Proposed Targets for Evaluation of the Bay of Quinte BUI 13 Degradation of phytoplankton and zooplankton populations using a functional food web approach (prepared September 2017)

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Proposed Targets for Evaluation of the Bay of Quinte BUI 13 Degradation of Phytoplankton and
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Abstract

Currie, W.J.S., Bowen, K.L., Niblock, H.A., Fitzpatrick, M.A., Rozon, R., Munawar, M., Koops, M.A.. Proposed Targets for Evaluation of the Bay of Quinte BUI 13 Degradation of phytoplankton and zooplankton populations using a functional food web approach (prepared September 2017). Can. Manuscr. Rep. Fish. Aquat. Sci. 3262: v + 37 p.

The evaluation of targets for Beneficial Use Impairment 13 "Degradation of phytoplankton and zooplankton populations" has been problematic in that there has previously been no consensus on the approach to assessment. The Fisheries and Oceans Canada Great Lakes Laboratory for Fisheries and Aquatic Sciences proposes a food-web function based approach using the 4 decades of plankton monitoring data in the Bay of Quinte to propose a set of 26 potential metrics for phytoplankton, zooplankton populations and trophic biomass ratios which will allow the assessment of this Beneficial Use Impairment for the Bay of Quinte Remedial Action Plan.

Résumé

Currie, W.J.S., Bowen, K.L., Niblock, H.A., Fitzpatrick, M.A., Rozon, R., Munawar, M., Koops, M.A.. Proposed Targets for Evaluation of the Bay of Quinte BUI 13 Degradation of phytoplankton and zooplankton populations using a functional food web approach (prepared September 2017). Can. Manuscr. Rep. Fish. Aquat. Sci. 3262: v + 37 p.

L'évaluation des objectifs de l'atteinte à l'utilisation bénéfique 13 « Dégradation des populations de phytoplancton et de zooplancton » a été problématique dans la mesure où il n'y avait pas eu auparavant de consensus sur l'approche d'évaluation. Le Laboratoire des Grands Lacs pour les pêches et les sciences aquatiques du MPO propose une approche basée sur la fonction du réseau trophique en utilisant les 4 décennies de données de surveillance du plancton dans la Baie de Quinte pour proposer un ensemble de 26 paramètres potentiels pour les populations phytoplancton et zooplancton et les ratios de biomasse trophique qui permettre l'évaluation de cette altération de l'utilisation bénéfique pour le plan d'action d'assainissement de la Baie de Quinte.

Introduction: Evaluation of Beneficial Use Impairment (BUI) 13 Using a Functional Food Web Approach

Targets choice for evaluation of BUI 13 "*Degradation of phytoplankton and zooplankton populations*" has a history of disagreement and lack of focus, leading to frustration for Remedial Action Plan (RAP) managers needing to assess this Beneficial Use Impairment (BUI). Assessment suggestions have been piecemeal in the past, with little integration and support by other Great Lakes scientists (e.g. Irvine and Murphy 2009). A number of Great Lakes AOC's have had the BUI 13 status as *Requires Further Assessment* (RFA) for many years, with little progress to assessment until recently (Currie et al. 2015a). The one exception is the Bay of Quinte where BUI 13 has a status of *Impaired*, however little information was given for this original classification, with most discussion confounded with eutrophication rather than plankton populations (Bay of Quinte Stage 2 Report, 1993), which has made it difficult to assess against. A number of approaches have been put forward over the years to assess impairment in this BUI including targets for phytoplankton biomass and zooplankton size. However, no theoretical framework was provided to support these targets and there was little consensus on what they were measuring.

In 2015, Fisheries and Oceans Canada (DFO), Great Lakes Laboratory for Fisheries and Aquatic Sciences presented a new framework using an ecosystem food web approach (Currie et al. 2015b). The fundamental idea is that there should be an effective, functional food web that transfers energy from primary producers to higher trophic levels in a non-impaired system. This food web approach is particularly suited to BUI #13, because phytoplankton and zooplankton fit neatly between two other biological impairments: BUI #8 *Eutrophication or undesirable algae*, and BUI #3 *Degradation of fish and wildlife populations*. It is also tightly related to BUI 14: *Loss of fish and wildlife habitat* (particularly related to submerged aquatic vegetation) and BUI 6: *Degradation of benthos*. A food web approach to BUI 13 also links to the *Great Lakes Water Quality Agreement* explicit commitment to an ecosystem approach.

The Bay of Quinte is a shallow eutrophic embayment, and as such is expected to have a robust planktonic community (McCauley and Kalff 1981, Scheffer 2004). Nutrients will stimulate growth of phytoplankton, which is consumed by zooplankton, which are in turn consumed by planktivorous fishes which are themselves eaten by predatory fishes, birds and reptiles. Shallow water systems are particularly prone to catastrophic switching between two states: a turbid

phase dominated by phytoplankton, and a clear-water phase with increased macrophyte growth and reduced phytoplankton biomass (Scheffer et al. 1993, Scheffer and Carpenter 2003). The change between these phases is known as regime shifts or alternative stable states and can occur rapidly on time scales less than a year, driven by changes in nutrients, chemistry, climate or water levels (Scheffer and Carpenter 2003).

The composition of the plankton community will be driven by both "bottom-up" and "top-down" processes (McQueen et al. 1986; Carpenter et al. 2001). Much of the early science of limnology was focused on the study of bottom-up processes, which maintain that phytoplankton populations, and ultimately the structure of the food web are controlled by nutrients (Harvey et al. 1935, Lindeman 1942, McCombie 1953, but see McQueen et al. 1986 for discussion). However, beginning in the 1960s it became clear that in some systems, consumption at the top of the food web can change the characteristics of the food web, in terms of zooplankton composition and size (Hrbáček et al. 1961, Brooks and Dodson 1965) and even phytoplankton biomass (Carpenter et al. 1987, Jeppesen et al. 2003). The theory of trophic cascade (Carpenter et al. 1985) quickly led to the idea that biomanipulation of lakes could change the community composition to one favored by managers, though the results were highly variable in outcome (Perrow et al. 1997, Meijer et al. 1999, Drenner and Hambright 2002).

To make the ecosystem approach work for the Bay of Quinte, it was necessary to have sufficient information on the physical environment (light transmission, temperature etc.), nutrients (phosphorus, nitrogen, silica), and the composition of phytoplankton, zooplankton and fishes. The Bay of Quinte is fortunate to be the site of one of Canada's long term ecological research (LTER) programs, Project Quinte, which has been collecting this information since 1972, though not continuously for every measure (see: Currie and Frank 2015). To make analysis possible, it was necessary to unite many disparate datasets from a number of agencies including: DFO – phytoplankton and microbial loop, zooplankton and fish habitat datasets, Ontario Miniastry of Natural Resources and Forestry (OMNRF) – fishes, Ontario Ministry of the Environment (OMOE) – water chemistry, and Environment and Climate Change Canada (ECCC) – climate. These data were date-matched, QA/QC'ed and combined into a single "flat" file with > 1M entries. Monthly and annual datasets were compiled so that the drivers of the biological communities could be assessed. The time-series of nutrients, phytoplankton, zooplankton and fishes illustrates that all of these measurements have changed during the period of sampling for Project Quinte (Figure 0.1).

This dataset was explored for underlying relationships using a number of multivariate approaches (correlation matrices, discriminant analysis), which expanded upon the one performed for the Bay of Quinte biogeochemistry (Currie and Frank 2015). This involved the investigation of thousands of relationships to determine independence and fundamental correlations between measurements such that statistical relationships could be developed. These data were used to determine the fundamental time-stanzas within the time-series. Using physical drivers such as temperature, Secchi depth, and total phosphorus, the Quinte data-series formed four distinct stanzas that could be grouped into two major phases:

Turbid Phase (1972 – 1994)

1) "**High P**" 1972 – 1982 was dominated by high nutrient levels and planktivorous fishes along with the transition to P-controls (high phytoplankton biomass)
2) "**Peak Walleye**" 1983 – 1994 was a stable period of climate, with intermediate nutrient levels which stabilized the system (high plankton, piscivorous fishes) and the start of submerged aquatic vegetation (SAV) regrowth

Clear Phase (1995 – 2014)

3) "**Clear Transition**" 1995 – 2000 began with a rapid transition to a clear-phase system, with higher clarity (deeper Secchi) and rapid expansion of macrophytes, most likely driven by the record cold winter of 1994
4) "**Climate Variability**" 2001 – 2014 shows much increased variability in precipitation and temperature and the expansion of zebra mussels in the upper bay

The year 2000 was an outlier year, with very high precipitation and a cool summer that led to recruitment failure in some of the zooplankton and fish species and has been removed from the analyses (noted) in some of the following sections.

