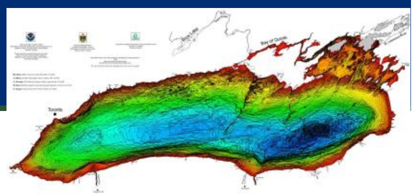
Appendix

Presentations made during the workshop titled “Identifying Research Priorities for Cisco in Lake Ontario,” held May 31, 2018 at the Cornell Biological Field Station at Shackelton Point, Bridgeport NY.

1. “Management of *Coregonus artedi* in New York waters of Lake Ontario.” Steven LaPan, NYSDEC
2. “Piecing together cisco assessment in Lake Ontario.” Jeremy Holden, OMNRF
3. “Cisco ecology in Lake Ontario and beyond.” Brian Weidel, USGS
4. “Spawning and early life history of cisco in Lake Ontario.” Ellen George, Cornell University
5. “Lake Ontario cisco, *Coregonus artedi*, population structure and diversity.” Matthew Hare, Cornell University.

New York State of Opportunity | Department of Environmental Conservation

"Management" of *Coregonus artedi* in New York Waters of Lake Ontario



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***Cisco rehabilitation is a NYSDEC initiative, and is not being pursued by the Lake Ontario Committee.**

3

"Recent" Background on *artedi*

- Commercial fishery largely eastern basin
- Last "meaningful" reported commercial catches in 1960s
- Very few (generally <100 pounds) reported through 70s/80s
- 2008 - unreported catches for several years
- Since 2009, 12 – 1,806 pounds reported annually

4

"Recent" Background on *artedi*

- Johnson and McKenna – mid-2000s larval sampling: *clupeaformis*, but no *artedi*
- 2012 USGS *artedi* stocking begins in Irondequoit Bay
- 2016 USGS *artedi* stocking begins in Sodus Bay

5

Lake Ontario Fish Community Objectives 1991

"Maintain a diverse complex of salmonine and coregonine (whitefish and ciscoes) fish species that produce an average annual yield of 2.5 kg/ha."

6

Lake Herring. (*Kerr and LeTendre 1991)*
In association with deepwater ciscoes, lake herring were also
a very important component of the commercial fishery until their collapse in the 1940s (Christie 1973). In recent years, the only commercial harvest has been by Canadian fishermen in the eastern portion of the lake. In 1989, this fishery harvested 1,510 kg of lake herring with a landed value of $1,931 (Canadian). Currently, lake herring stocks seem stable at relatively low levels of abundance (Bowlby 1990b). Lake herring, like whitefish, may be limited by abundant alewife and smelt populations in Lake Ontario. The

Offshore Benthic Fish Community
Objectives, Benefits, Risks, and Indicators Objectives
The offshore benthic fish community will be composed of self-sustaining native fishes characterized by

- Lake trout as the top predator
- A population expansion of lake whitefish from northeastern waters to other areas of the lake
- Rehabilitated native prey fishes (*Stewart et al. 1999)*

2.3 Increase prey-fish diversity—maintain and restore a diverse prey-fish community that includes Alewife, Lake Herring, Rainbow Smelt, Emerald Shiner, and Threespine Stickleback.

Status/trend indicator:

- Maintaining or increasing populations and increasing species diversity of the pelagic prey-fish community, including introduced species (Alewife and Rainbow Smelt) and selected native prey-fish species

(*Stewart et al. 2017)*

NYSDEC **DRAFT** Cisco Rehabilitation Strategy

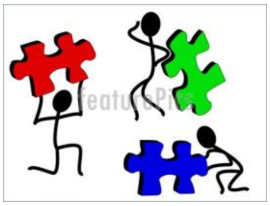
GOAL: Increase cisco abundance and improve our understanding of cisco status in the New York waters of Lake Ontario

Objectives:

- *Re-establish cisco spawning populations at historic sites.*
- *Evaluate existing and/or new assessment methods for indexing cisco population status and distribution*

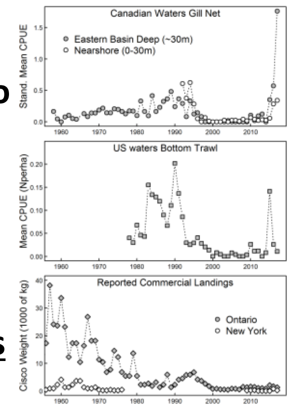
Questions?

