Freshwater cage aquaculture in Ontario: A synopsis of cage aquaculture effects on sediment and water quality in the Great Lakes

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Purpose / Outline

To provide an overview of the available science on the effects of freshwater cage aquaculture on sediment and water quality in the Great Lakes.

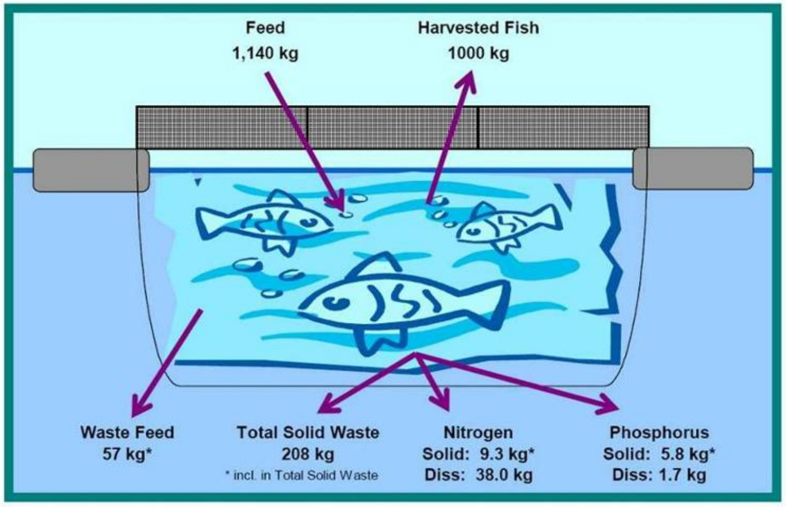
- Water Quality
  - Phosphorus
  - Dissolved oxygen
- Depositional Model Scenarios
- Sediment Quality
  - Sediment Chemistry
  - Benthic Invertebrate Community
  - Invertebrate Toxicity Bioassay
- Faecal Accumulation Rate Experiment

Background – Freshwater Cage Aquaculture in Ontario

- Commercial-scale cage aquaculture operations are located in public waters of Lake Huron/North Channel and Georgian Bay
- Lake Huron/North Channel and Georgian Bay are considered a pristine oligotrophic system
- Heterogeneous coastline (e.g., embayments, coastal nearshore, offshore); diverse shoreline (e.g., fringing wetlands, rock bluffs)
- Cage array range from clustered attached-to-shore to dispersed open-water offshore configuration; operations are located in shallow (< 20m) and deep (> 80m) areas
- Changes in feed formulation, use of low-phosphorus feed and improved feeding strategies have reduced the amount of nutrients and organic waste discharged to the natural environment

Waste Output

Figure 5.1: Typical inputs and outputs associated with cage culture of rainbow trout per tonne of fish produced (Data from Bureau et al. 2003)



(Stechey *et al*, 2005)

- Waste from aquaculture facilities is mainly excretory material (urine and faeces) with some feed waste
- Predicted food conversion ratio range 1.14 to 1.29 (Bureau *et al*, 2003)

Waste Output (Bureau *et al*, 2003)

- Total Nitrogen: 80% is in dissolved form, 16% in faeces
- Total Phosphorus (Cho & Bureau, 1998): 60 - 70% faeces
- Waste output per metric ton of fish produced (Bureau *et al*, 2003):
  - Total solid waste range 240 to 318 kg (or < 150 kg solid for low-pollution feed (Cho *et al*. 2000))
  - Total nitrogen waste range 47 to 71 kg
  - Total phosphorus waste range 7.5 to 15.2 kg
- A 500 metric ton (T) operation will discharge:
  - Solids waste – 120T to 159T (75T for low-pollution feed)
  - Total nitrogen – 23.5T to 35.5T
  - Total phosphorus – 3.8T to 7.6T

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Survey Description and Methods

Water Quality Surveys (spring, summer, fall surveys) (1980/90s, 1998 – present)

- Nutrients (e.g., total phosphorus, total nitrogen),
- conductivity, chloride, dissolved organic carbon (DOC), total suspended solids (TSS), chlorophyll pigments, pH, hardness, colour, turbidity

Physical profiles (1987 – 2011)

- Dissolved oxygen concentration, temperature, transmission, conductivity with depth profiles
- Underwater light climate (PAR, UVR)

Real-time *in situ* sensors (2007 – 2011)

- Real-time data generally collected in 10 – 30 min increments throughout ice-free season
- Dissolved oxygen (%, mg L^{-1}): temperature in 2 – 3 meter increments
- Water level logger, conductivity, turbidity, chlorophyll a, PAR, current velocity and direction

Sediment Quality Surveys (1999 – 2009)

- Total organic carbon (TOC), total phosphorus (TP), total Kjeldahl nitrogen (TKN), zinc, copper, loss on ignition, particle size distribution
- Sediment toxicity bioassays
- Benthic macroinvertebrate community – taxonomy and enumeration

Faecal waste accumulation experiment

- Test organism: *Lumbriculus variegatus*
- Overlying water quality parameters measured; sediment chemistry
- Toxicological Indicators: % mortality, reproduction, total biomass, individual biomass, behaviour

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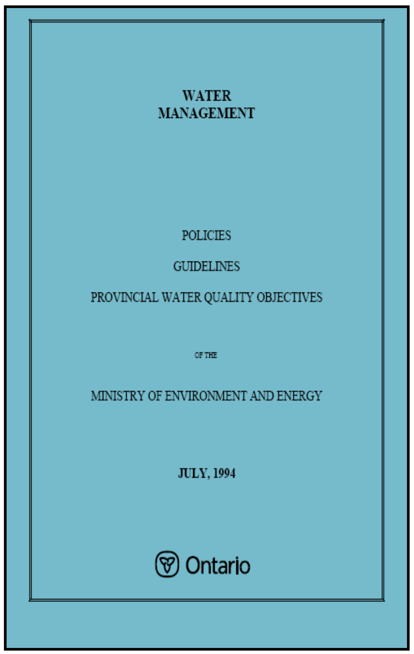
The Great Lakes:
Water Quality and Cage Aquaculture



WATER
MANAGEMENT

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PROVINCIAL WATER QUALITY OBJECTIVES

OF THE

MINISTRY OF ENVIRONMENT AND ENERGY

JULY, 1994

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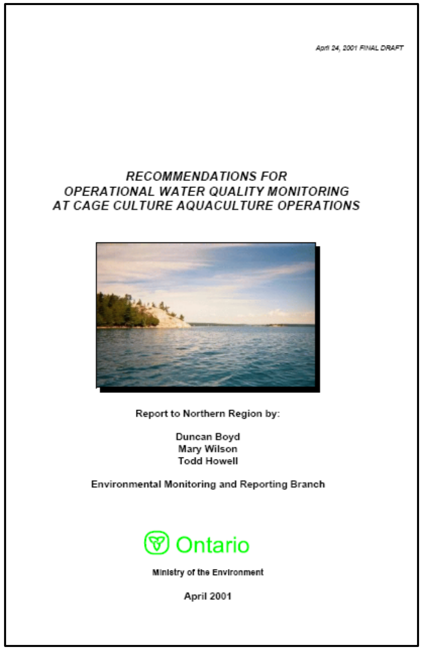


April 24, 2001 FINAL DRAFT

RECOMMENDATIONS FOR
OPERATIONAL WATER QUALITY MONITORING
AT CAGE CULTURE AQUACULTURE OPERATIONS

Report to Northern Region by:

Duncan Boyd
Mary Wilson
Todd Howell

Environmental Monitoring and Reporting Branch

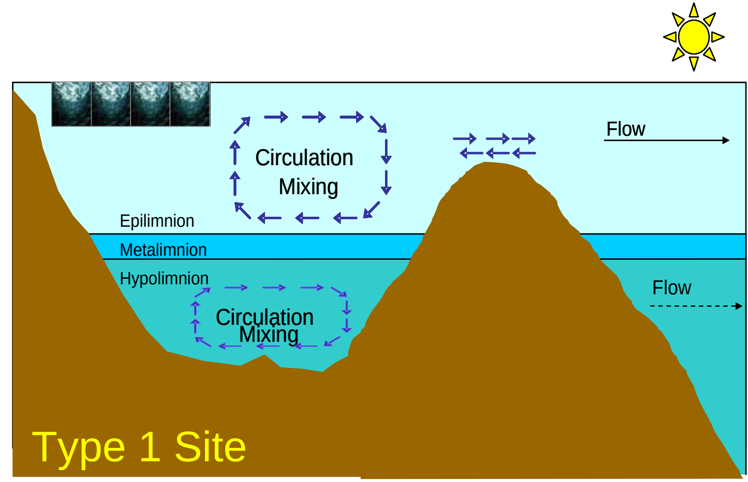
Ontario

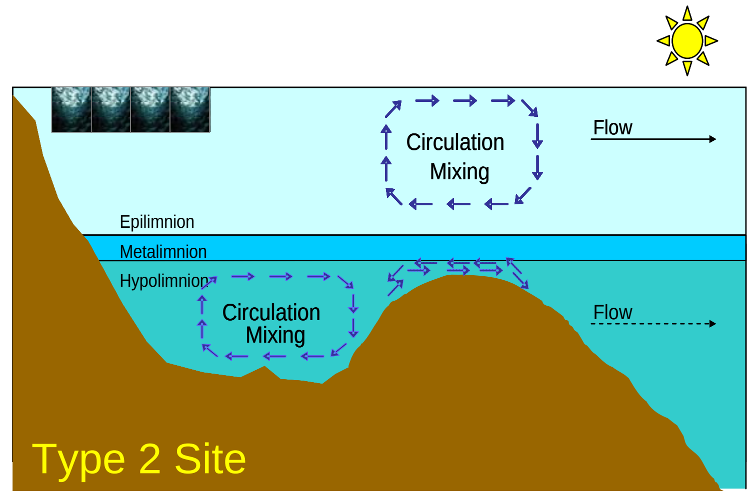
Ministry of the Environment

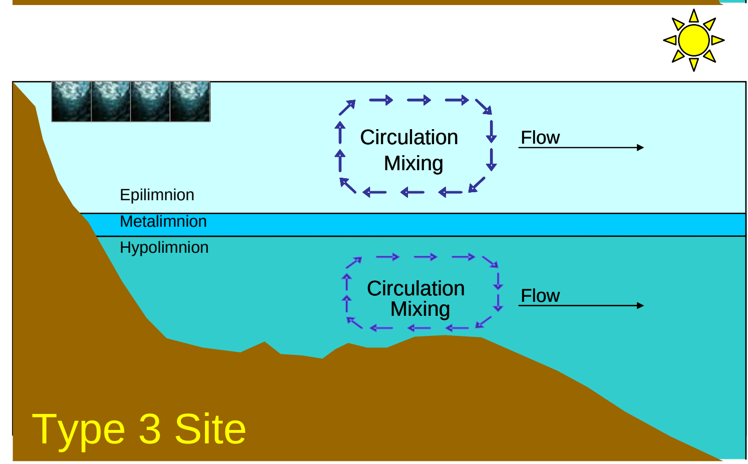
April 2001

Water Quality - Highlights

- Potential for water quality effects
  - Range from negligible effects at exposed, well-flushed sites to eutrophication effects at sheltered sensitive site
  - Eutrophication effects include severe dissolved oxygen depletion, algal blooms and nuisance algae
- Sites can be classified based on their potential sensitivity to discharges from cage aquaculture operations:
  - Type 1: Enclosed (lake like) waterbodies/ embayments with limited flushing;
  - Type 2: Partially exposed sites having good surface water layer (epilimnion/metalimnion) flushing but having limited or no deep water layer (hypolimnion) exchange; and
  - Type 3: Exposed locations where the deep water layer (hypolimnion) is also well flushed
- Most commercial-scale cage aquaculture operations are located in exposed open-water areas (Type 3) of the North Channel/Georgian Bay
- Type 3 locations are not susceptible to hypolimnetic oxygen depletion and are unlikely to exhibit significant nutrient related water quality effects







Water Quality - Phosphorus

(Reid et al, 2006)

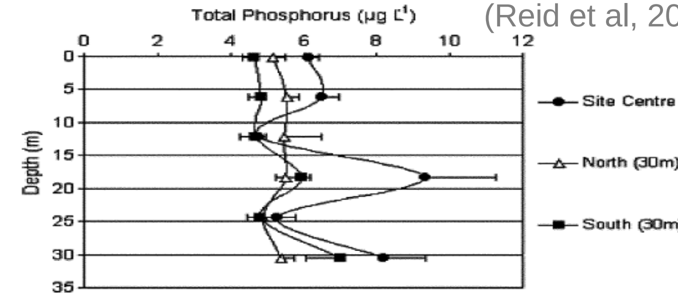


Fig. 4 Mean, five-day Tot-P depth profiles during peak annual production in 2002. The range of one standard error is shown only on a single side of each mean to facilitate figure viewing.