To evaluate targets for BUI 13, a three-part approach is presented. The first approach (Section 1) is an analysis of the linkages between nutrients and biomass to determine underlying relationships within the food web. This will be done through the calculation of trophic ratios (e.g. zooplankton:phytoplankton biomass) as a function of a nutrient gradient (Jeppesen et al. 2000), and the use of a structured equation model (SEM) or path-analysis to show the trophic linkages within the pelagic food web for the turbid and clear phases. The second approach (Section 2)

will detail changes in composition within the phytoplankton community and determine which measures can be used as indicators to track changes over time. The third part (Section 3) will undertake a similar analysis for zooplankton community changes to determine indicator measures which will be effective in monitoring the status of BUI 13 within Bay of Quinte. These targets are used in the corresponding document which assesses the status of the Bay of Quinte ecosystem against these targets over time (Currie et al. 2023).
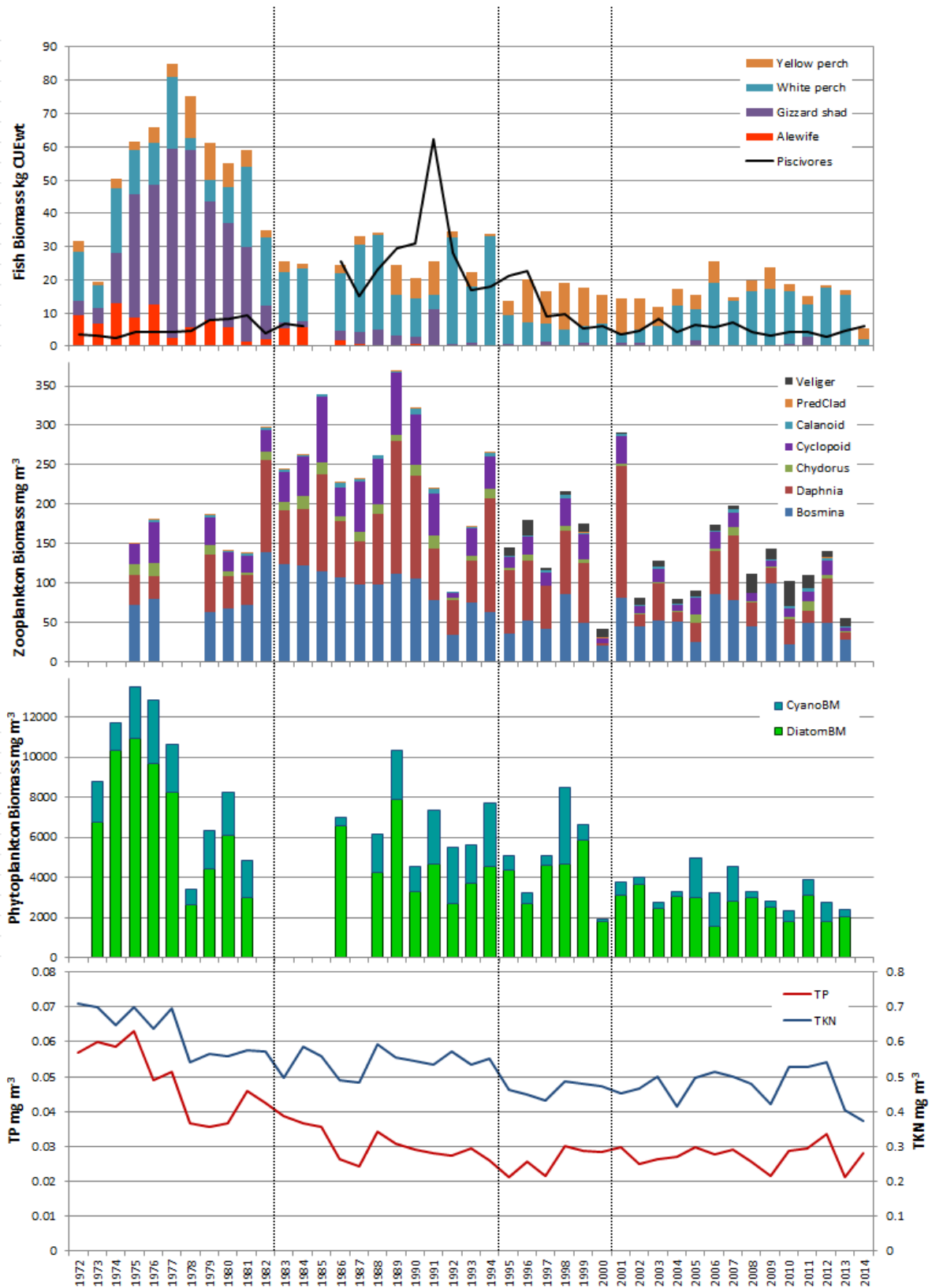
Figure 0.1: Bay of Quinte upper bay at Belleville annual May – Oct time-series of nutrients (TP,TKN), phytoplankton (diatoms and cyanobacteria), zooplankton and fish biomass (planktivores and piscivores). Vertical dotted lines delimit the four time-stanzas, with 1 & 2 turbid phase and 3 & 4 clear phase.

Section I: Trophic Efficiencies and Food Web Approach

Applying an ecosystem food web approach to assess the impairment of *Phytoplankton and Zooplankton Populations* in the Bay of Quinte (Currie et al. 2015b) will involve two approaches. First is an investigation of changes in trophic ratios (e.g. zooplankton:phytoplankton). This approach directly measures the linkage between standing stocks of biomass between trophic levels and has both theoretical and empirical support in the literature (McCauley and Kalff 1981, Jeppesen et al. 2005). Higher ratios between adjacent members of the food web are expected when efficiency increases in oligotrophic systems. A functional food web should transfer energy from primary producers to higher trophic levels in ratios found in similar systems (in this case, a shallow, eutrophic freshwater ecosystem). The second analytical approach is the use of path or structured equation modeling (Bollen 1989, Arhonditsis et al. 2006) to identify linkages through a simplified Bay of Quinte food-web to investigate any changes over time. Negative linkages suggest ecological interactions such as competition or predation (higher predators predict lower prey biomass), while positive linkages suggest facilitation (e.g. increased nutrients support larger biomass of algae) with intensified values indicating a stronger connection.

Trophic ratios

When considering ratios between trophic groups, a direct linkage (e.g. predation or uptake) is necessary for the ratios to have meaning, but the relationships can be highly sensitive (McCauley and Kalff 1981, McQueen et al. 1986, Jeppesen et al. 2005, Heathcote et al. 2016). The more linear the relationship (e.g. "food chain" rather than "food web"), the better the ratio will respond to changes in the system (Drenner and Hambright 2002) and the number of levels (odd vs. even) is expected to change the expectations of community structure (Mazumder 1994). It is also recognized that shallow lakes respond differently than deeper lakes (Jepessen 1997a) which can be a factor for the Bay of Quinte since the upper bay is considered shallow while the middle and lower bay would be considered deep systems. Regardless, these trophic ratios have been shown to be very effective in tracking changes to ecological groups over ranges of drivers including trophic status (bottom-up effect) as a function of total phosphorus (McCauley and Kalff 1981, Jeppesen et al. 1997a), macrophyte density (Jeppesen et al. 1997a), and planktivorous fish (top-down effect) (McQueen et al. 1986, Jeppesen et al. 1997b, Mehner 2010).

How biomass was determined

The determination of biomass for phytoplankton and zooplankton are outlined in Sections 2 and 3. Though it is expected that benthos will play an important role in shaping pelagic community structure, biomass of benthos was not directly included in the analysis, in part due to the lack of continuous data, so we limited our analyses to pelagic ecosystem interactions. Fish abundance and biomass were collected by OMNRF (Jim Hoyle, Glenora Fisheries Station). Data from standardized gill net and bottom trawls were combined since there can be strong gear bias for certain species, e.g. Gizzard Shad (*Dorosoma cepedianum*) is almost absent from bottom trawls (see: Hoyle et al. 2012), and rather than prioritize one gear over another, they were combined equally and average weight for each species were applied to get CPUE weight. To estimate Planktivorous Fish biomass changes over time, species that are primarily consumers of zooplankton: Alewife (*Alosa pseudoharengus*), Cisco (*Coregonus artedi*), Rainbow Smelt (*Osmerus mordax*), Spottail Shiner (*Notropis hudsonius*), and Bluegill (*Lepomis macrochirus*) were combined with fishes that are considered omnivorous but whose diet is dominated by zooplankton for at least part of their life-cycle: White Perch (*Morone americana*), Golden Shiner (*Notemigonus crysoleucas*), Gizzard Shad (*Dorosoma cepedianum*), Yellow Perch (*Perca flavescens*). Yellow Perch and White Perch in particular are known for their prey switching and adult Yellow Perch were expected to be more piscivorous (Parrish and Margraf 1990). We have no data on age-0 fish in the Bay of Quinte which are likely to be planktivorous, but the presence of the adult fish is expected to be correlated with the biomass of YOY. Fish considered Piscivores were: Walleye (*Sander vitreus*), Longnose Gar (*Lepisosteus osseus*), Northern Pike (*Esox lucius*), American Eel (*Anguilla rostrata*), Bowfin (*Amia calva*), Smallmouth Bass (*Micropterus dolomieu*), Channel Catfish (*Ictalurus punctatus*) also, but rare in the upper bay: Brown Trout (Salmo trutta), Chinook Salmon (*Oncorhynchus tshawytscha*), Lake Trout (*Salvelinus namaycush*), Rainbow Trout (*Oncorhynchus mykiss*), Burbot (*Lota lota*), White Bass (*Morone chrysops*) and Largemouth Bass (*Micropterus salmoides*).