Piecing together cisco assessment in Lake Ontario

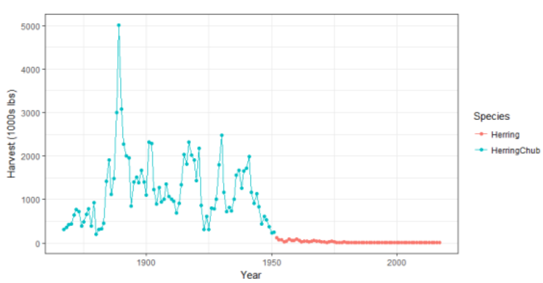


J. Holden &
J. Hoyle (MNRF)
B. Weidel (USGS)
M. Connerton (NYSDEC)

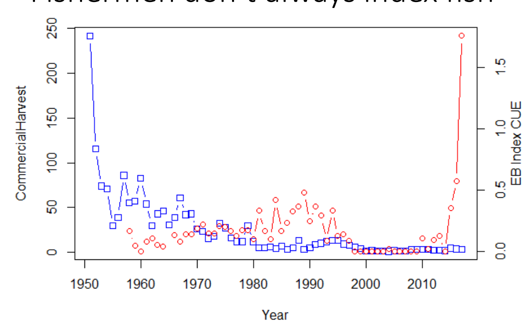
We have no dedicated cisco assessment program BUT we have many programs that provide trends over <u>6 decades</u>



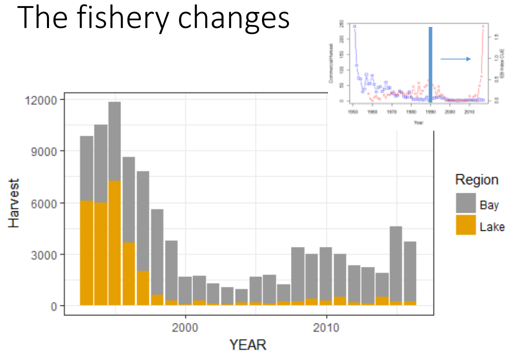
A 'long time' is relative...



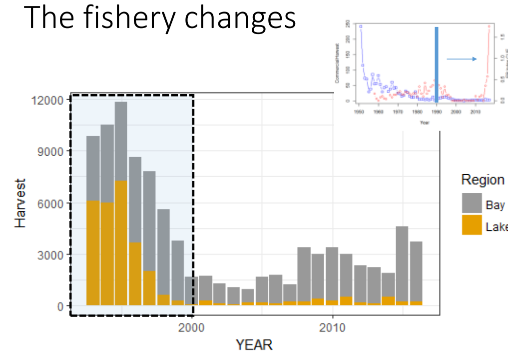
Fishermen don't always index fish



The fishery changes



The fishery changes



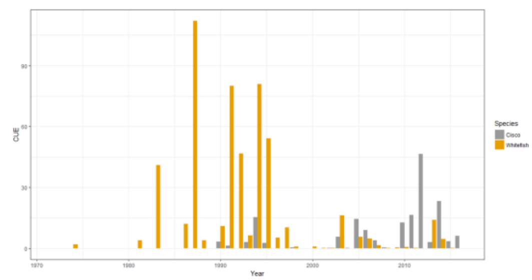
Geography REALLY matters

3N1 meets Bay of Quinte
2 tows = 20 Juvenile Cisco, plus some Whitefish

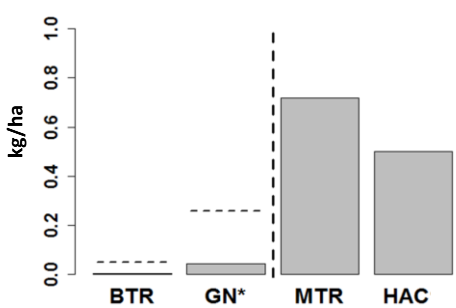
The previous 39 surveys of ≈ 100 tows/year never caught more than 15

Season is kind of important too

Summer/early fall Bay of Quinte bottom trawl index of Cisco and Whitefish YOY



Gear might matter **MORE**



Where we are going?