- Water quality impacts are more likely in a location that is locally enclosed (Type 1) or where the there is little to no hypolimnetic exchange with that of the open-waters (Type 2)

- Phosphorus (TP) is a limiting nutrient in temperate freshwater waterbodies; elevated TP can lead to eutrophication

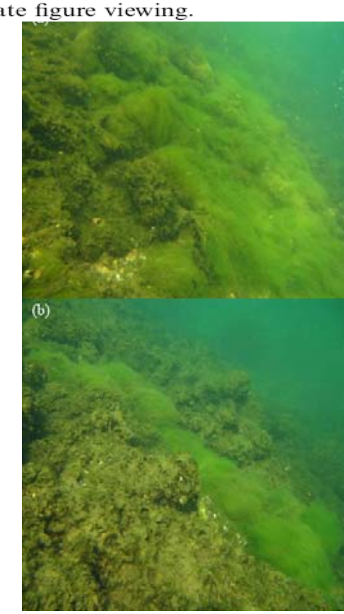
- Local water quality gradients; increases with proximity to cages
  - TP can be high and variable in the immediate vicinity of the cages
  - Generally TP is < 10 µg L^{-1} at 30m from the cages (Reid *et al*, 2006)

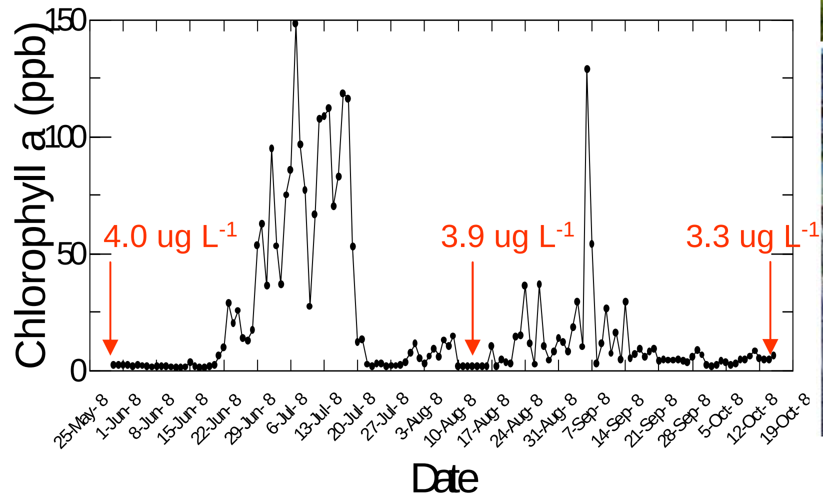
- Phosphorus (TP) levels are generally < 10 µg L^{-1} at Type 3 sites

- Elevated TP levels > 10 µg L^{-1} observed at Type 1 and 2 sites
  - Seasonal variability
  - Springtime TP < 10 µg L^{-1};
  - Summer and fall TP > 10 µg L^{-1}

- Algal blooms observed
  - Occur multiple times annually
  - Produce toxins (Microsystin-LR)

- Occurrences of nuisance algae





(Hille, 2006)

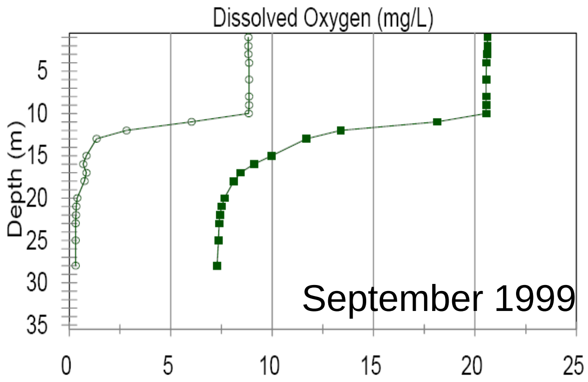
Water Quality – Dissolved Oxygen

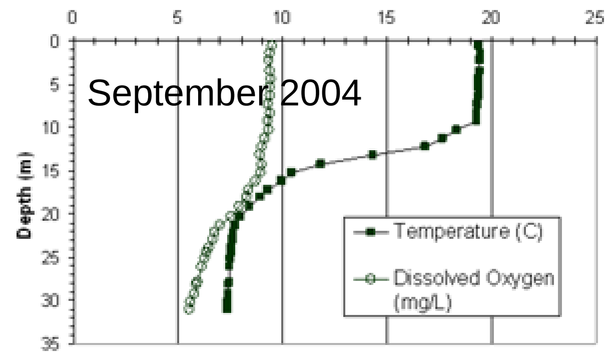
- Severe dissolved oxygen (DO) is a concern as this condition is lethal to the aerobic aquatic biota; can lead to the release of metals and nutrients from the sediment
  - Type 1 and 2 sites are more susceptible to dissolved oxygen depletion during the summer stratification period as there is a finite amount of dissolved oxygen available in the deep cooler waters

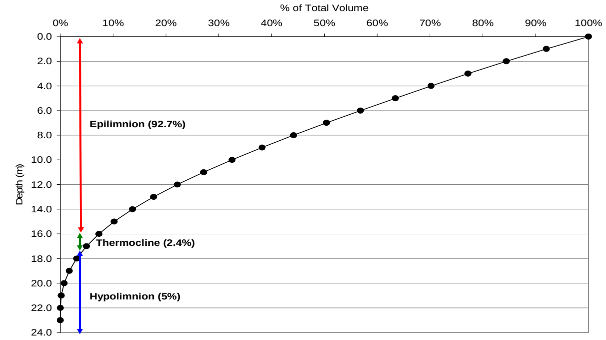
- Maintaining a minimum DO level is essential for aerobic aquatic biota
  - Hypoxia: DO levels significantly below 100% saturation
  - Anoxia: DO levels below 1 mg L^{-1}

- Discharge of nutrients and high-BOD waste into sensitive ecosystems can lead to severe dissolved oxygen depletion
  - Potential for wide-spread hypolimnetic anoxia

- Type 3 locations are not susceptible to severe hypolimnetic dissolved oxygen depletion
  - No significant depletion of oxygen in the immediate vicinity of the cages; dissolved oxygen concentration > 6.0 mg L^{-1}







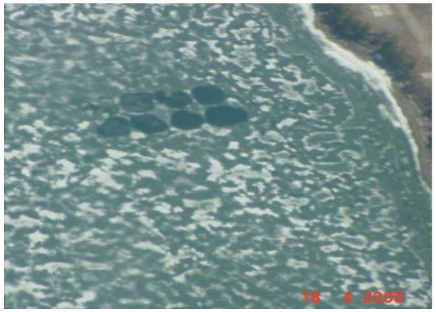
Dissolved Oxygen Depletion: Profiles

- Volume-weight averaged hypolimnetic dissolved oxygen (VWHDO) approach recommended for Type 1 and 2 sites if the following information is available:
  - Detailed bathymetry data
  - Temperature and dissolved oxygen profile data

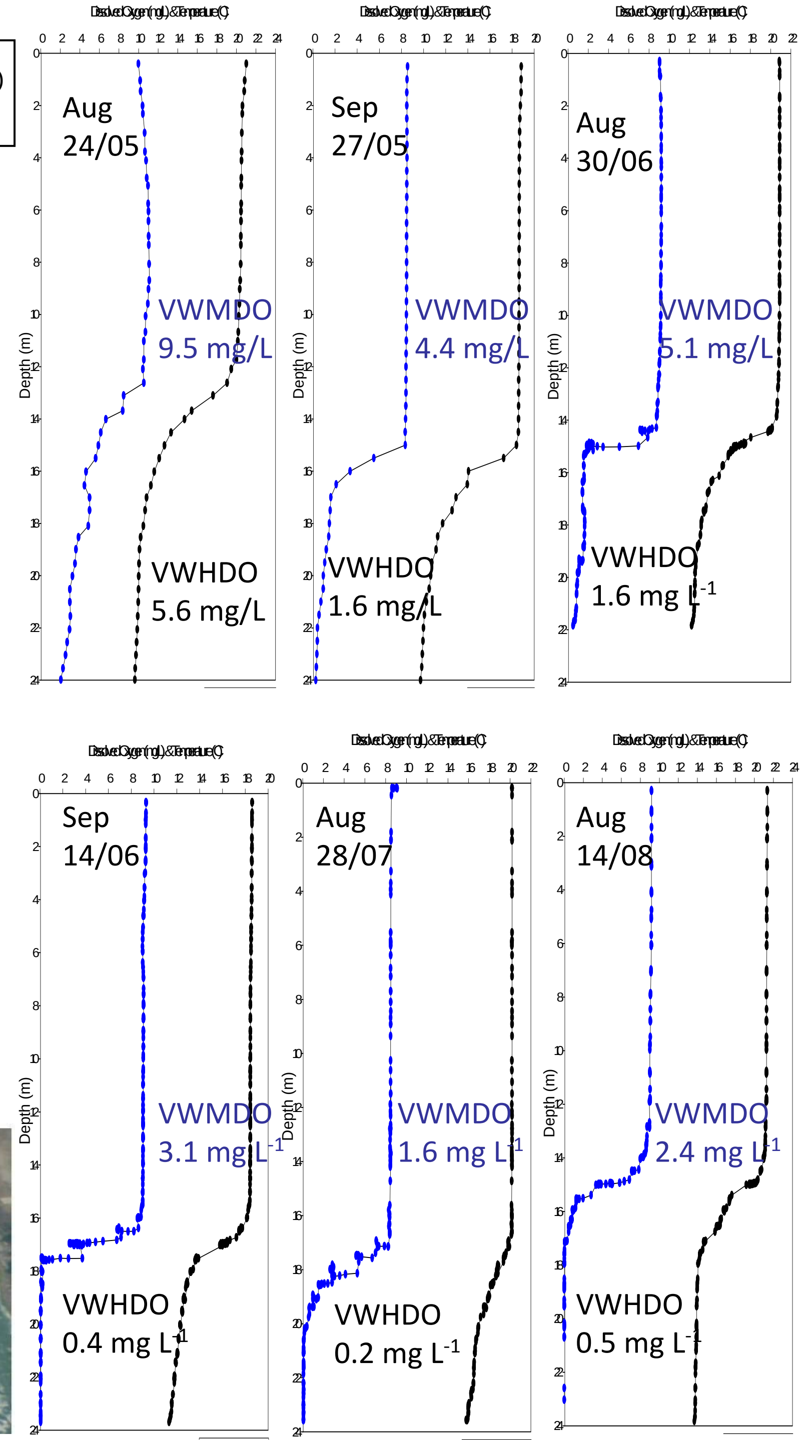
- VWHDO approach integrates DO concentration over depth and area

- Tracked progressive deterioration of hypolimnetic DO condition
  - Wide-spread hypolimnetic anoxia with VWHDO < 1 mg L^{-1}

- Recovery observed at decommissioned Type 1 site
  - ~ 6 years after site was decommissioned, DO levels returned to normal



Type 1 Site, 2005 (decommissioned 1997/98)



Dissolved Oxygen: VWHDO

VWHDO concentrations are high in early-summer

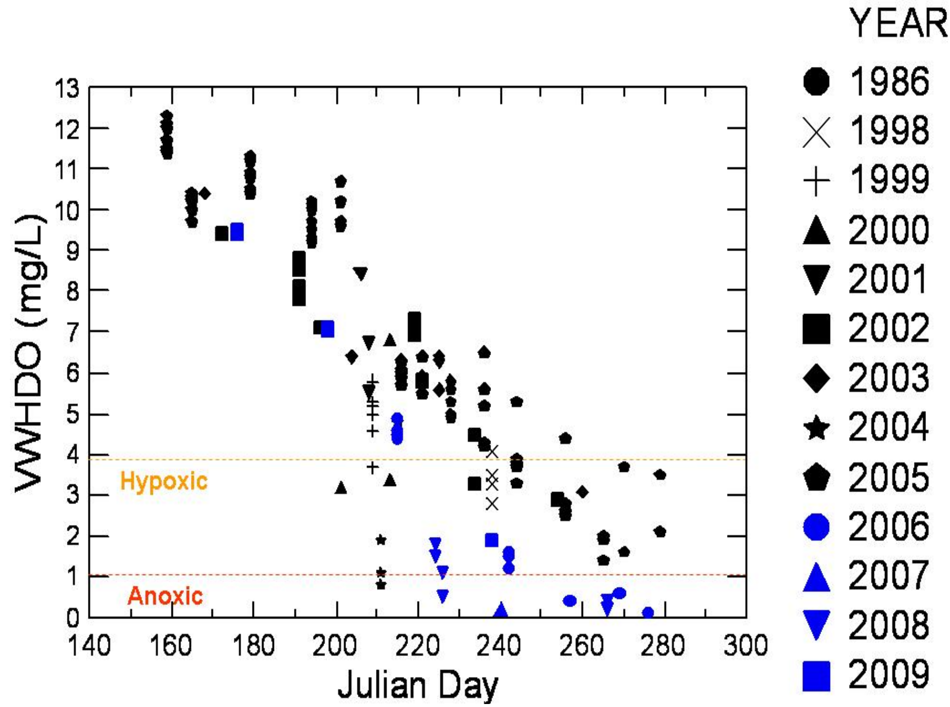
- Declines over the ice-free season
- Loss of cold-water habitat when VWHDO < 1.0 mg L^{-1}
- Loss of cool-water habitat when VWMDO < 1.0 mg L^{-1}