Regression Relationships

There are known, robust relationships between nutrients and phytoplankton biomass, though the response is variable and highly site dependant (Nicholls and Dillon 1978). There is an expectation that the relationship between phytoplankton biomass and phosphorus will not fundamentally change for a location, and the Bay of Quinte has existing published relationships that can be utilized (Jackson 1976, Nicholls and Hurley 1989). The slope of the nutrient to phytoplankton relationship (e.g. TP:Chl-a) has also been proposed as a measure of the effect of

piscivores (Drenner and Hambright 2002), though this relationship was found to not hold in Canadian Shield lakes (Currie et al. 1999).

Although total phosphorous (TP) is generally viewed as the limiting nutrient in freshwater systems (Schindler 1977), when present in high concentrations through sediment release, nitrogen can become limiting in eutrophic systems (Elser et al. 2007, Conley et al. 2009). This is the case in the Bay of Quinte where Total Kjeldahl Nitrogen (TKN) is a significantly better predictor of total phytoplankton biomass (Table 1.1) (also found in Nicholls and Hurley 1989), and all the other phytoplankton groups (except Chrysophyceae), so TKN will be used as the driver of production in most of the food web analyses, but when comparing with previous research, TP relationships will still be used since the predictive power is still high. See Section 3 for analysis of phytoplankton communities for discussion of nitrogen limitation during summer.

Table 1.1: *ANOVA results of Total Phytoplankton Biomass by nutrient driver.*

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Model	2	1542011271	771005635	178.7296	<.0001
Error	149	642757735	4313810.3		
C. Total	151	2184769006			

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-3514.767	643.7745	-5.46	<.0001
TKN	12350.207	2317.422	**5.33**	**<.0001**
TP	67272.261	23316.24	2.89	0.0045

Source	DF	Sum of Squares	F Ratio	Prob > F
TKN	1	122517830	**28.4013**	**<.0001**
TP	1	35910045	8.3244	0.0045

The zooplankton:phytoplankton biomass ratio differs from the phytoplankton:nutrient ratio in that there is an expectation of both top-down and bottom-up drivers being important determinants (Jeppesen 1997a). These drivers act in opposite directions with a trophic gradient, so that as total phosphorus increases, zooplankton production (and grazing) increases, but so will fish production, and planktivorous fishes consume zooplankton driving down the biomass. Unlike piscivorous fish biomass, the relationship between biomass of piscivorous fishes and nutrients is weak (Friederichs et al. 2011) and tends to not increase linearly, but rather is dome-shaped with a maximum at intermediate nutrients (Yurk and Ney 1989). Phytoplankton biomass however is tightly linked to system total phosphorus, so that it will increase more rapidly than zooplankton biomass (steeper slope), which itself increases more rapidly than fish biomass (Figure 1.1a). The differential increases will lead to non-linearity in the

zooplankton:phytoplankton and planktivore:zooplankton ratios (Figure 1.1b). This characteristic of the ratios can be utilized to track changes in the trophic status of a system because the expected ratio change can be large for a small change in nutrient concentration (it is a sensitive metric).
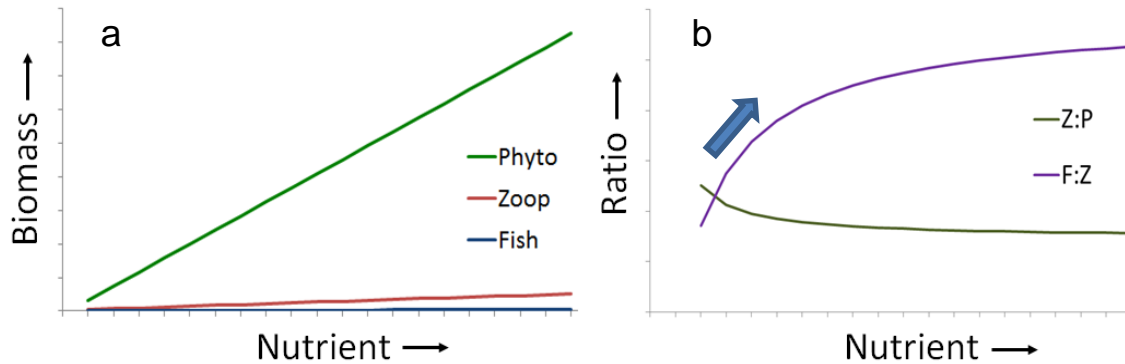
Figure 1.1: *Phytoplankton, Zooplankton and Planktivorous Fish biomass responses by nutrient level (a) and resulting ratios of zooplankton:phytoplankton and fish:zooplankton showing non-linearity (b). Arrow shows the zone of rapid change in the ratio.*

The trophic ratios found in the Bay of Quinte will be compared to published relationships from similar sites, particularly those located in shallow lakes in North America and Europe, though there is an expectation that Quinte will deviate from other sites. It has been noted that each lake has unique trophic relationships due to differences in abiotic and biotic drivers (Jeppesen et al. 1997a) and the Bay of Quinte has an open boundary to Lake Ontario which will confound the results (fish species in particular can migrate to and from the Bay). There is a wide range of possible trophic ratios to utilize (Table 1.2), but for the purposes of assessment of BUI 13, the ratios which are established to show differences in the composition of phytoplankton and zooplankton will be the focus (1-6 are bottom-up, 7-12 are top-down):

1. phytoplankton biomass to TKN (P:TKN)
2. zooplankton biomass to TKN (Z:TKN)
3. planktivorous fish biomass to TKN (PlanktF:TKN)
4. zooplankton biomass to phytoplankton biomass (Z:P)
5. Z:P regression with TP and TKN
6. Daphnia biomass to phytoplankton biomass (D:P)
7. Z:P regression with planktivorous fish biomass
8. planktivorous fish biomass to zooplankton biomass (F:Z)
9. planktivorous fish biomass to Daphnia biomass (F:D)
10. planktivorous fish biomass to phytoplankton biomass (F:P)
11. piscivorous fish biomass to zooplankton biomass (Pis:Z)
12. piscivorous fish biomass to phytoplankton biomass (Pis:P)
13. yellow perch to white perch biomass (Yperch:Wperch)

Comparisons will take place along a spatial trophic gradient from the upper Bay of Quinte designated as impaired to the lower Bay: Belleville, Napanee, Hay Bay, and Conway stations. These ratios will be calculated for each of the four time-stanzas listed above as well as for the turbid (1972 – 1994) and clear phases (1995 – 2014), so will effectively be over a temporal nutrient gradient as well.

Table 1.2: Previously published trophic ratios and drivers that can be used for the assessment of plankton communities. These also include the change in ratios with physical drivers of lake systems. The relationships may be between: Total Phosphorus (TP), Total Nitrogen (TN), Depth (D), Secchi (S), Macrophytes (M), Chlorophyll-a (Chl), Phytoplankton Biomass (P), Cyanobacterial Biomass (C), Zooplankton (Z), Daphnia (D), Planktivorous Fishes (PF), Soft-rayed Fishes (SF), Spiny-rayed Fishes (SpF), Total Fish Biomass (TF), Piscivores (Pis). Studies using lake categories (presence/absence of macrophytes) are denoted p/a.