Population models

?

Absolute abundance vs annual index

Biological reference points

Who's doing the assessment?

Is 'a diverse fish community that includes alewife' possible with enough alewife to feed salmon?

In closing; I'm confident that:

1. If you want to catch cisco; focus on the east.
2. If you want to catch a lot of cisco; focus on the Bay of Quinte
3. There's a recent increasing trend
4. Assessment of Cisco and Bloater would be easier if stocked fish had marks that identified species and origin

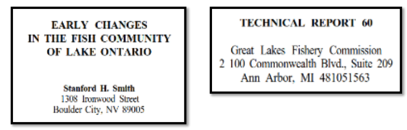
Cisco Ecology In Lake Ontario and Beyond

Historic food web role

did *artedii* have the highest biomass?

early descriptions and catch records indicate that the lake herring must have been the most-abundant individual species in each of the Great Lakes

Smith 1995, Early Changes in The Fish Community of Lake Ontario


EARLY CHANGES
IN THE FISH COMMUNITY
OF LAKE ONTARIO

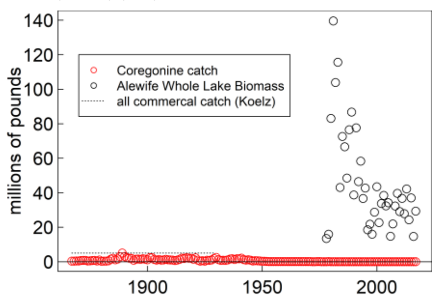
Stanford H. Smith
1308 Ironwood Street
Boulder City, NV 89005

TECHNICAL REPORT 60

Great Lakes Fishery Commission
2 100 Commonwealth Blvd., Suite 209
Ann Arbor, MI 481051563

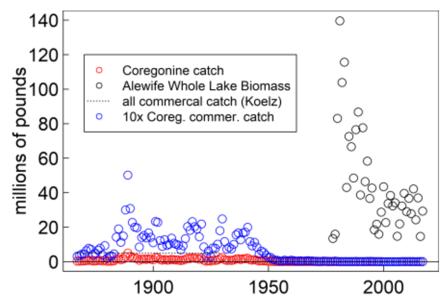
Historic food web role

how did historic commercial catch relate to more contemporary prey fish biomass?



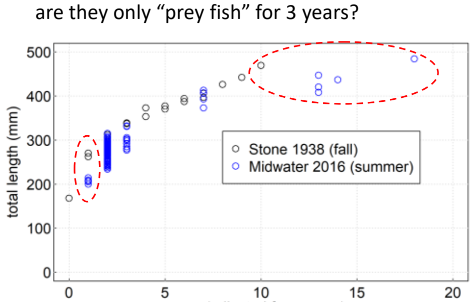
Historic food web role

Assume 10% biomass exploitation?



Historic food web role

are they only “prey fish” for 3 years?



incredibly fast growth

Historic food web role

are they only “prey fish” for 3 years?

Coregonines (mainly Cisco) in LT diets, Superior

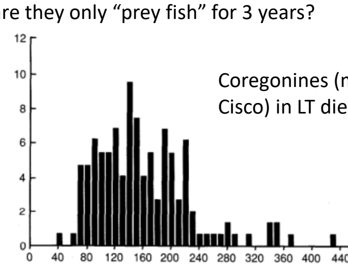


Fig. 3. Length-frequency distribution of coregonines from lake trout stomachs collected from Lake Superior, 1981-87.

Cisco as a predator

zooplanktivores…right?