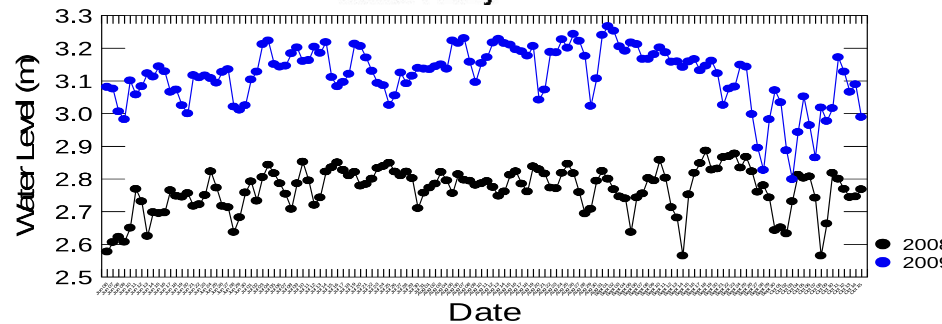
Type 2 site is naturally hypoxic

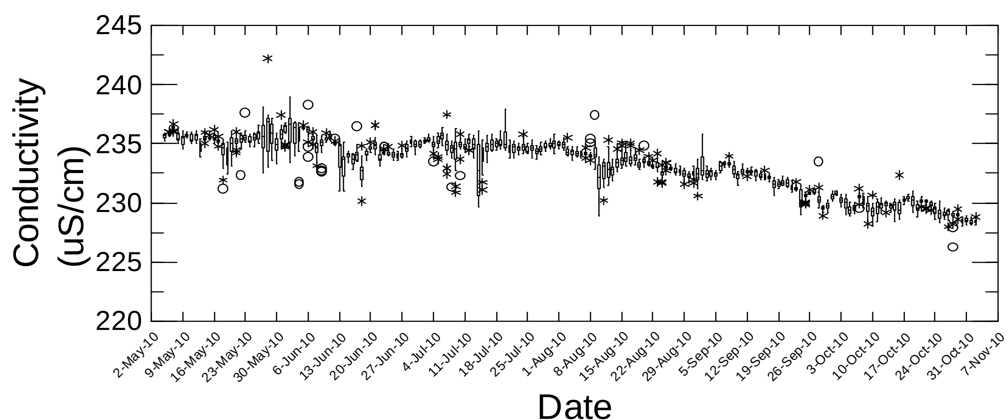
- VWHDO reached anoxic levels in post-2005
- VWMDO reached anoxic levels in 2008

Embayment characteristics

- Chlorophyll *a* levels < 5 µg L^{-1}
- Clear-water system: low DOC (< 4 mg L^{-1}) and particulate (SS < 2 mg L^{-1}) levels
- Physically dynamic environment with fluctuating water level and hypolimnetic thickness
- Vigorous water exchange with the Great Lakes
- Watershed loading assessment

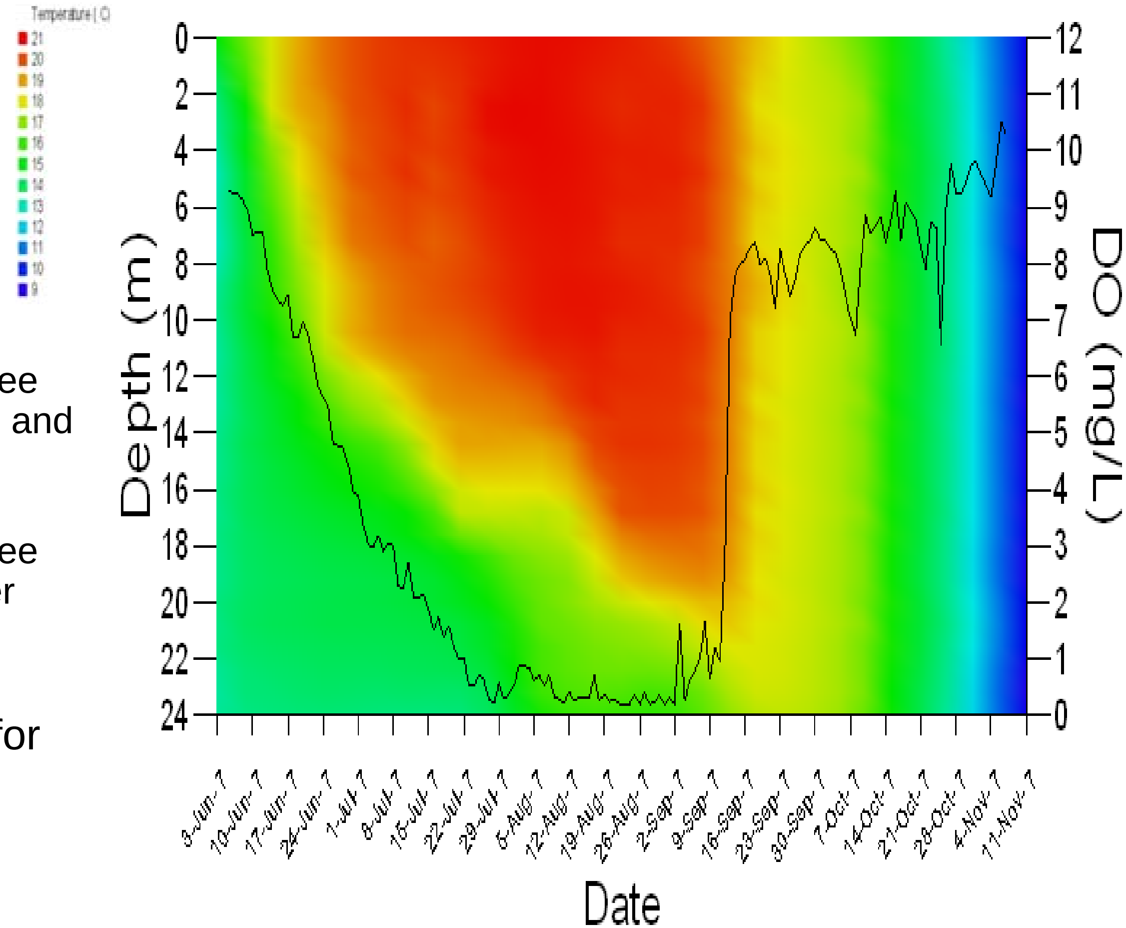


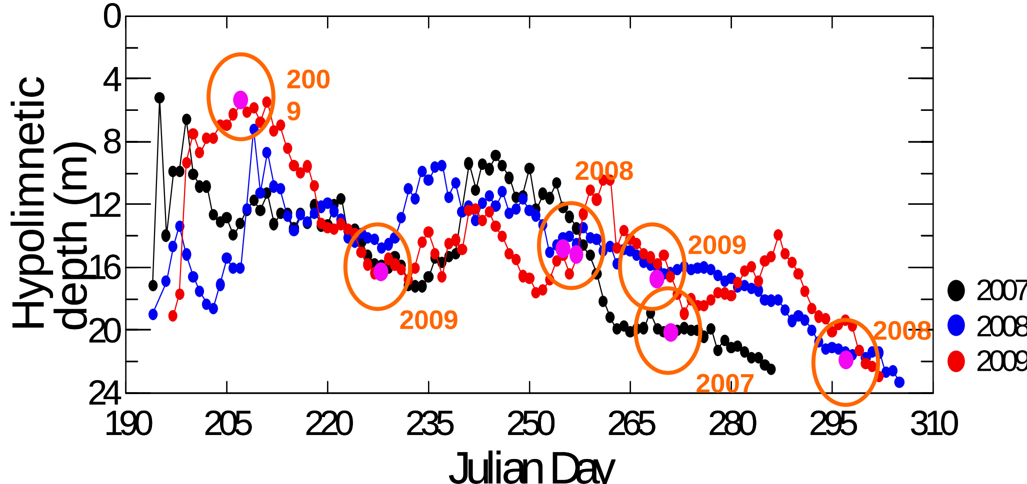


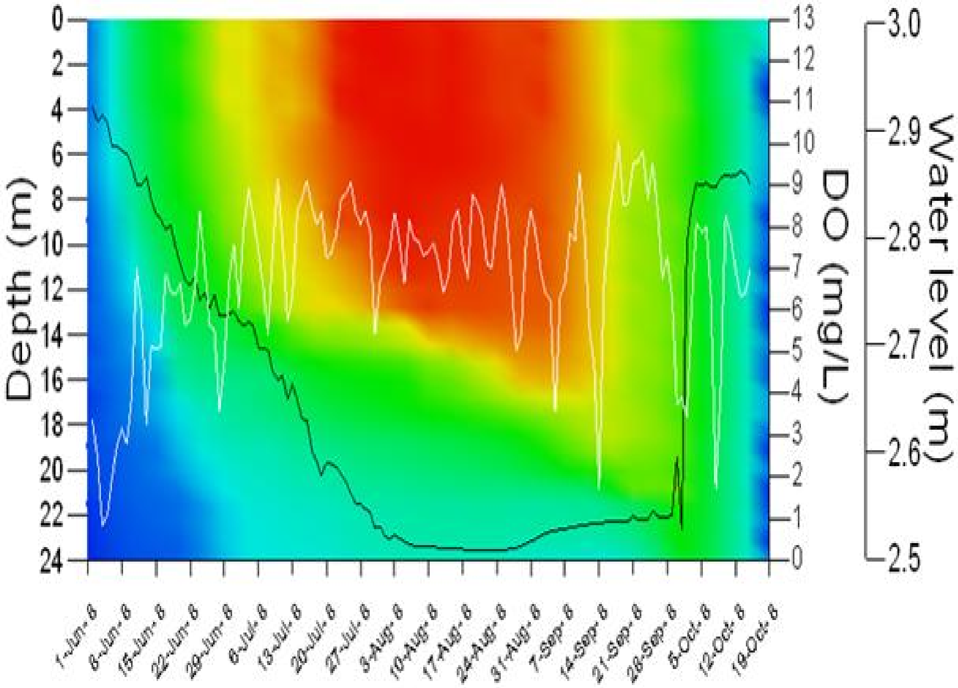


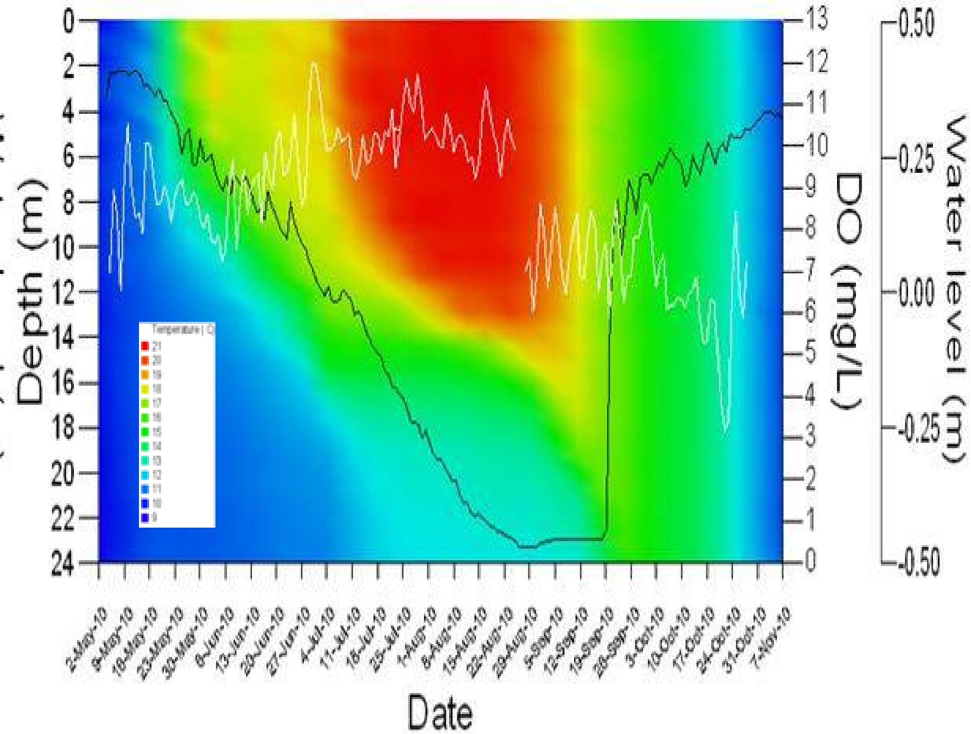
Real-time Continuous Sensors

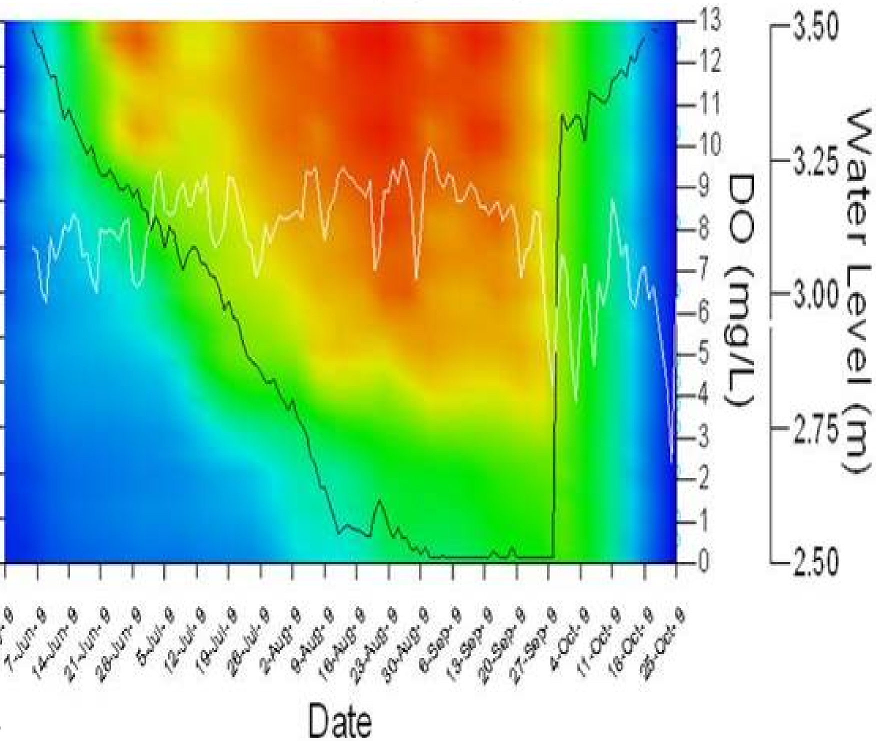
- High resolution dataset
  - DO concentration in 30 minute increments throughout the ice-free season (epilimnion, hypolimnion and mid-water column)
  - Temperature in 10 - 15 minute increments throughout the ice-free season and throughout the water column
- Thermal structure of waterbody for ice-free season
- Data used to determine:
  - Stratification period
  - Temperature range
  - Duration of hypolimnetic hypoxia and anoxia
  - Rate of hypolimnetic DO depletion
  - Hypolimnetic depth
- Multi-year dataset allows for comparisons between years