Relationship	Type	Source
Chl:TP	Regression	Dillon and Rigler 1974, Nicholls and Dillon 1978, McCauley and Kalff 1981, McQueen et al. 1986, Peters 1986, Nicholls and Hurley 1989, Currie et al. 1999, Jeppesen et al. 1997a; Bertolo et al. 2005
Chl:TP : PF	Regression p/a	Nicholls and Hurley 1989, Jeppesen et al. 2004, Drenner and Hambright 2002
Chl:TP : Pis	Regression p/a	Drenner and Hambright 2002, Friederichs et al. 2011, Carpenter et al 2001
Chl : D	Regression	McQueen et al. 1986, Strus and Hurley 1992, Mehner 2010
P:TF : TP	Regression	Hanson and Leggett 1982, Jeppesen etal. 1997a
Z:P : TP	Regression	McCauley and Kalff 1981, McQueen et al. 1986, Sager and Richman 1991, Jeppesen et al. 1997a, 2003, Muylaert et al. 2003, Hessen et al. 2006
Z:P : PF	Regression, mean compare	Peters 1986, Jeppesen et al. 1997b, Jeppesen et al. 2004, Hessen et al. 2006, Muylaert et al. 2003, Havens and Beaver 2013
Z:P : D	Regression	Jeppesen et al. 1997a, Jeppesen et al. 2004
Z:P : M	Regression, mean compare	Cryer et al. 1986, Jeppesen et al. 2004, Muylaert et al. 2003
Z : Chl	Regression	McQueen et al. 1986, Jeppesen et al. 2004
Z : P	Regression	McCauley and Kalff 1981, McQueen et al. 1986, Jeppesen et al. 1997a, 1998, 2004, Mehner et al. 2008, Heathcote et al. 2016; Kissman et al. 2017
Z:Pis	Regression	Jeppesen et al. 2003, Friederichs et al. 2011,
Z:PF	Regression	McQueen et al. 1986, Jeppesen et al. 1998, Mehner et al. 2008, Bertolo et al. 2005
Pis:TP	Regression	Hanson and Leggett 1982, Peters 1986, Persson et al. 1998, Jeppesen et al. 1994, Downing et al. 1990, Friederichs et al. 2011
Pis:Chl	Regression	Mehner 2010, Jeppesen et al. 1994
Pis:PF	Regression	Mehner 2010
Pis:SF	Regression	Potthoff et al. 2008, Friederichs et al. 2011
Pis:SpF	Regression	Friederichs et al. 2011,
P:D	Regression	Jeppesen et al. 1997a
C:D		Jeppesen et al. 1997a
TF:D		Hanson and Leggett 1982
Pisc:D		Mehner 2010

Path Analysis

The second part of the food-web analysis for the Bay of Quinte will be a simplified path analysis (Bollen 1989, Grace et al. 2010). This form of analysis identifies the linkages (causal effects) between a model that is produced a-priori, in this case a pelagic food-web model. The model developed was designed to match the ratios that were determined in part 1 of this analysis: nutrient – phytoplankton – zooplankton – planktivorous fishes – piscivorous fishes. While it is true that the Bay of Quinte food web is far more complicated than this (Figure 1.2), much of the information is not available or is very sparse (e.g. benthos). The intent of this analysis is not to fully model the food web dynamics of the system (e.g. Koops et al. 2004, Blukacz-Richards and Koops 2012), but rather to identify any changes to trophic transfer within the system and potentially identify the drivers.
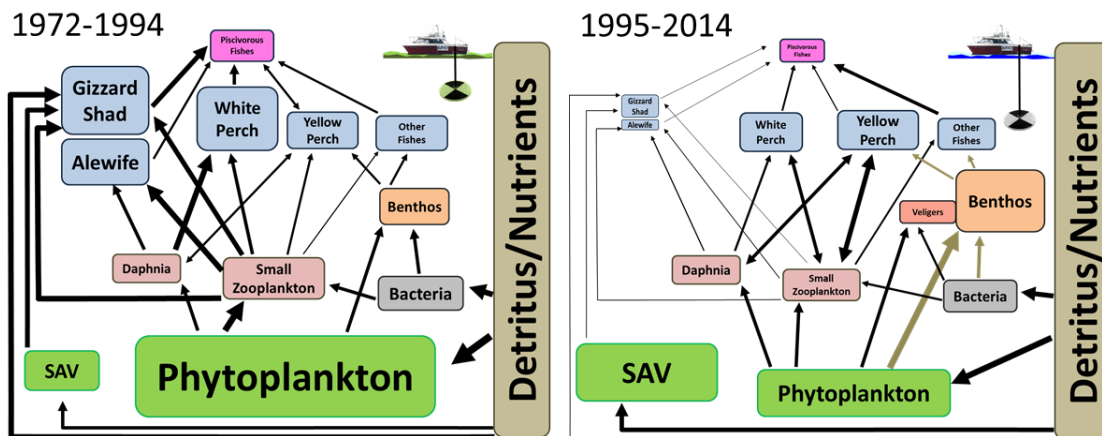
Figure 1.2 *Example Bay of Quinte simplified food web for the turbid (left) and clear (right) phases. During the clear phase, water clarity is greater, there is less phytoplankton, more macrophytes (SAV), less small zooplankton and much less planktivorous (especially Alewife and Gizzard Shad) and piscivorous fishes. Given the limited data, the benthic linkages will not be included in the path analysis.*

Some refinement is useful to add to the simple model. Since we know that zooplankton composition is expected to change with the underlying nutrient concentrations, the zooplankton composition has been split among "large" (*Daphnia* sp., predatory Cladocera and large herbivorous copepods) and "small" zooplankton (e.g. *Chydorus*, *Bosmina* etc.). Since there has been great change in the composition of planktivorous fishes, these were also split into the major species: Alewife (*Alosa pseudoharengus*), Gizzard Shad (*Dorosoma cepedianum*), White Perch (*Morone americana*), and Yellow Perch (*Perca flavescens*). No young of year data are available, so there is an underlying assumption that the biomass of these fishes also accounts for the age-0+ biomass of other fishes. An initial attempt to split the biomass of phytoplankton

into 2 groups (edible, less edible) added additional complication to the model, but was no different from the use of total phytoplankton biomass. The path analysis will be run for the upper and middle Bay of Quinte data (Belleville, Napannee and Hay Bay), but Conway is omitted since the fish community is very different and influenced by Lake Ontario species. Annual biomass data are used for the path analysis and the 1972 – 1994 (turbid-phase) stanza is compared to the 1995 – 2014 (clear-phase) stanza to identify changes in the bottom-up and top-down forcings on the food web.

Section II: Phytoplankton Delisting Criteria

Existing Criteria

1. Demonstrate a positive change in phytoplankton species composition with a decrease in nuisance and eutrophic (and noxious) indicator species (e.g. Cyanobacteria – Microcystis, Anabaena).
AND
2. For the spring, summer and fall algal assemblages demonstrate a significant decrease in the biomass of eutrophic indicator species to the fullest extent possible consistent with the goals of the municipal phosphorous load management strategy for the Bay of Quinte.

Comment and Framework for Revision

These two criteria make the same point: that improved water quality can be demonstrated through changes in phytoplankton composition. They differ in that only the second criterion offers some guidance as to how this change should be assessed (seasonally: spring, summer and fall) and quantified (using biomass). There are several considerations regarding these criteria which require some explanation in order to make a proper assessment. First, both address eutrophication. For that reason alone, they might also be considered as part of BUI 8 (Eutrophication or Undesirable Algae). Second, the composition of the phytoplankton community should not be separated from the assessment of phytoplankton biomass (currently part of BUI 8). Third, the term 'eutrophic indicator species' is very broad (see for example Reynolds et al. 2002; Padisak et al. 2009) and can include species belonging to many different taxa such as Chlorophyta, Cyanobacteria, Diatomeae, Euglenophyta and Dinophyceae. The criterion itself only makes reference to species of *Microcystis* and *Anabaena* (now called *Dolichospermum*), both of which are Cyanobacteria. Historically (and presently) diatoms including *Aulacoseira granulata*, *A. ambigua* and *Stephanodiscus binderanus* have formed the largest proportion of the algal biomass calculated on an annual basis (e.g. Nicholls and Carney 2011). There is also evidence that diatom blooms occur more frequently than Cyanobacteria blooms (Munawar et al. 2018). However, none of this directly addresses BUI 13: Degradation of Phytoplankton and Zooplankton Populations.

In defining, or redefining BUI 13, we have taken the position that it should be expressed in terms of food web function. In general terms, is the autochthonous production associated with the

phytoplankton community sufficient to support zooplankton populations and in turn healthy fish populations? Phytoplankton composition can serve as a robust indicator of both eutrophication and food web function and hence can be used to assess BUI 8 as well as BUI 13 with a straight forward refinement of the existing criteria. This refinement includes long term trends in nuisance algae (eutrophication) and edible algae (food web efficiency) with some specific measures that can be assessed from existing data.