Stomach contents, Grand Traverse Bay, Lake M Cisco, Winter 2017-2018

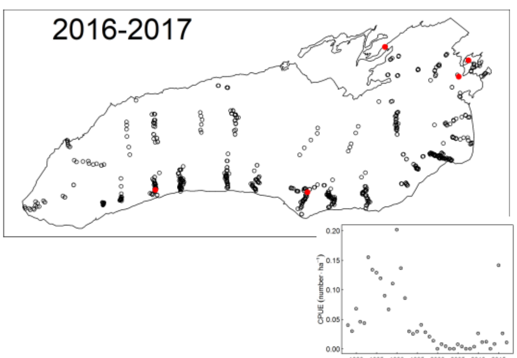
Cisco as a predator

Stone knew they ate fish in the 1930'

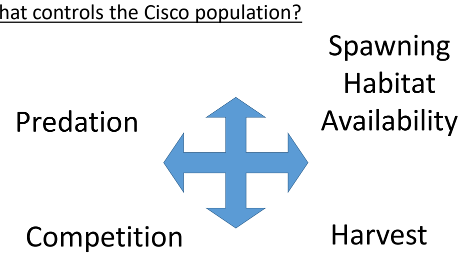
remains. Four stomachs from fish taken September 17, 1936, held large numbers of cladocerans and copepods, one stomach contained a Diptera larva, and another fish remains.

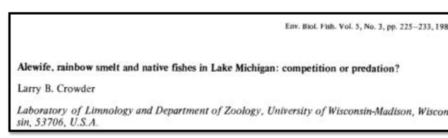
Futia, Karboski, Jonas : diets and fatty acids

Cisco lakewide distribution – straying or detection prob.



What controls the Cisco population?





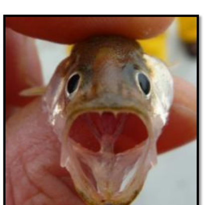
Env. Biol. Fish. Vol. 5, No. 3, pp. 225–233, 1980

Alewife, rainbow smelt and native fishes in Lake Michigan: competition or predation?

Larry B. Crowder

Laboratory of Limnology and Department of Zoology, University of Wisconsin-Madison, Wisconsin, 53706, U.S.A.

What controls the Cisco population?



the relative densities of the two species, and the predators daily ration of the, we estimated that smelt consumed 3.3–11% of the herring larvae. **Selgeby et al. 1978**

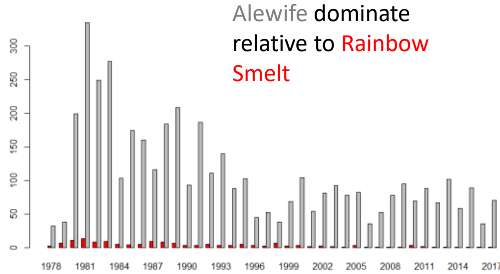
….Rainbow Smelt were introduced in the 1980.....it is highly likely that ciscoes will be extirpated from Sandybeach Lake Ontario. **Reid and Wain 2016**

In Sparkling Lake, WI, cisco were preyed upon by rainbow smelt where habitats overlapped below the thermocline. Eventually, smelt predation caused recruitment failure and the cisco extirpation **Hrabik et al. 1998**

rainbow smelt may have been a more important contributor to the demise and slow recovery of Lake Superior ciscoes than previously thought. **Myers et al. 2009**

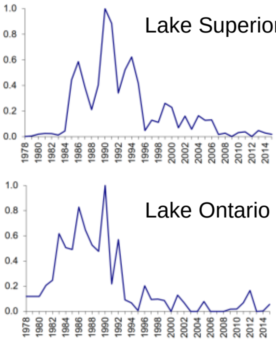
Rainbow Smelt predation impact on Lake Whitefish depends on Lake Whitefish growth, environmental conditions causing Whitefish hatching periods to coincide with Rainbow Smelt spawning, and habitat overlap between spawning Rainbow Smelt, nonspawning subadult Rainbow Smelt, and hatching Lake Whitefish. **Gorsky and Zydelewski 2013**

Alewife dominate relative to Rainbow Smelt



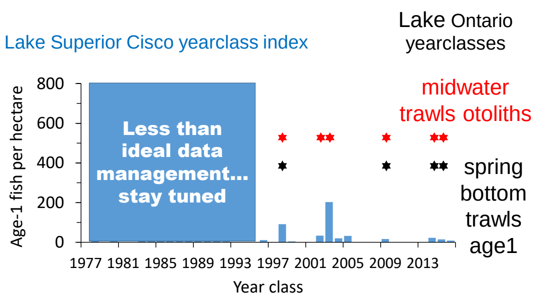
What about climate influencing early life survival?