- Thermal structure varies between years; anoxic condition observed annually
- Number of stratified days range 93 - 112 days
- Temperature range 8.2 - 24.1°C
- Number of days to reach anoxic conditions range 41 - 82 days
- Physically dynamic system – water level variability

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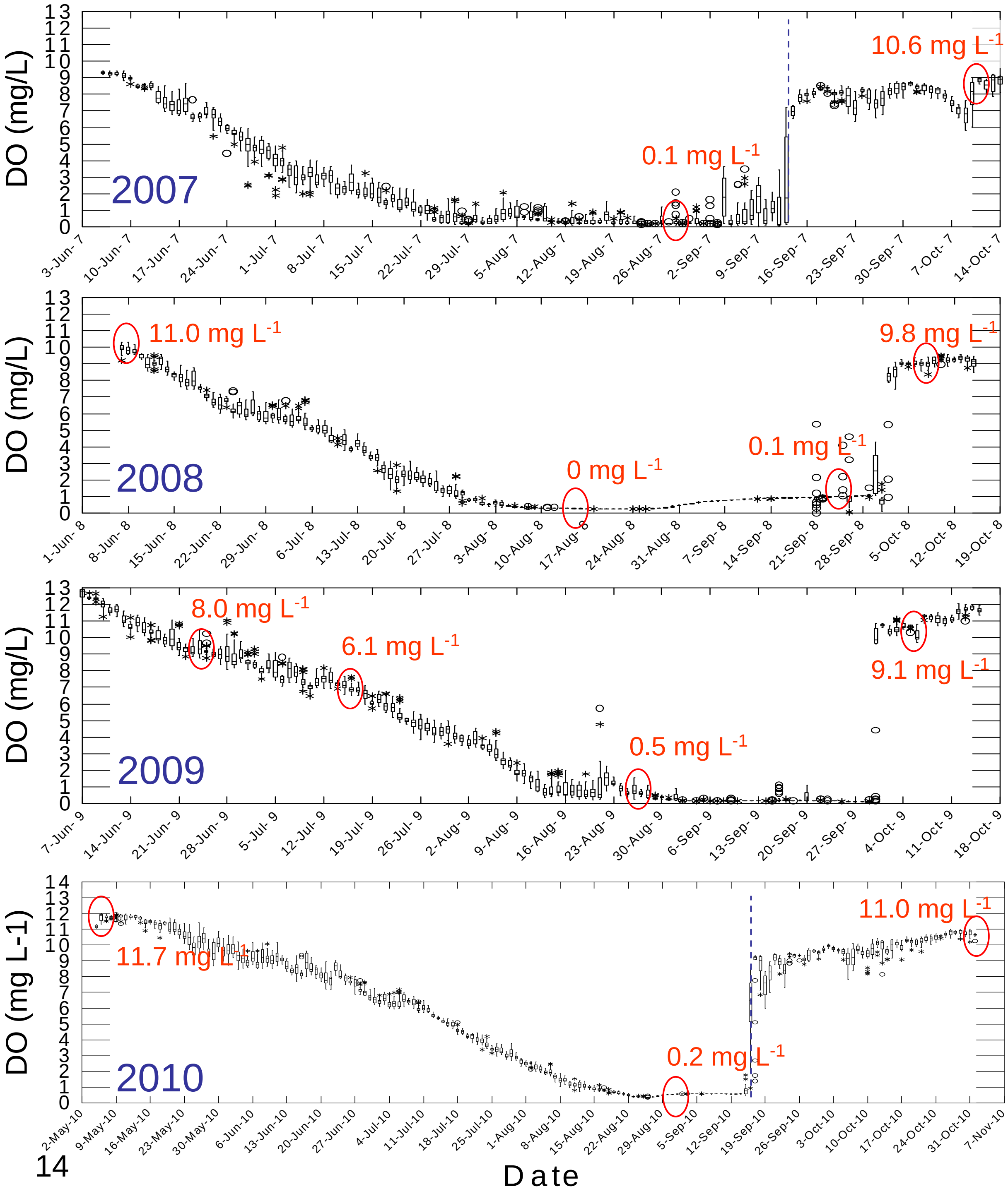


DO Depletion

- Good correspondence between real-time measurements and physical depth profile data
- Initial DO and thermal condition vary between years
  - 2010 onset of stratification occurred ~ 3 weeks earlier; cooler more oxygenated hypolimnion

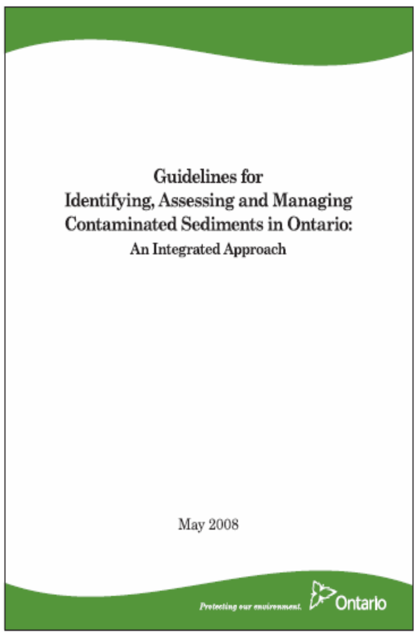
Hypolimnetic hypoxia (< 4.0 mg L^{-1})

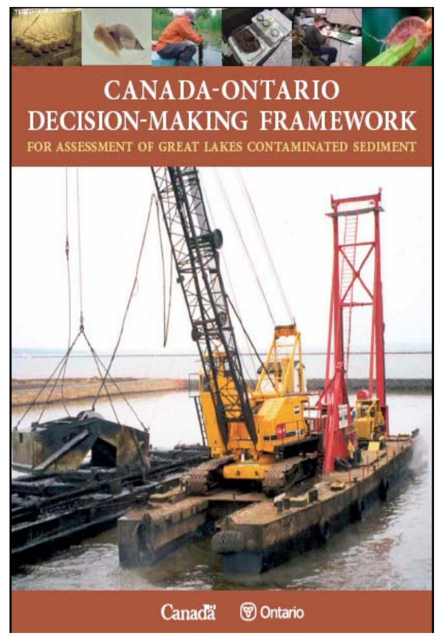
- 2007: 73 days
- 2008: 81 days
- 2009: 59 days
- 2010: 55 days

Hypolimnetic anoxia (< 1.0 mg L^{-1})

- 2007: 45 days
- 2008: 52 days
- 2009: 47 days
- 2010: 32 days

The Great Lakes:
Sediment Quality and Aquaculture





Sediment Quality - Highlights

- Sediment serves two key functions:
  - a habitat for aquatic organisms
  - a food source for benthic organisms which in turn form the base of the benthic food web for fish and are good indicators of ecosystem health
- Effects are local; occur in the immediate vicinity of cages
- Contaminant levels can be variable, but generally follow a spatial gradient of decreasing concentration with distance from the cages

Table 1: Provincial Sediment Quality Guidelines for Metals and Nutrients[a]

	No Effect Level	Lowest Effect Level	Severe Effect Level
METALS			
Arsenic	-[b]	6	33
Cadmium	-	0.6	10
Chromium	-	26	110
Copper	-	16	110
Iron (%)	-	2	4
Lead	-	31	250
Manganese	-	460	1100
Mercury	-	0.2	2
Nickel	-	16	75
Zinc	-	120	820
NUTRIENTS			
TOC(%)[c]	-	1	10
TKN[c]	-	550	4800
TP[c]	-	600	2000

[a] Values in µg/g dry weight unless otherwise noted (µg/g = ppm). Values less than 10 have been rounded to one significant digit. Values greater than 10 have been rounded to two significant digits except for round numbers which remain unchanged (e.g., 400).

[b] "-" denotes insufficient data/no suitable method

[c] TOC – Total Organic Carbon; TKN – Total Kjeldahl Nitrogen; TP – Total Phosphorus

- Local sediment quality effects range from:
  - nutrient-enriched sediment with high densities of pollution-tolerant macroinvertebrates, indicative of waste assimilation ***to***
  - Sediment devoid of macroinvertebrates (azoic), sediment chemistry exceeds the PSQG-SEL and/or sediment toxicity, indicative of gross pollution effects
- Waste assimilation occurs at low accumulation rates (amount of waste deposited per m^2, per day) through conversion of waste to benthic biomass as indicated by abundance, high growth rates and/or reproduction
- Waste assimilation does not occur at high accumulation rates as growth rates are inhibited and conditions can be toxic to benthos

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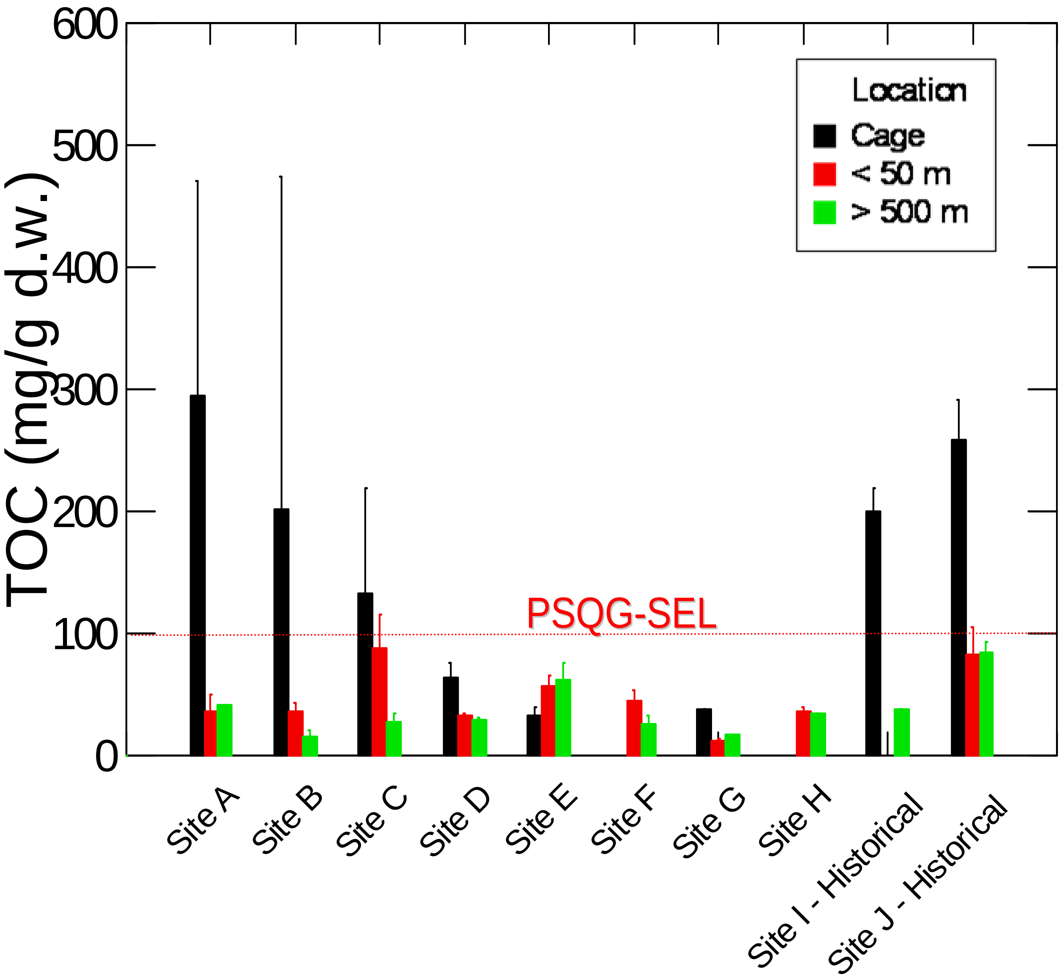
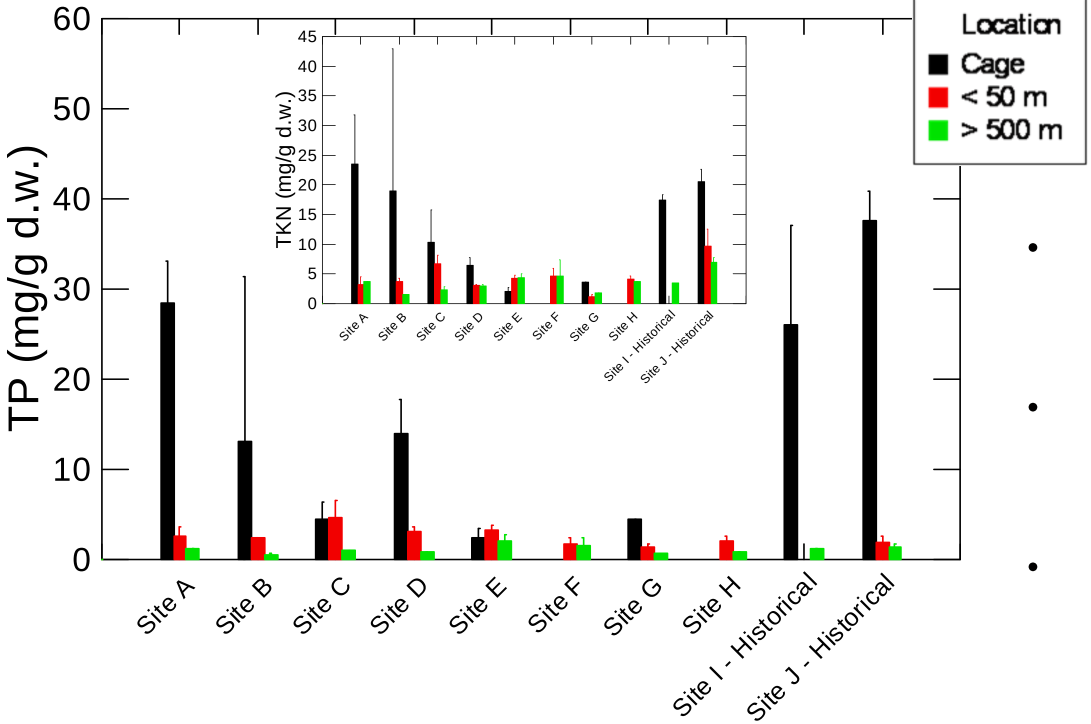
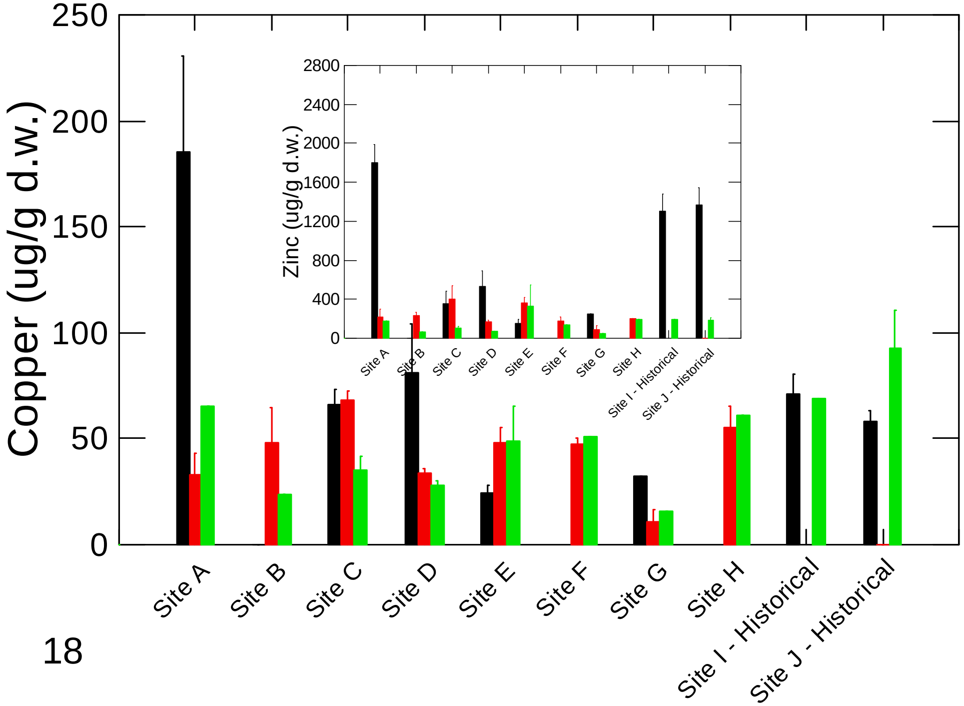
Sediment Chemistry – Organic Carbon