The term nuisance algae can be applied to a variety of taxa, but in the Bay of Quinte we are referring specifically to those known to produce algal blooms. That includes filamentous diatoms (e.g. *Aulacoseira* spp.), filamentous Cyanobacteria (e.g. *Dolichospermum* spp) and colonial Cyanobacteria (*Aphanocapsa* sp., *Cyanodictyon* sp., *Microcystis* sp), thus broadening the original definition. Some Cyanobacteria have unique properties including the ability to fix nitrogen and produce toxins (like microcystin) making them a particular threat in eutrophic environments. While this is in general an indicator of eutrophication, it can also be an indicator of food web function as many of these species may not be palatable or readily grazed by zooplankton. Our interpretation is that both the biomass and % composition of nuisance algae should be reduced over time given the phosphorus abatement measures. The secondary result should be an improvement in food web efficiency.

Edible algae are defined on the basis of size and shape with smaller unicellular forms being the most likely to be grazed by zooplankton (e.g. Ross and Munawar 1981; Sandgren 1988; Cyr and Pace 1992). A healthy food web must have a significant biomass of edible phytoplankton; we would anticipate that the proportion of edible algae will increase as a system recovers from eutrophy even if the actual biomass remains stable or shows a slight decline.

Chrysophyceae are a class of phytoplankton that are particularly important in the transfer of autochthonous production in oligotrophic systems and often used as an indicator of ecosystem health (Munawar et al. 1978; Nicholls et al. 1986). For a system like the Bay of Quinte, with a long history of eutrophication, we would expect that the proportion of Chrysophyceae would increase over time if the system is in a recovery phase. Chrysophyceae have been shown to account for approx. 15 – 35 % of the total phytoplankton biomass in some of the more efficiently operating food webs in the Great Lakes (Munawar and Munawar 2003; 2009; Munawar et al. 2013).

We propose that the existing criteria be replaced with two complementary targets that measure food web function, one based on the assessment of nuisance algae (including filamentous diatoms and colonial and filamentous Cyanobacteria) and one based on the assessment of edible algae (including an assessment of Chrysophyceae). While this report is, above all else, an assessment of BUI 13: Degradation of Phytoplankton and Zooplankton Populations, we made every effort to be consistent with the objectives of BUI 8: Eutrophication or Undesirable Algae.

Revised Criteria for Assessment

Target 1

Demonstrate a positive change in phytoplankton species composition with a decrease in nuisance and eutrophic and noxious indicator species that may impair food web function.

Measures

1. A decrease in nuisance phytoplankton to less than 50% of the biomass (i.e. < 2.5 g m^{-3} in the upper bay offshore based on the existing target for BUI 8 of phytoplankton biomass of $4 - 5$ g m^{-3})

2. A decreasing trend in filamentous and colonial / mucilaginous Cyanobacteria (both in terms of biomass and relative composition)

3. A decreasing trend in filamentous diatoms (biomass and % composition).

Scientific Rationale

We have used the term "nuisance phytoplankton" in the broadest possible sense so that it includes among other things: eutrophic indicator species, potential toxin producers, colonial and filamentous forms. The first measure is meant to be universal; it can be used to assess any ecosystem. At the given target for Total Phosphorus from BUI 8 (30 µg l^{-1}), the expectation is that approximately 50% of the phytoplankton biomass will fall into the broad category of 'nuisance algae' based on the relationships established by Watson et al. (1992). Measures 2 and 3, however, are specific to the Bay of Quinte. The nuisance taxa in the upper bay tends to fall under the broad categories of colonial/mucilaginous and filamentous Cyanobacteria and filamentous diatoms which dominate the phytoplankton community (Nicholls and Carney 2011; Munawar et al 2012; Shimoda et al 2016). While nuisance algae are a strong indicator of eutrophication, we use it here as a measure of food web function. While these indicators may suggest impairment under BUI 8: Eutrophication or Undesirable Algae; our concern under BUI

13 is whether or not the phytoplankton community provides sufficient food resource to support the broader pelagic food web regardless of trophic state.

The nuisance phytoplankton category includes large filamentous and colonial forms as well as those with spines. Because of their structure, these types of phytoplankton are less available to filter feeders and may therefore limit energy transfer up the food web (e.g. Burns 1968; DeMott 1982; Sournia 1982; Price 1988; Munawar et al. 2011). While some zooplankton may be able to feed on these nuisance forms under certain conditions, the ingestion of nuisance algae may be impaired by the feeding mechanisms and food preferences of individual species (e.g. DeMott 1982; Balcer et al. 1984). Most importantly, a decrease in nuisance algae is expected to be associated with an increase in energy transfer efficiency up the food web.

Our expectation is that reductions in all nuisance forms (Measure 1) and, specifically reductions in filamentous and colonial blue-greens (Measure 2) as well filamentous diatoms (Measure 3) will result in a phytoplankton community assemblage that is more palatable to the zooplankton community and result in a more efficient transfer of autochthonous production up the food web.

Explanation of Measures

1. Nuisance algae have been defined here based on algal structure and shape, specifically filamentous forms and colonial forms that have gelatinous coatings or aggregate in large colonies. In the case of filaments, these tend to have a length > 20 μm or in the case of colonies, a diameter > 20 μm (Munawar et al. 1978; 2012). Smaller colonies were not included in this category. Also included in this category are Cyanobacteria known to produce toxins (documented production of toxin in the Bay of Quinte is not a requirement for inclusion).

2. A refinement on the first measure, this includes all the larger Cyanobacteria that are common to the Bay of Quinte including filamentous forms, primarily species of *Dolichospermum* and colonial forms (including species of *Microcystis*, *Cyanodictyon* and *Gloeotrichia*). Some of these species are known to fix nitrogen and / or produce algal toxins, but our concern here is their ability to avoid top-down control.

3. Also a refinement of the first measure, filamentous diatoms notably species of *Aulacoseira* (syn. *Melosira*) have been the largest component of the phytoplankton biomass since assessments began in the 1970s. They are also considered inedible and a poor food resource.

Target 2

Show an increasing trend in phytoplankton taxa that provide an ample food resource for zooplankton and other grazers.

Measures

1. An increase in the more edible phytoplankton taxa to approximately 30% of the biomass

2. An increase in the biomass of Chrysophyceae with an ideal target of > 15% of total phytoplankton biomass

 Scientific Rationale

This is intended to be and should be interpreted as the counterpart to Target #1. Concurrent with a decline in both the biomass and relative composition of nuisance algae, we would expect an increase in the relative composition of other forms, notably single celled flagellates (e.g. *Cryptomonas*, *Rhodomonas*), small colonies (e.g. *Chroococcus* sp) and centric diatoms (e.g. *Cyclotella*) which are important for supporting herbivorous zooplankton populations (e.g. Brett et al. 2009; Munawar and Fitzpatrick 2017). There is certainly ample evidence from the literature that zooplankton prefer smaller particles (e.g. Porter 1972; Briand and McCauley 1978; Ross and Munawar 1981) that can be actively ingested through either direct grazing or filter feeding (e.g. Balcer et al 1984; Price 1988; Vanderploeg 1994). We acknowlege that some taxa do not readily fall into either edible or nuisance categories (i.e. larger flagellates, pennate diatoms, cysts). It is for this reason that we set the target of edible phytoplankton biomass at 30% rather than the counter to nuisance of 50%. Measure 1, therefore, is intended to show that there is a ready supply of food available to support zooplankton.

It should also be stressed with respect to Measure #1 that if the phytoplankton composition shifts to a more edible assemblage then total phytoplankton biomass would be expected to fall. There are two main reasons for this: 1) grazing pressure should increase and 2) smaller, edible forms weigh less than the nuisance forms that currently dominate the assemblage.

Chrysophyceae are a class of phytoplankton that have long been considered indicators of ecosystem health (e.g. Munawar and Munawar 1978; 2009; Nicholls et al. 1986; Sandgren 1988). An increasing presence in the Bay of Quinte would be indicative of both improvements in trophic state and an increase in the generally edible forms of algae. Chrysophyceae have been shown to account for less than 5% of the total phytoplankton biomass in hypereutrophic environments and up to 75% of the biomass in oligotrophic environments (Sandgren 1988). Sandgren and Walton (1995) found that the relative contribution of Chrysophyceae at comparable TP concentrations (30 µg l^{-1}) and in the presence of *Daphnia* was in the range of 1-30% of the total biomass. So in setting a target of 15% of the total phytoplankton biomass, we are aiming for a modest improvement in trophic state and food resource availability that is also consistent with measures from Lake Ontario (Munawar and Munawar 2003).

