that of TP making the estimates more difficult. I think it is important to put the aquaculture loads in context with both the TP and TDP loadings. Monitoring and modeling will show the impacts of the additional phosphorus inputs and leave it up to policy makers to determine if the impacts are significant to warrant further action.