- Organic enrichment in the immediate vicinity of the cages
- Total organic carbon (TOC) is variable and elevated at the cages
  - Range: 25 to 520 mg/g
- Provincial Sediment Quality Guideline Severe Effect Level (PSQG-SEL) (100 mg/g) is exceeded at 3 active and 2 historical cage sites
- TOC levels at < 50 m is general low, but can be as high as 400 mg/g
- TOC at reference site is low (33 mg/g)
- Loss on ignition is elevated at cages; maximum LOI 750 mg/g
  - LOI > 300 mg/g observed at 2 actives and 2 historical sites
  - Reference LOI is generally low (66 mg/g)



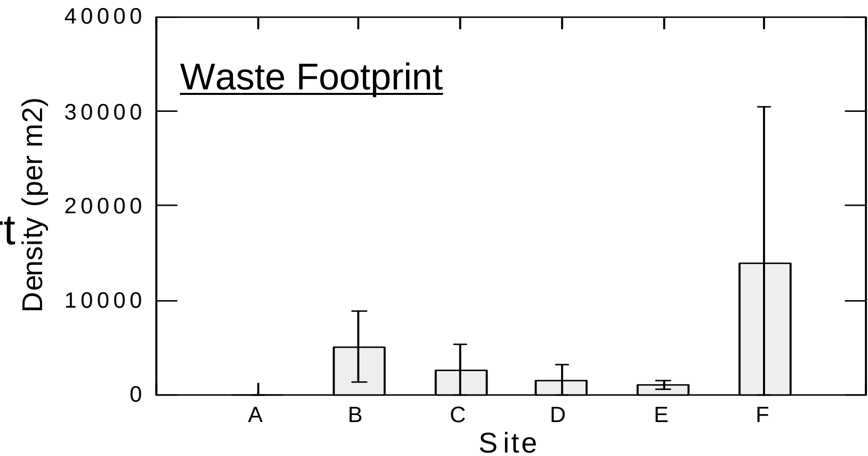


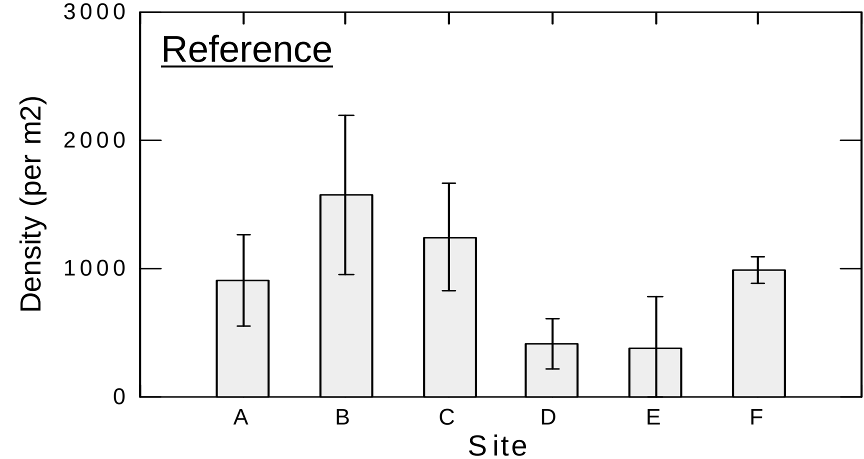
Sediment Chemistry

- Nutrient and metal enrichment (TP, TKN) in the immediate vicinity of the cages
- All sites exceeded PSQG-SEL for TP (2.0 mg/g); maximum concentration 59.9 mg/g
- Most sites exceeded PSQG-SEL for TKN (4.8 mg/g) (4 active and 2 historical sites); maximum concentration 35 mg/g
- One site exceeded PSQG-SEL for copper (110 ug/g) and 3 sites for zinc (820 ug/g)
  - Maximum copper concentration 210 ug/g
  - Maximum zinc concentration 2300 ug/g
- Reference sites generally low TP (0.8 mg/g), TKN (3.2 mg/g), copper (37 ug/g) and zinc (76 ug/g) compared to cage sites

Benthic Invertebrate Community

- Benthic macroinvertebrates are an important part of the aquatic ecosystem
  - Key food source for benthivorous fish
  - Good biological indicator of lakebed condition
- Upper Great Lakes exhibit a diverse, but sparse benthic invertebrate community:
  - ~ 1100 to 1800 per m^2 (MOE, EC, Barton 1989)
  - ~ 700 to 2500 per m^2 (DFO, 2008)
- Benthic invertebrate densities in the waste footprint are variable
  - 0 to 35,050 per m^2
  - High densities observed at energetic sites; Maximum observed at site with dispersed cages
- Benthic effects observed at and beyond land tenure boundary
  - Land Tenure Boundary: range 20* to 10,360 per m^2
  - Waste footprint extends beyond land tenure
- Reference density is low (< 3000 per m^2)
  - Reference: range 100 to 2,680 per m^2
- Evidence of waste assimilation: high densities of macroinvertebrates





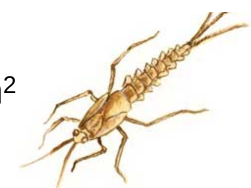
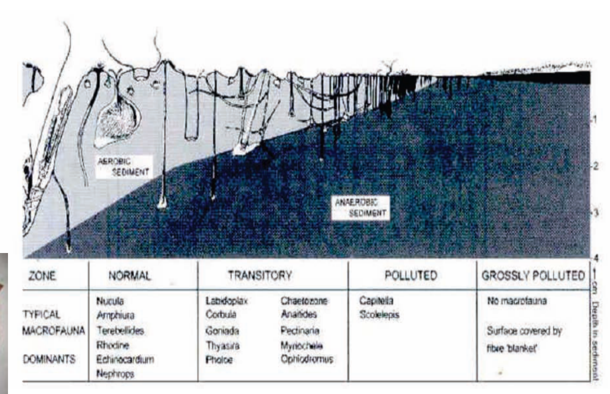


Figure 6.1.7 : Infaunal succession on an organic enrichment gradient (Pearson and Rosenberg, 1978)

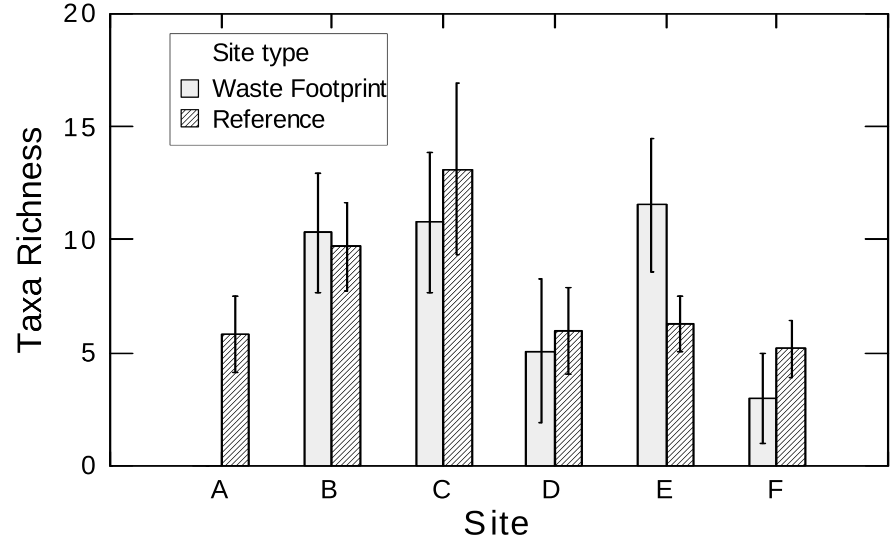


Benthic Invertebrate Community

- Diverse benthic community at reference site
  - Taxa richness range 4 – 18
- Effects at and beyond land tenure boundary
  - Taxa richness range 1 – 16
- Altered benthic community at cages; lower richness at cages compared to reference
  - Taxa richness range 0 - 10
  - Pollution-tolerant deposit feeders in areas of high abundance; high proportion of immature Tubificidae
- Azoic conditions at former operation in Type 1 site and select locations at active sites corresponding to highly enriched sediment conditions
- Maximum densities typically correspond to low richness
- Within waste footprint effects range from:
  - High waste assimilation with high densities of pollution-tolerant benthos; altered benthic community with high proportion of immature deposit feeders

  to

  - No waste assimilation and absence of macroinvertebrates; sediment toxicity



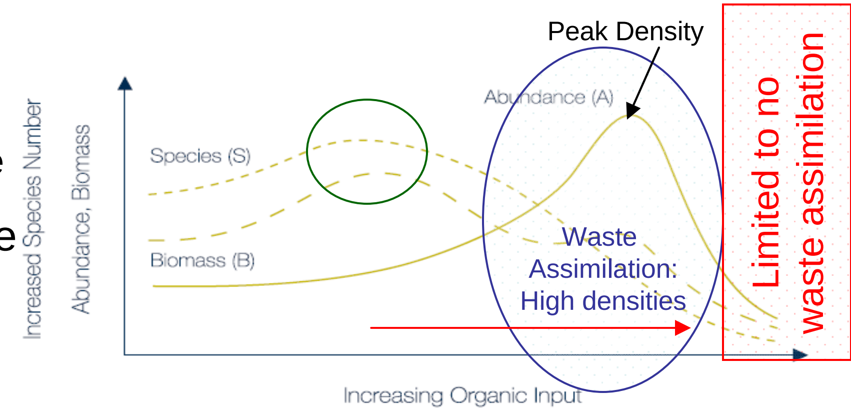
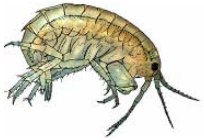
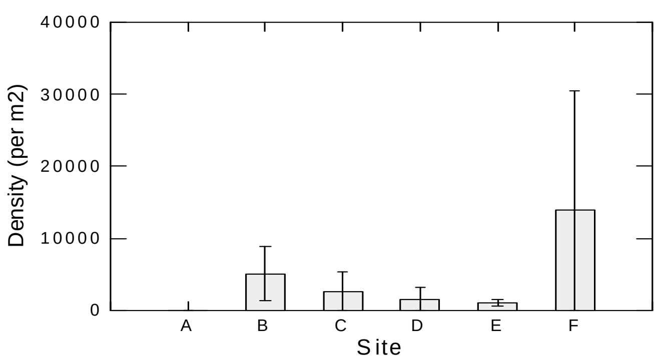


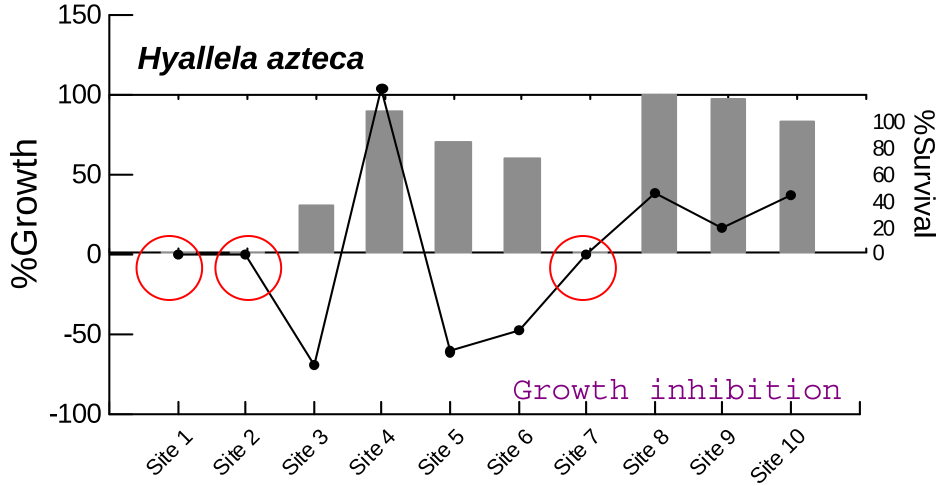
Figure 6.2: Pearson and Rosenberg's model of organic enrichment, the Species, Abundance and Biomass (SAB) curves (from Pearson and Rosenberg, 1978).