Explanation of Measures

1. 'Edible' phytoplankton are defined on the basis of general morphology (e.g. size, shape) and physiological considerations. For example, a large colonial blue-green (Cyanobacteria) like *Microcystis* which is also known to produce algal toxins would definitely <u>NOT</u> be considered edible, whereas a small colonial blue green like *Chroococcus dispersus* would be considered edible. In general, these edible forms would be small, single celled or colonial, and less than 20 µm in length or diameter.

2. Chrysophyceae are readily identified and enumerated by a skilled taxonomist. Because of changes in the hierarchal classification that have occurred since the 1970s, some species of Xanthophyceae and Haptophyta could also be included here, but their occurrence in the Bay of Quinte is limited (e.g. Munawar et al. 2018). For this analysis, we will consider the biomass of all Chrysophyceae as well as its % contribution to total phytoplankton biomass.

Data and Analyses for New Targets

The data used for this assessment were collected under Project Quinte from 1972 – 2015. Sampling was of integrated euphotic or epilimnetic depth from mid-Bay stations. Typically sampling was bi-weekly, but some years it was conducted weekly. Lugol's preserved phytoplankton samples were counted by inverted microscope technique for weekly, biweekly, monthly or a single composite sample, depending on the station and year. For full details see

Nicholls and Carney (2011). In all cases the individually counted samples were used in preference to a composite sample for data analysis if available. For all measures, the data used in the analyses will be presented as May – October means for both biomass and % composition.

For nuisance algae, the 2.5 g m^{-3} of biomass target is simply 50% of the total phytoplankton biomass target listed in BUI 8. For each of the measures associated with the revised targets (5 in total), long term trends will be assessed using an Analysis of Variance (1-way ANOVA) of the entire data set by stanzas outlined in the introduction (1. the turbid phase "high phosphorus" years 1972 – 1982; 2. the turbid "peak walleye" 1983 – 1994; 3.the Clear phase "transition" 1995 – 2000; and 4. clear phase "climate variability" period of 2001 – 2014). Significant differences among groups (time stanzas) will be assessed using the Tukey-Kramer comparison.

Study Area

The Area of Concern designation applies mainly to the upper bay and the site at Belleville has been consistently monitored for phytoplankton composition since 1973. We will also include another upper bay site (Napanee), a middle bay site (Hay Bay) and an open water site at Conway where data are available.

Section III: Zooplankton Delisting Criteria

Current BUI Status: Impaired

BUI#13 Delisting Target:

"Demonstrate that the upper Bay of Quinte phytoplankton and zooplankton community structure do not differ significantly from an unimpaired Great Lakes / control site of comparable physical and chemical characteristics

General Background:

Zooplankton fill a key role in the aquatic food web as they form an important link between autotrophic and heterotrophic microorganisms (e.g., phytoplankton, bacteria) and larger heterotrophs such as planktivorous fishes. As such, zooplankton community structure and productivity are controlled not only by the physical environment (e.g., habitat, water temperature and clarity), but also by the type and quantity of available food and the effects of predation by both fish and invertebrate planktivores.

In the Bay of Quinte, zooplankton have been sampled biweekly from early May to October at three monitoring stations (upper bay – Belleville (B), middle bay - Hay Bay (HB) and lower bay – Conway (C)) in the Bay of Quinte since 1975. Details of this sampling program are given in Cooley et al. (1986) and Bowen and Johannsson (2011). Monitoring of zooplankton tracks species composition, size structure, abundance, biomass and productivity in an effort to understand the response of the community to changes in the controlling factors and assess its 'health' as a component of the ecosystem.

Zooplankton Metrics or Indicators for The Bay of Quinte

A number of studies have assessed the usefulness of zooplankton as indicators of environmental conditions in a variety of temperate aquatic systems, particularly with respect to trophic status (e.g., Attayde and Bozelli 1998; Čeirāns 2007; Gannon and Stemburger 1978; Gulati 1983). As part of the RAP's delisting process, the following zooplankton indicator or metric was developed for BUI #13 in the 1990s:

> "Measure a trend toward a more diverse zooplankton community shown as a
> range of mean individual sizes between 0.45 and 0.5 mm for cladocerans."

It must be clarified that using cladoceran mean length as a measure of a more diverse zooplankton community is incorrect. More direct measures of abundance and biomass of various zooplankton taxa must be used to determine diversity. Diversity and cladoceran mean size can both be useful zooplankton indicators, but they are independent measures. Although it can provide information on the levels of planktivory and eutrophy, using cladoceran mean size alone is not sufficient to assess the health of the zooplankton community. To better assess the zooplankton community in the Bay of Quinte, we propose using these two measures, along with six new indicators. These were chosen because they work for both "top-down" (fish planktivory) and "bottom-up" (nutrients and food limitation) impacts, and help to describe food web function. Their inclusion is based on literature review and exploratory analyses of the long-term Quinte zooplankton data.

It should be recognized that most of the zooplankton and rotifers regularly encountered in the Bay of Quinte are ubiquitous taxa commonly found throughout the Great Lakes and other temperate areas in the Northern Hemisphere. Many are considered to be "indifferent taxa" able to tolerate a wide range of ecological conditions, and therefore are not suitable to be used as indicators of changing trophy or other environmental conditions.

Proposed Metrics: Indicators of Eutrophy and High Fish Planktivory

1) Cladoceran Mean Size

Herbivorous cladocerans are the dominant macrozooplankton in the Bay of Quinte, and form an important trophic link between primary producers and planktivorous fishes. *Daphnia galeata mendotae* is generally the largest herbivorous zooplankton species in the bay, and *Daphnia* are efficient filterers of algae (Knoechel and Holtby 1986). Systems with a higher proportion of larger zooplankton may have lower chlorophyll per unit TP (Pace, 1984; Shapiro and Wright, 1984). However, systems with an overabundance of planktivorous fishes usually contain fewer large cladocerans as fish selectively consume larger zooplankton species and mean size decreases. (Evans and Jude 1986; Mills et al. 1987; Brooks and Dodson 1965). Small-bodied fishes consuming plankton and benthic invertebrates dominated the Bay of Quinte in the 1970s, a species assemblage common in eutrophic systems (Hurley 1986). These fishes included high numbers of Alewife (*Alosa pseudoharengus*) and juvenile White Perch (*Morone americana*) in the upper and middle bays. Increasing numbers of piscivores (primarily walleye) and an

unusually cold winter in 1977 – 78 decreased planktivore abundance starting in the late 1970s (Ridgway et al. 1990). Piscivore biomass peaked in the early-mid 1980s (see Section 1).

Work in Oneida Lake and Lake Erie suggested that a system with a mean summer zooplankton size of 0.57 mm or greater is indicative that the fish communitiy is in balance – it contains a good ratio of piscivorous to planktivorous fish (Mills et al. 1987; Johannsson et al. 1999). This assumes that zooplankton samples were collected with a 64 µm net, which is the mesh size used in Project Quinte. These values may be even lower and the system still in balance if it is a nursery area for YOY fish, such as the upper Bay of Quinte. Given these factors, a target of 0.45 mm or greater for mean cladoceran size was listed as a BUI metric in the Bay of Quinte. This size indicator is sensitive not only to planktivory but also to changes in eutrophy in the system. More eutrophic systems, particularly those dominated by filamentous algae, tend to be dominated by smaller cladocerans such as *Chydorus*, *Bosmina* and *Eubosmina* (Currie et al. 1999; de Bernardi and Guissiani 1990; Jeppeson et al. 2021). However, as these eutrophic conditions are often accompanied by the abundance of planktivorous fishes, it is often difficult to separate out which are the most important drivers.

In summary, the cladoceran mean size metric addresses both top-down and bottom up impacts. Reduction in size is an indicator of eutrophic conditions and/or high planktivory, thus we expect an increase in cladoceran mean size over time in the Bay of Quinte.

2) *Chydorus* **Biomass**

Chydorus sphaericus is a small herbivorous cladoceran that is abundant in the Bay of Quinte, particularly in the Upper Bay. It has a feeding advantage over large cladocerans during filamentous algal blooms (de Bernardi and Guissiani 1990), partly due to its ability to cling to and scrape food particles from algal filaments (Fryer 1968). *C. sphaericus* has been proposed as an indicator of eutrophic conditions since it often appears in the littoral zone when blue-green algae blooms are occurring (Gannon and Stemberger 1978; Gulati 1983; Pejler 1983; Haberman and Haldna 2014). Small zooplankton, including rotifers, *Bosmina* and *Chydorus* often dominate under conditions of high eutrophy (e.g Jeppesen et al. 2011), but also under high planktivory (Andersson et al. 1978; Brooks and Dodson 1965). Although *Chydorus* is likely not a preferred food item for planktivorous fishes due to its small size, Strus and Hurley (1992) identified it in the diets of Alewife in the upper Bay of Quinte. This indicates that it is still incorporated into the food web.

Chydorus is a common taxon in eutrophic systems such as shallow lakes, embayments and reservoirs (e.g. Lair 1991; Vijverberg and Boersma 1997, Haberman and Haldna 2014). As conditions improve in the Bay of Quinte, *Chydorus* biomass should decrease relative to the values in the 1970s and early 1980s.

Chydorus sphaericus

Leach 1843

Chydorus sphaericus is the smallest chydorid species in the Great Lakes, with lengths ranging from 0.2 mm to 0.4 mm (see Balcer et al. 1984). In Quinte their mean size is 0.25 mm (1995 – 2015) and is similar across stations. *C. sphaericus* can be found at varying densities in all five Great Lakes. It is found year round in Lake Erie, but only during the summer and fall in the other lakes.

K. Bowen, DFO

C. sphaericus is a nearshore, littoral species which migrates away from the bottom sediments at night. They have two feeding styles; they filter-feed on small algae as well as scrape off attached diatoms or detritus from large algal filamentous algae to which they cling using their specialised limbs. *Chydorus* can be a food source for planktivorous fishes, although it is not a preferred species due to its small size.
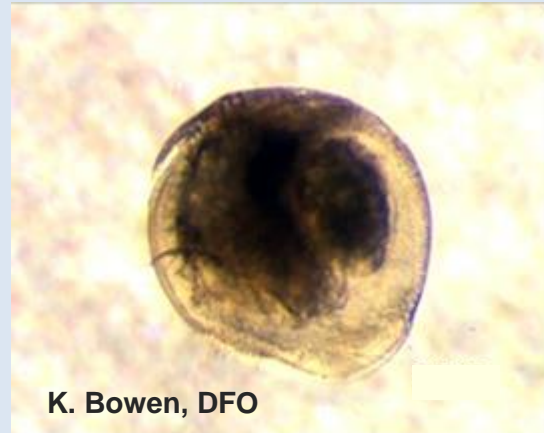
3) Percent *Acanthocyclops vernalis*

A*canthocyclops vernalis*, which is sometimes called *Cyclops vernalis,* is a medium-sized cyclopoid copepod that is common in eutrophic systems, including the upper and middle reaches in Quinte. A. *vernalis* is considered to be a good indicator of eutrophy in the Great Lakes by Gannon and Stemberger (1978). It is generally only found in eutrophic embayments such as Saginaw Bay, Green Bay, as well as the western basin of Lake Erie (Gannon and Stemberger 1978). Furthermore, this species is likely less vulnerable to fish predation than the larger *Mesocyclops* due to size selective planktivory. Meyer and Effler (1980) reported that it increased in abundance in Onondaga Lake when planktivory increased.

As B and HB become less eutrophic and the biomass of planktivorous fishes drops, the proportion of *A. vernalis* relative to total adult cyclopoid biomass is expected to decline relative to the pre-phosphorous control period. However, it is not expected to work as effectivley as an indicator at C due to the low biomass of this species in the lower bay. The cooler, more open lake conditions at this site are not this species' desired habitat.

Acanthocyclops vernalis (*Cyclops vernalis*)

Fischer 1853
The following information has been summarized from Balcer et al. (1984). *Acanthocyclops vernalis* is one of the most common and widely distributed copepods in North America and is found in water bodies of all sizes. They are between 0.8 mm and 1.4 mm long with males being smaller. In Quinte, *A. vernalis* tend to be smaller with a mean length of 0.78 µm. They overwinter in low numbers and increase in density quickly with warm water temperatures, peaking between June and August.
A. vernalis are abundant in warm, eutrophic lakes and nearshore areas as well as shallow bays and harbours. They tend to migrate up off the bottom at night and feed on nano- and net-plankton. They are a food source for a wide variety of fish species, including bass, crappie, sauger, freshwater drum, trout-perch, yellow perch, and young whitefish, as well as bottom feeding fish like suckers.

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4) Shannon Diversity Index

Biodiversity in an ecosystem represents the variety and heterogeneity of organisms found within that system. In attempts to describe biodiversity, a number of indices were developed by ecologists in the 1960s and 1970s. A diversity index is a mathematical measure of species diversity that combines species richness (S, the number of species present) and species abundance (the number of individuals per species). One example of a taxonomically based index is Shannon's diversity (H'), with higher values representing a more diverse ecosystem. H' values typically fall between1.5 and 3.5 in most ecological systems, and rarely exceed 4. Degraded systems dominated by one or a few tolerant species have lower diversity scores. Evenness is the degree to which individuals are divided among species with low values indicating that one or a few species dominate, and high values indicating that individuals are spread more equally among species (Morris et al. 2014). However, diversity indices only describe community structure, and not how well the ecosystem functions (Heip et al. 1998). A review by Washington (1984) found that the most commonly used diversity indices, including the Shannon Index, were unsatisfactory as a stand-alone measure due to the lack of exploration of their biological relevance. This article concluded that diversity does not automatically lead to either stability or instability in an ecosystem.

Despite these limitations, diversity is a well-known ecological concept and it is mentioned (although applied incorrectly to mean cladoceran size) in the original BUI Zooplankton delisting

metric. It is still useful as a tool in comparing trends over time within an ecosystem, or to adjacent systems. For the Bay of Quinte, we have chosen the Shannon Diversity Index as a measure of diversity. Haberman and Haldna (2014) indicates that this index decreases with increasing eutrophy, as highly eutrophic systems are often dominated by only a few zooplankton taxa. A trend toward increasing diversity index scores in the Quinte zooplankton community over time is an indication of reduced dominance by a few taxa.

Indicators of Low Fish Planktivory:

5) Percent Large *Daphnia*

Percent large *Daphnia, in this case those* >0.75 mm, is a refinement of the cladoceran mean size metric. *Daphnia* are among the largest herbivorous zooplankton found in the Bay of Quinte, and their size and abundance can be reduced when planktivorous fishes are abundant (Brooks and Dodson, 1965). This is a new indicator related to cladoceran mean size, but it responds more directly to changes in planktivory (top-down impacts). It is much less influenced by shifts in taxonomy, although a higher proportion of *D. galeata mendotae*, which tend to be large, may increase mean size. Domination by larger cladocerans (e.g., *Daphnia*) represents an increase in trophic transfer efficiency, as these species are efficient filters of small algae (Pace, 1984; Shapiro and Wright, 1984). However, large *Daphnia* may decline during blooms of filamentous cyanophytes (de Bernardi and Guissiani 1990, Ghadouani et al. 1998). Jeppesen et al. (2002) found that both the proportion of *Daphnia* relative to crustacean biomass and the size of *Daphnia* tend to decrease as phosphorus levels increase. Haberman and Haldna (2014) found that the proportion of large cladocerans relative to all cladocerans decreased as eutrophy increased.

In summary, the % large *Daphnia* metric primarily addresses top-down impacts, although it can also be negatively affected by increasing eutrophy. Reduction in size is an indicator of high planktivory by fishes including White Perch and Alewife, which may be present under more eutrophic conditions and when there are few piscivores in the system. In the Bay of Quinte, a trend toward increasing large *Daphnia* over time is expected as planktivory declines.

6) Percent *Daphnia galeata mendotae*

The percent of *D. galeata mendotae* biomass relative to total crustacean biomass also relates to cladoceran mean size and percent large *Daphnia*. This species is considered by some as an indicator of oligotrophy (Pejler 1983), although their numbers are often controlled by plankivory. *Daphnia* are preferentially consumed by a variety of planktivorous fish species including Alewife (Brooks and Dodson 1965; Strus and Hurley 1992), age-0 White Perch and Yellow Perch (Prout et al. 1990) and adult White Perch (Couture and Watzin 2008). *D. galeata mendotae* seldom reaches high densities when planktivorous fishes are abundant (Brooks and Dodson, 1965; Evans and Jude 1986; McQueen and Post 1988; Pothoven et al. 2013). Strus and Hurley (1992) suggested that Alewife abundance <40 kg.ha^{-1} was necessary for *D. galeata mendotae* to persist in the upper Bay of Quinte. Furthermore, large cladoceran species such as *Daphnia* may be more negatively affected than small cladocerans and rotifers in systems dominated by potentially toxic filamentous cyanophytes during blooms (de Bernardi and Guissiani 1990, Ghadouani et al. 1998, Kirk and Gilbert 1992). In the Bay of Quinte, a trend toward increasing *% D. galeata mendotae* is indicative of reduced food web impacts from potentially toxic filamentous cyanophytes during blooms.