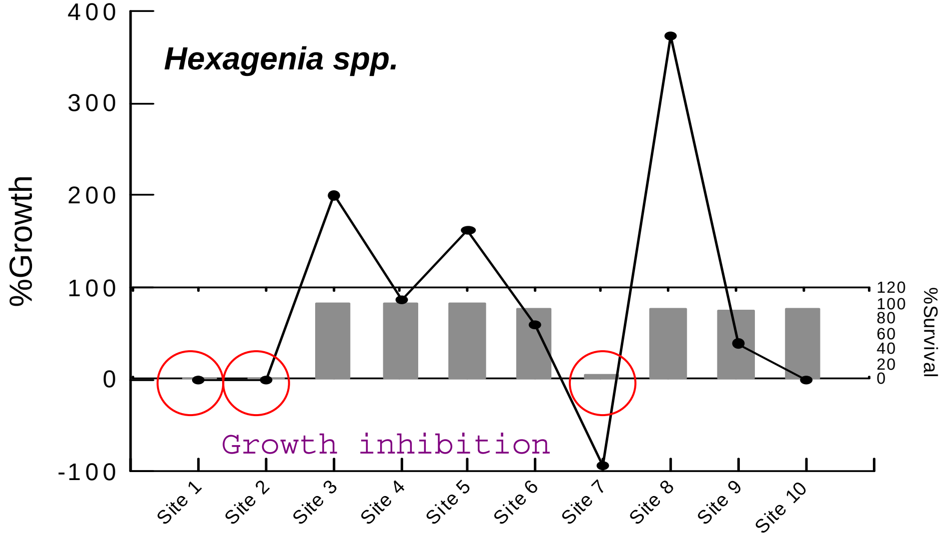


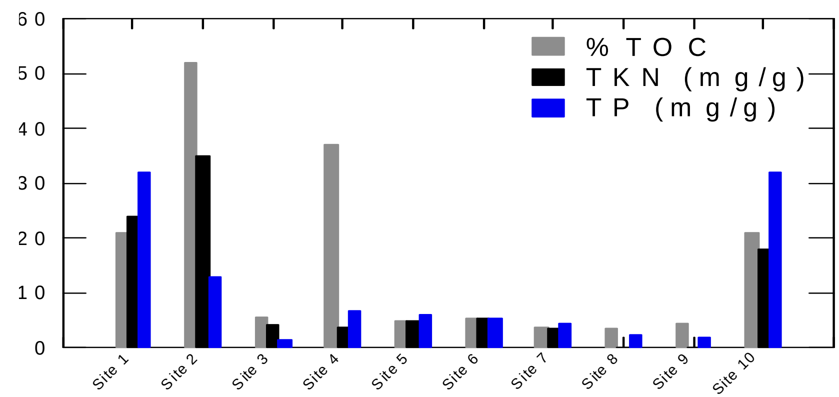


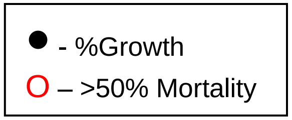
Sediment Toxicity Bioassays - Highlights

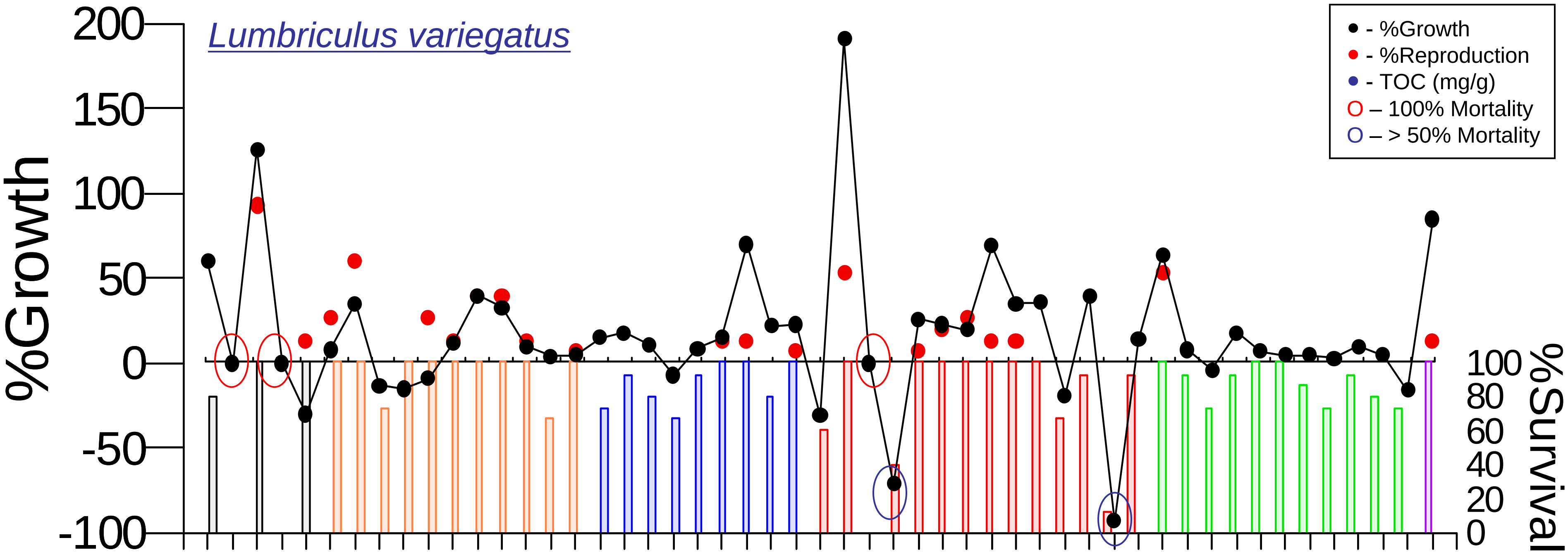
- Sediment toxicity bioassays: reliable method to measure toxicity; provides a direct estimate of lethal and sublethal effects
- Sediment Toxicity Bioassay Indicators: % mortality, biomass, reproduction, behaviour
  - Test Organisms: *Hyalella azteca*, *Hexagenia spp.*, *Chironomus dilutus*, *Lumbriculus variegatus*
- Sediment toxicity can occur and is likely due to low oxygen conditions and production of un-ionized ammonia and hydrogen sulphide
- 100% mortality observed at two active operations and one historical operation
  - Elevated un-ionized ammonia concentrations; maximum 12.3 mg L^{-1}
  - (*H. azteca*); 16.1 mg L^{-1} (*Hexagenia*)
  - Anoxic conditions; dissolved oxygen concentrations < 1 mg L^{-1}
  - Enriched sediment conditions; exceeds PSQG-SELs



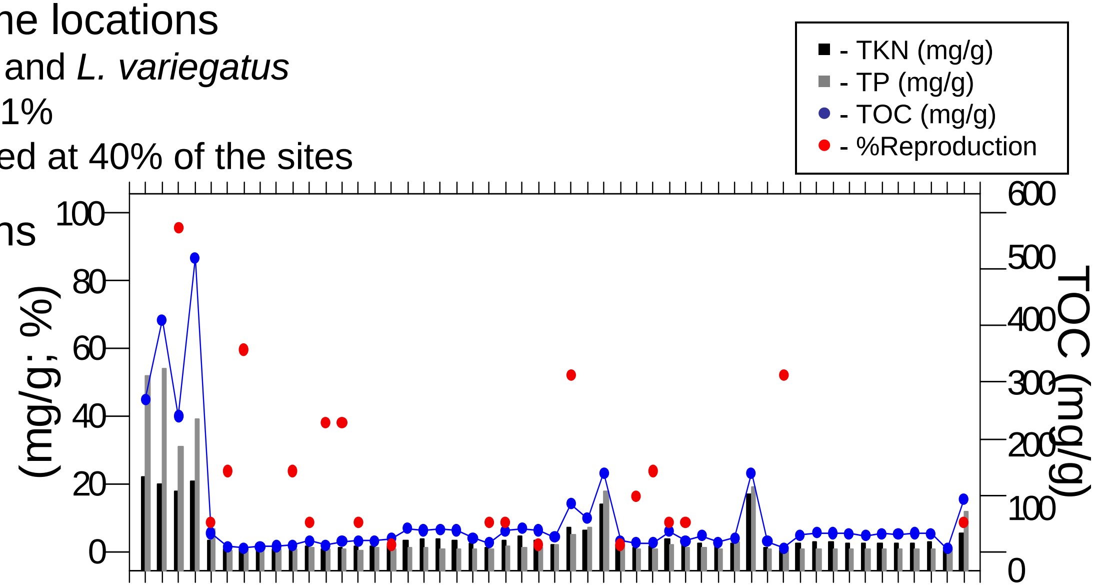




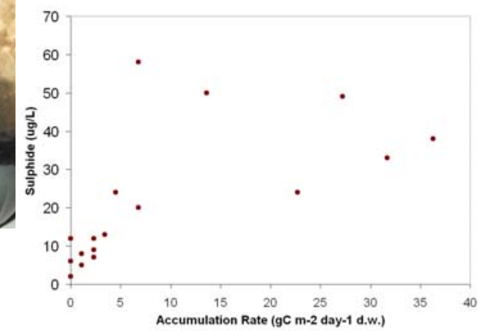




- > 50% mortality observed select locations for *L. variegatus*
  - No significant mortality observed at most locations and at reference
- Biostimulatory effect observed at some locations
  - Growth of *Hexagenia spp., C. dilutus* and *L. variegatus*
  - Maximum % growth range 191% - 331%
  - Reproduction of *L. variegatus* observed at 40% of the sites
- Growth inhibition observed at locations with significant mortality
- Reproduction was not observed at locations with significant mortality
- Waste assimilation through growth and reproduction of test organisms

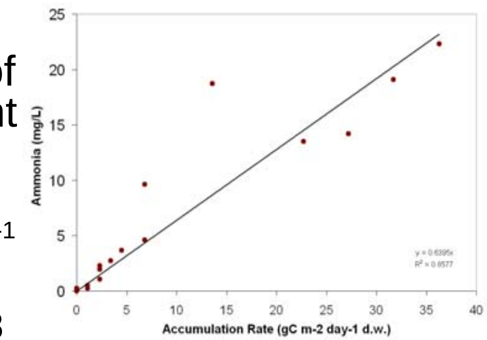


Waste Accumulation Rate Experiment - Highlights



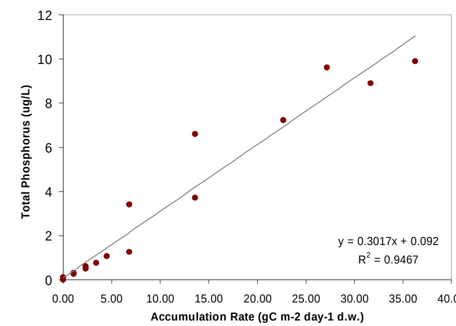
- Experiment quantified biological response of pollution-tolerant deposit feeder to various fish waste accumulation rates

- Results can be factored into models to predict potential severity of effect in conjunction with spatial estimates of depositional footprint



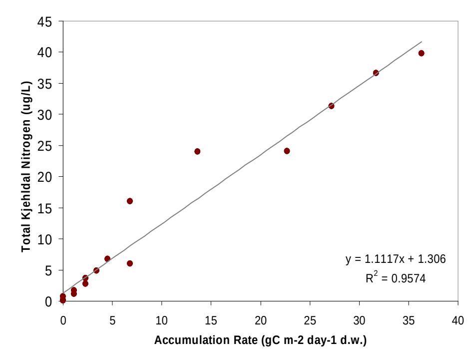
Benthic invertebrates

- High growth rates at waste accumulation rates $\leq$ 6.8 g carbon (gC) m^{-2} day^{-1}
- Reproduction occurred at waste accumulation rates $\leq$ 6.8 gC m^{-2} day^{-1}
- Inhibited growth and avoidance behavior at waste accumulation rates > 6.8 gC m^{-2} day^{-1}



Water Quality

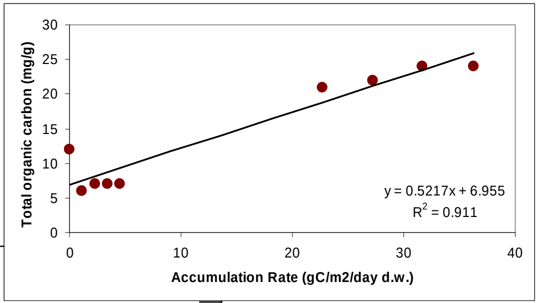
- Changes in biogeochemistry:
  - Increased DOC, TSS, conductivity and alkalinity with increased accumulation rates
- Nutrient Enrichment:
  - Increased TP, TKN, phosphate and ammonia concentrations with increased accumulation rates
- Elevated sulphide and un-ionized ammonia concentrations

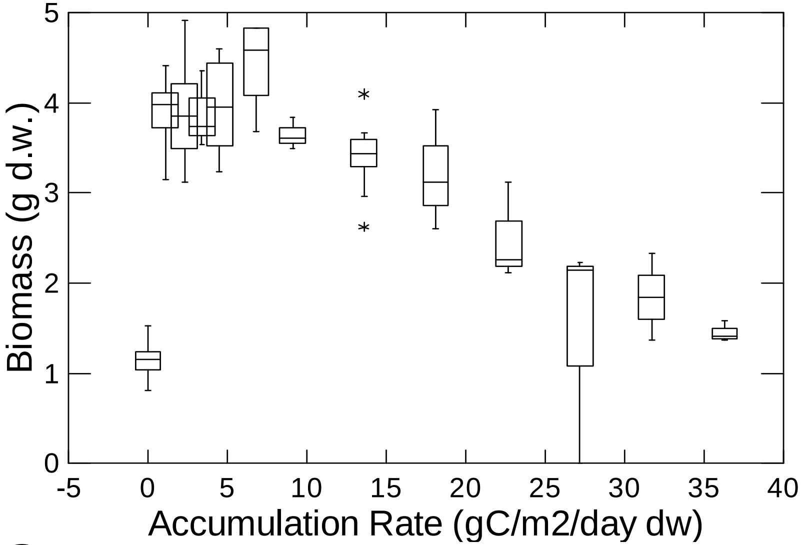


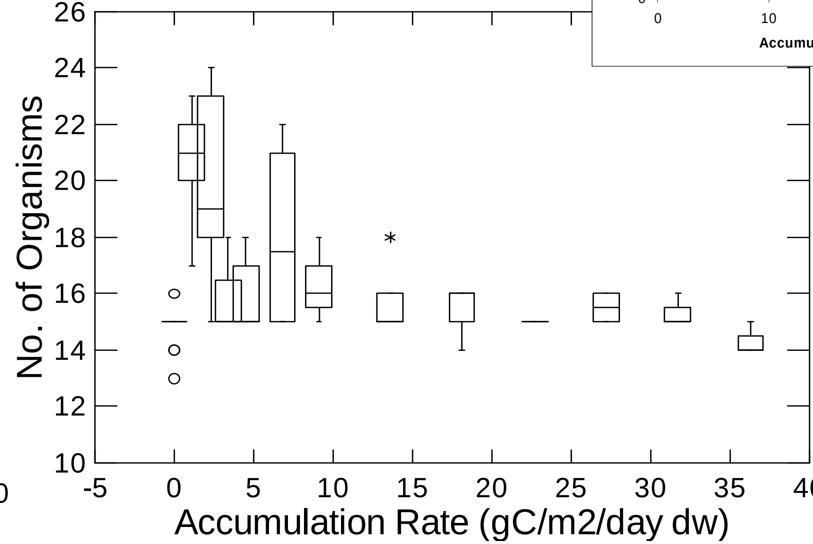
Changes in sediment chemistry parameters

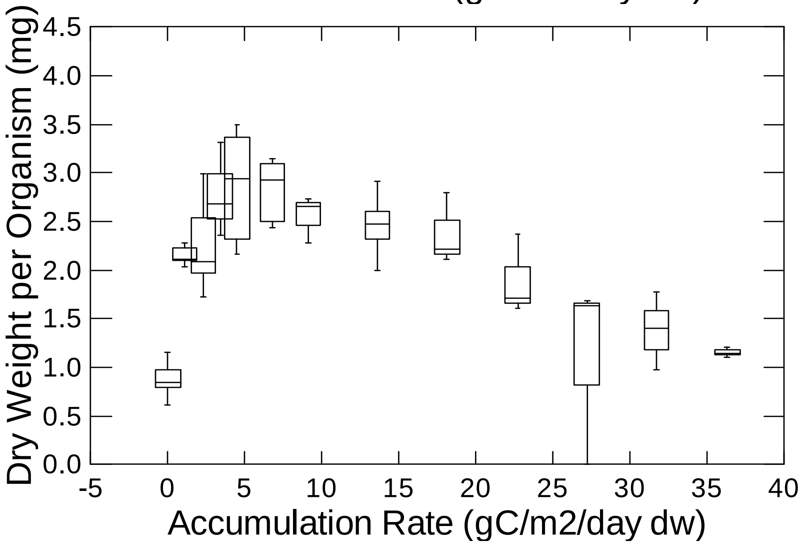
  - Elevated nutrients (TP, TKN), TOC, sulphide and LOI at high accumulation rates

Accumulation Rate Experiment – Biological Endpoints





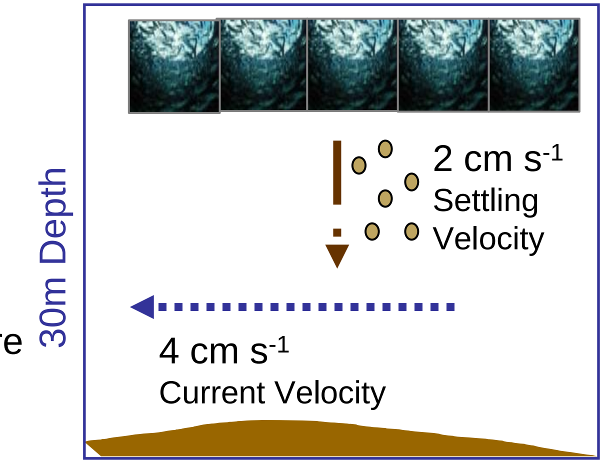




- At low accumulation rates (≤ 6.8 gC m^{-2} day^{-1} d.w.)
  - ~ four-fold increase in total biomass
  - ~ three-fold increase in individual mass
  - Reproduction
- At high accumulation rates (> 6.8 gC m^{-2} day^{-1} d.w.)
  - No reproduction; modest increase in biomass; behavioural changes
- MOE accumulation rates are comparable to other proposed thresholds

Ontario

Waste Footprint – Depositional Modelling



- Deposition and dispersion models can be used to:
  - estimate waste accumulation rates
  - predict the footprint size of the solid waste from cage aquaculture
  - Identify scenarios where waste loading potentially exceeds the waste assimilation capacity of macroinvertebrates

- An operation will have a larger solid waste footprint and lower waste accumulation rates if:
  - Physical limnology
    - Sited over deep waters
    - Sited in an exposed, energetic well-flushed area
  - Cage configuration
    - Dispersed cage configuration with single or multiple-mooring system
    - Main axis of the cage array is perpendicular to water flow
  - Operational practices
    - Feed formulation that result in excretory waste with low faecal settling velocity
    - Lower stocking density will lower waste accumulation rates

- Site type
  - Type 3 sites are more energetic with larger waste footprints and lower accumulation rates than Type 1 and 2 sites

- Lower accumulation rates increases the potential for waste assimilation and decreases potential for severe and/or toxic sediment effects

Ontario

Depositional Model Output

- General assumptions: 500T operation; bi-directional flow shore parallel
- Scenario parameters:
  - Main cage axis parallel or perpendicular to shore
  - Clustered or dispersed cage configuration
  - Shallow (20 m) or deep site depth (50 m)
  - Energetic or quiescent site; current velocity 1 cm s^{-1} or 4 cm s^{-1}
  - Faecal settling velocity 2 cm s^{-1} to 4 cm s^{-1}

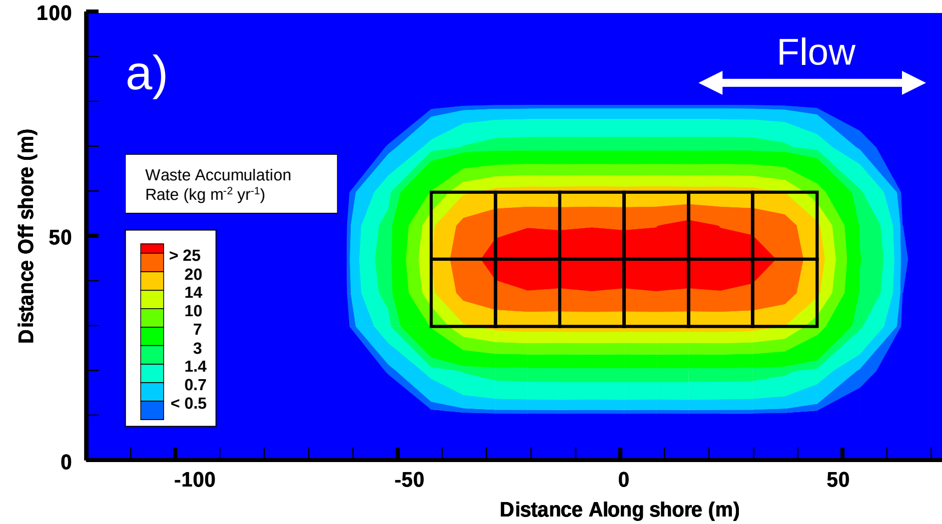
__1. Cage Array Orientation Scenario:__

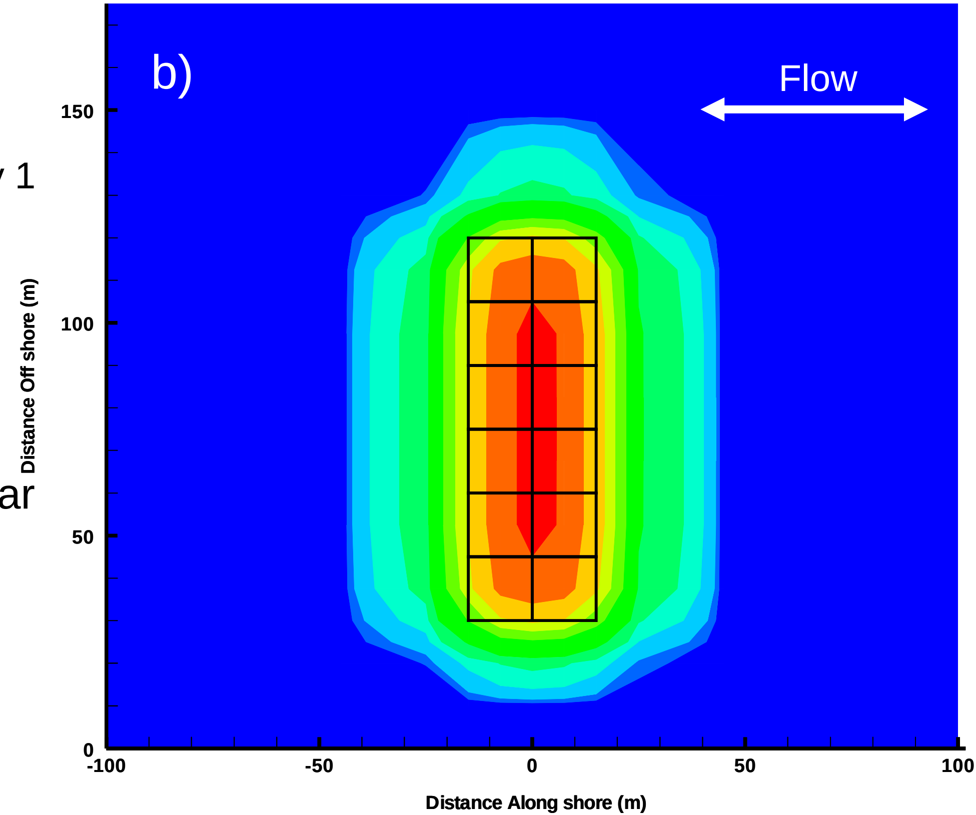
Main cage axis is a) parallel or b) perpendicular