Daphnia galeata mendotae
Sars 1864; Birge 1918

Daphnia galeata mendotae is one of the largest herbivorous cladoceran species in the Great Lakes and can range in length from 1.0 – 3.0 mm (Balcer et al. 1984). In the Bay of Quinte, individuals from the upper and middle bay have a mean size of 0.95 mm (1995 to 2015), with individuals from the lower bay being slightly smaller (0.88 mm). They are found in all five Great Lakes and are most abundant in Lake Erie. *D. galeata mendotae* reproduces rapidly in early summer and population sizes peak in the late summer and fall. *D. galeata mendotae* are most common in large, deep, transparent water and prefer the upper water strata (top 10 m).

They migrate towards the surface at night. This species is sometimes higher in the water column than *D. retrocurva*, although they can occur near the bottom of shallow lakes due to their adaptation to low dissolved oxygen concentrations. They are filter feeders preferring small algae in the 1 to 20

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μm size range (preferentially chlorophytes), although they can also feed on filamentous algae.

7) Percent *Mesocyclops*

Mesocyclops is a large cyclopoid copepod that is common in the Bay of Quinte. Other studies report this species to be abundant in eutrophic systems. For example, *Mesocyclops edax* was among the most dominant crustacean zooplankton in small eutrophic lakes in Ontario (Brandl and Fernando 1979), Florida (Wyngaard et al. 1982) and eutrophic Lake Vőrtsjärv in Estonia (Haberman and Haldna 2014).

The percentage of *Mesocyclops* biomass relative to total adult cyclopoid biomass is proposed as an indicator of fish planktivory in the Bay of Quinte This species is desirable to planktivorous fishes due to its large size relative to other cyclopoids and small cladocerans. It is a preferred prey of Alewife in the Bay of Quinte (Strus and Hurley 1992). Other studies show it can be reduced or eliminated by high planktivory (e.g., Brooks and Dodson 1965; Wells 1970; Meyer and Effler 1980; Chang et al. 2005,). As *Mesocyclops* itself is predatory, feeding on rotifers and other crustacean zooplankton (Brandl and Fernando 1979), it also provides a measure of invertebrate planktivory in the system. It may be especially important as an invertebrate predator in the upper bay where other predators such as *Cercopagis* and the cyclopoid *Diacyclops thomasi* are less common.

Mesocyclops edax

S.A. Forbes 1891
Adult female *Mesocyclops edax* can range from 1 – 1.7 mm in length and the males are slightly smaller (0.7 – 1.0 mm) (Balcer et al. 1984). In the Bay of Quinte, they have historically been smaller, averaging 0.92 µm. They are common in small lakes and ponds throughout North America, and are found in all five Great Lakes. Their highest densities are in eutrophic lakes (Lake Erie) and embayments (Green Bay, Lake Michigan), with peak populations occurring between July and September. *M. edax* distribution is linked to warm temperatures. They are common in the littoral zone and near the bottom in warm, shallow lakes, but in larger cooler lakes will concentrate in the epilimnion and nearshore areas. Their diet consists of small *Daphnia*, rotifers, copepod copepodids and nauplii and even small larval fish. While they are preferentially carnivorous, they will also consume detritus, protozoans, bacteria and algae. *M. edax* are eaten by White Bass, Alewife, bullheads, Black Crappie, Freshwater Drum and perch species.

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In summary, *Mesocyclops* is typically thought of as an eutrophic species, but because it is so strongly controlled by high planktivory (considered to be undesirable in the Bay of Quinte), we expect to see an increase in the proportion of *Mesocyclops* relative to other cyclopoids over time in the Bay of Quinte.

8) Rotifers

Rotifers are small non-crustacean zooplankton that can be very abundant in freshwater systems worldwide. They consume larger bacteria, heterotrophic flagellates and small ciliates (Arndt 1993) and are an important prey item of fish fry and invertebrate predators (Wallace 2002). Among the invertebrate predators known to consume rotifers are *Diacyclops thomasi* and *Mesocyclops edax* (Balcer et al. 1984) and rotifers may be predated upon by the invasive cladocerans *Cercopagis* and *Bythotrephes* as they fall within their preferred prey size range (Makarewicz and Lewis 2015).

Rotifers are among the most widely accepted zooplankton indicator taxa (Čeirāns 2007; Gannon and Stemburger 1978; Sládeček 1983). Most of the common rotifers found in the Bay are ubiquitous taxa that are also dominant at other Great Lakes locations (e.g., Makarewicz and Lewis 2015, Barbiero and Warren 2011). In the Bay of Quinte, rotifers have only been collected since 2000 and therefore available rotifer data are coincident with a narrow range in trophic conditions especially within stations. During the 2000 – 2015 time period, when all stations are combined, the trophic gradient is sufficient to expect a rotifer response. Rotifer taxa identified as indicators of eutrophic conditions in the Great Lakes by Gannon and Stemburger (1978) include species of the genus *Brachionus*, *Polyarthra euryptera, Anuraeopsis fissa*, *Keratella cochlearis f. tecta, Trichocerca cylindrica, T. multicrinis* and *Filinia longiseta*. As the trophic state shifts to less eutrophic conditions in the Bay of Quinte, we would expect to see a declining proportion of the eutrophic taxa.

Summary: Proposed BUI 13 Delisting Criteria

Demonstrate that the upper and middle Bay of Quinte phytoplankton and zooplankton populations are unimpaired based on ecosystem function. Evidence based on the function of food web processes, community composition, and biodiversity will be combined in a multi-parameter weight of evidence approach for this assessment.

1) Demonstrate that the efficiency of energy and nutrient transfer through the food web from phytoplankton to zooplankton to fishes is consistent with a functional shallow freshwater ecosystem of similar trophic status, as demonstrated through the following suite of trophic ratios describing bottom-up (a-f) and top-down (g-m) food web processes:

    a. phytoplankton biomass to TKN (P:TKN)
    b. zooplankton biomass to TKN (Z:TKN)
    c. planktivorous fish biomass to TKN (PlanktF:TKN)
    d. zooplankton biomass to phytoplankton biomass (Z:P)
    e. Z:P regression with TP and TKN
    f. Daphnia biomass to phytoplankton biomass (D:P)
    g. Z:P regression with planktivorous fish biomass
    h. planktivorous fish biomass to zooplankton biomass (F:Z)
    i. planktivorous fish biomass to Daphnia biomass (F:D)
    j. planktivorous fish biomass to phytoplankton biomass (F:P)
    k. piscivorous fish biomass to zooplankton biomass (Pis:Z)
    l. piscivorous fish biomass to phytoplankton biomass (Pis:P)
    m. yellow perch to white perch biomass (Yperch:Wperch)

2) Demonstrate food web function of the phytoplankton community based on the assessment of nuisance algae (including filamentous diatoms and colonial and filamentous Cyanobacteria) and edible algae (including an assessment of Chrysophyceae).

    a. Demonstrate a positive change in phytoplankton species composition with a decrease in nuisance and eutrophic and noxious indicator species that may impair food web function as indicated through the following measures:
        i. A decrease in nuisance phytoplankton to less than 50% of the biomass (i.e. < 2.5 g m^{-3} in the upper bay offshore based on the existing target for BUI 8 of phytoplankton biomass of 4 – 5 g m^{-3})
        ii. A decreasing trend in filamentous and colonial / mucilaginous Cyanobacteria (both in terms of biomass and relative composition)
        iii. A decreasing trend in filamentous diatoms (biomass and % composition).

    b. Show an increasing trend in phytoplankton taxa that provide an ample food resource for zooplankton and other grazers through the following measures:
        i. An increase in the more edible phytoplankton taxa to approximately 30% of the biomass
        ii. An increase in the biomass of Chrysophyceae with an ideal target of > 15% of total phytoplankton biomass

3) Demonstrate that the zooplankton community structure is consistent with a functional food web through the following measures:

   a. Indicators of reduced impact from eutrophy and high fish planktivory by:

      i. An increase in cladoceran mean size
      ii. Decreased *Chydorus* biomass relative to the values in the 1970s and early 1980s
      iii. Reduced proportion of *A. vernalis* relative to total adult cyclopoid biomass
      iv. A trend toward increasing diversity index scores in the zooplankton community over time

   b. Indicators of low fish planktivory by:

      i. A trend toward increasing large *Daphnia* over time
      ii. A trend toward increasing *% D. galeata mendotae*
      iii. An increase in the proportion of *Mesocyclops* relative to other cyclopoids
      iv. A declining proportion of eutrophic rotifer taxa

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