Maximum waste accumulation is similar

- Changes to footprint shape and size

__Cage Array Orientation__





… Depositional Model Output

2. Faecal Settling Velocity Scenario:

Faecal setting velocity c) 4 cm s^{-1} or d) 2 cm s^{-1}

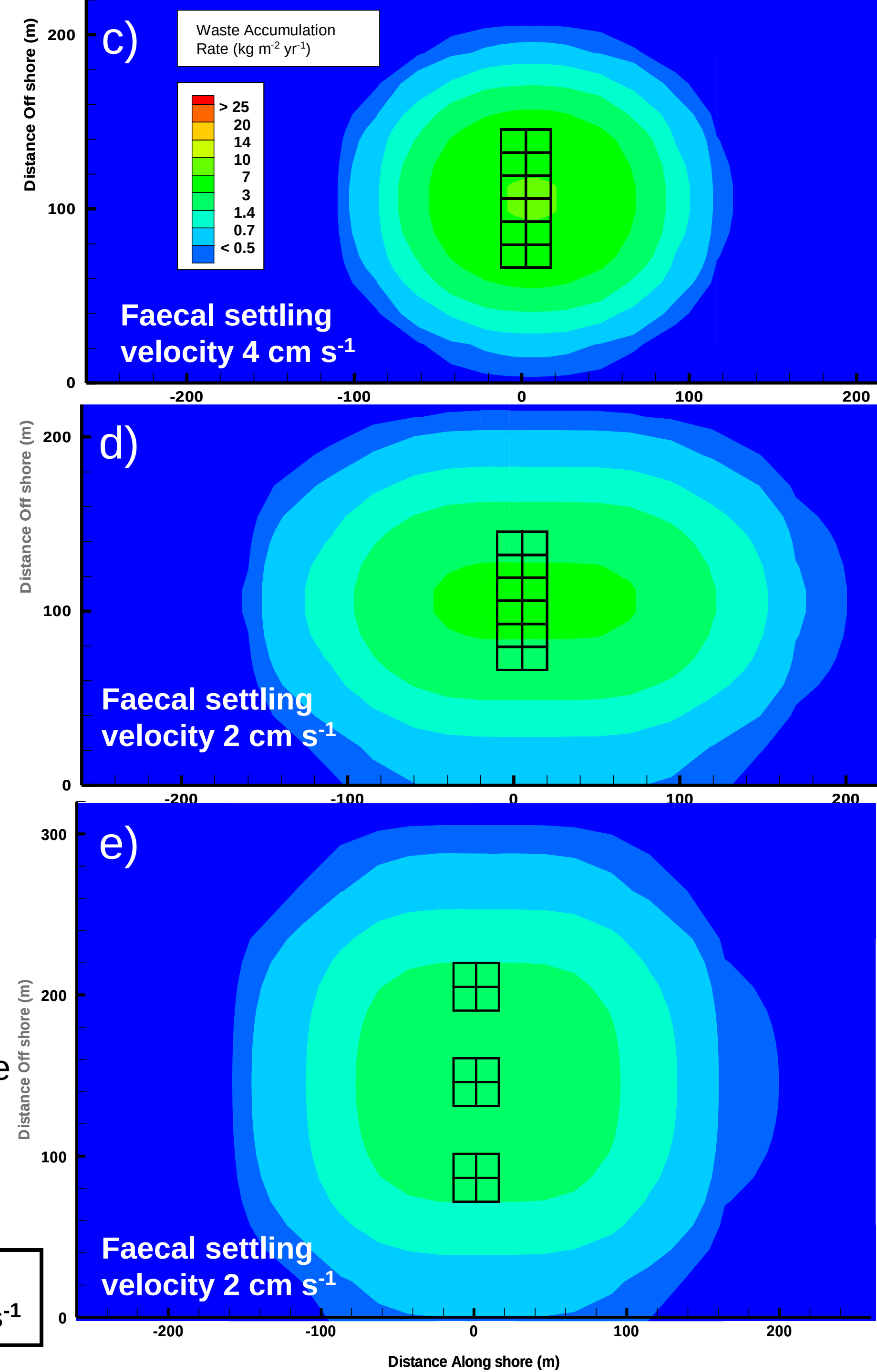
- Low density faecal material (low faecal settling velocity) results in larger waste footprint and lower accumulation rate
  - Scenario c) – waste footprint 1.84 ha; maximum accumulation rate 7.2 kg m^{-2} yr^{-1}
  - Scenario d) – waste footprint 2.53 ha; maximum accumulation rate 3.1 kg m^{-2} yr^{-1}

3. Cage Configuration Scenario:

Cages are d) clustered or e) dispersed

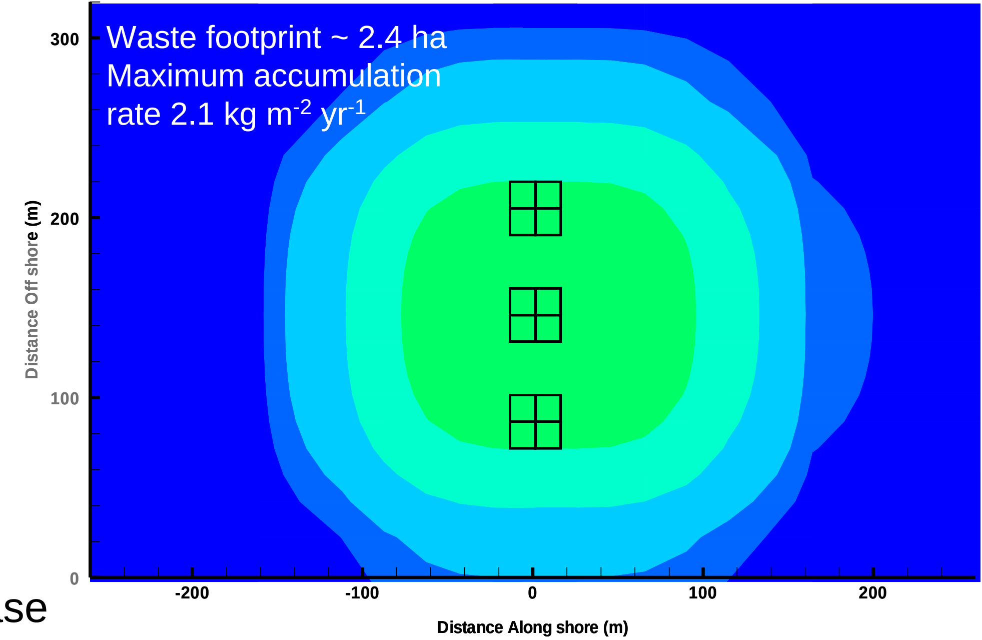
- Similar waste footprint size
- Dispersed cage configuration results in lower waste accumulation rate (2.1 kg m^{-2} yr^{-1}) compared to clustered cage configuration (3.1 kg m^{-2} yr^{-1})

Site depth = 50 m
Current Velocity = 4 cm s^{-1}

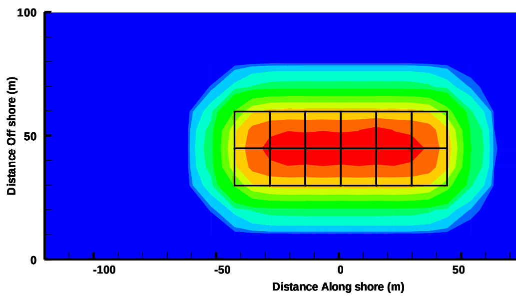


Waste Footprint and Accumulation Rates

- Siting, operational practices and configurations are integral to minimizing sediment-related effects
- Minimizing waste accumulation rates will prevent gross pollution effects and increase potential for waste assimilation
- Options for minimizing waste accumulation rates, which will result in a larger waste footprint, include:
  - Site in a deep and energetic location
  - Orientating cage array with main axis perpendicular to water flow
  - Use of feed types that result in low faecal settling velocity
  - Decreasing stocking density
  - Dispersing cages over a larger area



Waste footprint ~ 0.6 ha
Maximum accumulation rate > 30 kg m^{-2} yr^{-1}



Site Depth	Cage Configuration	Main Axis of Cages	Current Velocity	Settling Velocity
20 m (Shallow)	2 rows of 6	Parallel Perpendicular	1 cm/s	2 cm/s
50 m (Deep)	2 rows of 6	Perpendicular	4 cm/s	2 cm/s 4 cm/s
	3 clusters of 4	Perpendicular Parallel	4 cm/s	2 cm/s

Water Quality Summary

Site-characteristics: Water quality effects are dependent on site-characteristics. Embayments (Type 1 and 2 sites) are more sensitive to additional nutrient and organic loadings. Open-water nearshore and offshore sites (Type 3) are more resilient and do not exhibit eutrophication effects

Nutrient Enrichment: Type 3 sites do exhibit local water quality gradients, but TP levels are $< 10\ \mu g\ L^{-1}$. Type 1 and 2 sites exhibited elevated TP ($> 10\ \mu g\ L^{-1}$) in summer and fall; occurrences of algal bloom, nuisance algae and HABs

Severe Dissolved Oxygen Depletion: Type 3 site DO levels are $> 6.0\ mg\ L^{-1}$. For Type 1 and 2 sites susceptibility to severe hypolimnetic DO depletion (anoxia) increases if:

- Waterbody is naturally hypoxic; more sensitive to additional nutrient and organic/BOD loading
- Restricted hydrologic connectivity to the open-waters of the Great Lakes
- Physical limnology – thermal structure, stratification patterns, turnover, initial DO conditions

- VWHDO and real-time DO/temperature sensors used to track hypolimnetic DO conditions over time and space
  - Determine the duration, magnitude and frequency of hypolimnetic DO depletion

- Appropriate siting is integral to minimizing the effects of cage aquaculture on water quality

Ontario

Summary – Sediment Quality

Benthic Invertebrate Community: Benthic community can vary from absence of invertebrates to highly altered community dominated by high densities of pollution-tolerant deposit feeders

Sediment Toxicity Bioassay: Sediment from cage aquaculture facilities can result in a biostimulatory effect or can be toxic. Sediment toxicity is likely due to low dissolved oxygen conditions, production of un-ionized ammonia and/or hydrogen sulphide. Biostimulatory effects include increased growth and/or reproduction

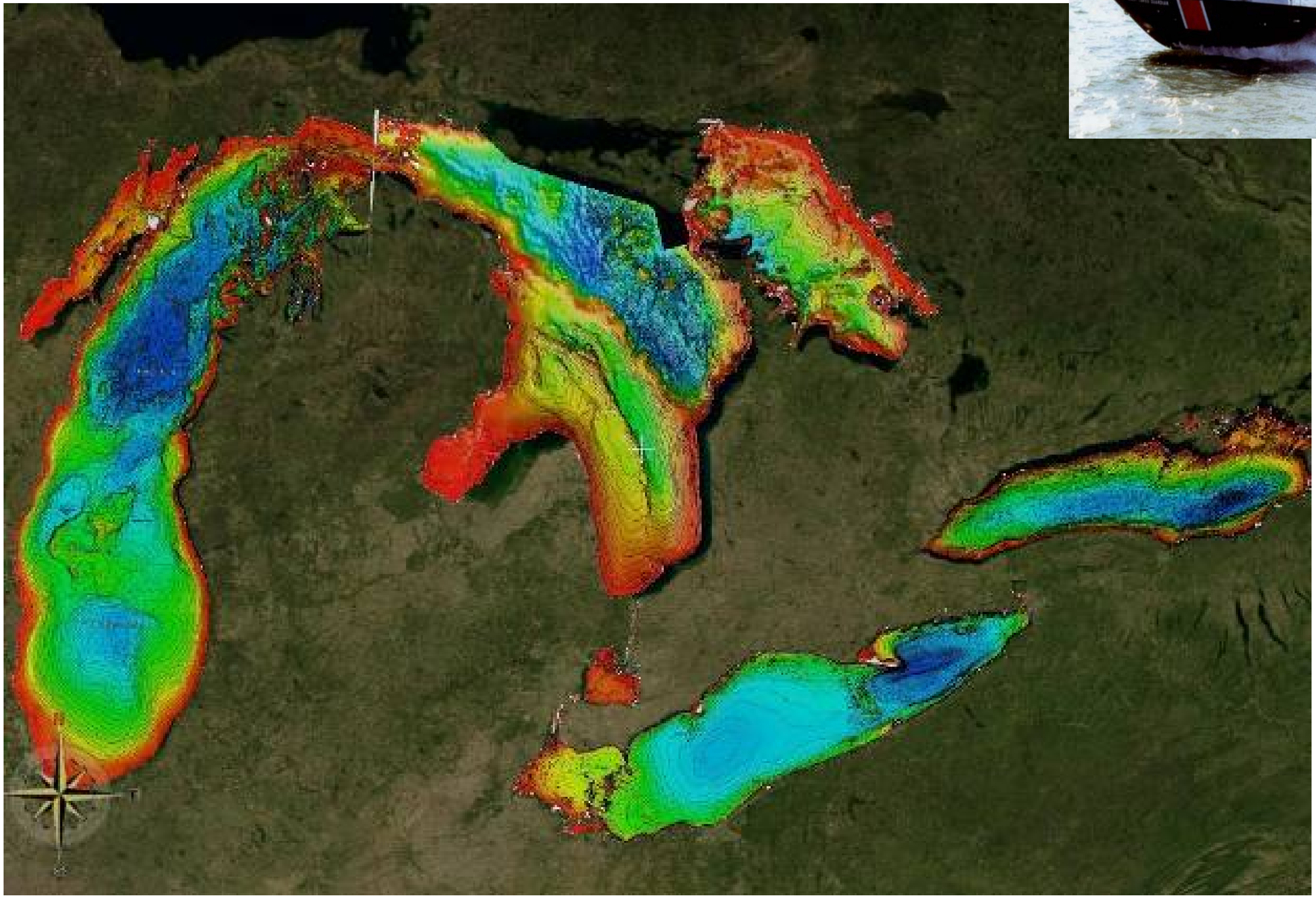
Fish Waste Accumulation Experiment: Biomass and reproduction increased at low loading rates; biomass decreased and no reproduction at high loading rates. Upper threshold for carbon accumulation rate, based on the fish waste experiment, is consistent with marine thresholds

Depositional Footprint: Site-specific factors drive dispersion and accumulation of fish waste at the lake bed. Can be predicted if current velocity and direction, cage configuration, operational practices and bathymetry are known. Sediment-related effects are generally local and site-specific

Waste Assimilation: Conversion of waste to benthic biomass observed at existing operations as evidenced by high macroinvertebrate densities, increased growth and reproduction. Limited to no waste assimilation at high waste accumulation rates

- Appropriate siting and operational practices or configuration are integral to minimizing waste accumulation rates and effects on sediment quality

Ontario



Questions?