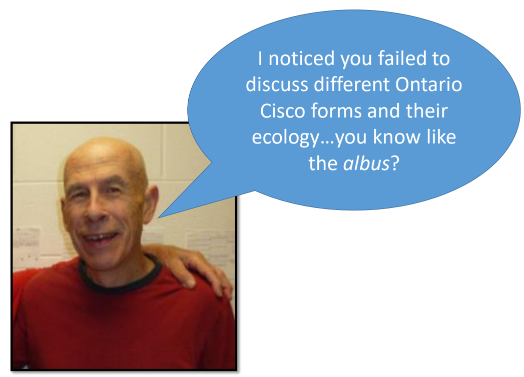
How do we explain synchrony in bottom trawl biomass indices



Gorman and Weidel (2016)

Is a good yearclass in Lake Ontario a good yearclass in Lake Superior?





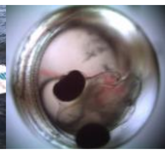
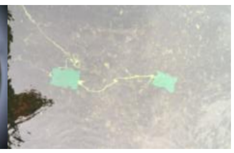
discussion

- diet of salmonines- do they eat Cisco in other lakes, gape limitation of salmonines vs growth? When or do Cisco grow out of gape of large predators?
- cisco spawning- transfer of energy offshore to nearshore (interesting but so what, do sites without subsidies produce less?
- spatial distribution- patterns and processes- limitations? (alewife, habitat, homing populations, straying not enough to overcome survival bottlenecks), adult home range (homebody or long distance traveler)?
- vertical distribution- changes from juvenile to adult or susceptibility to gear?, temperature preferences, diel migration?
- cisco diet (alewife predator?, and or competitor)
- if Cisco is a smelt, then is there any chance of increased populations. Smelt has a larger distribution, why?
- changes in morphometry related to food web position

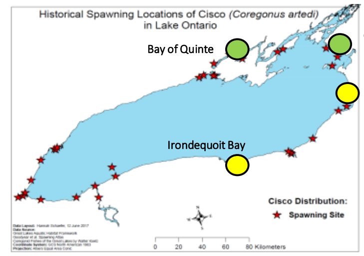
Spawning and Early Life History of Cisco in Lake Ontario

Lake Ontario Cisco Workshop

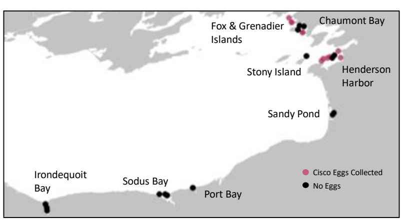
31 May 2018

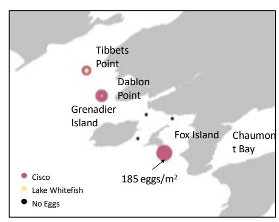
Historical Spawning Areas

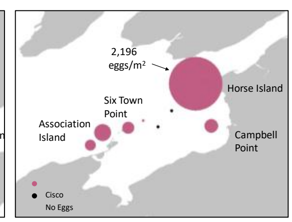


Spawning Areas Expanding?



Spawning Areas Expanding?





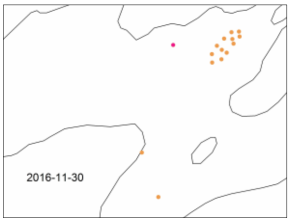
Spawning Habitat Models

- Habitat suitability model for Cisco and Lake Whitefish in Lakes Ontario and Erie (H. Schaefer, USGS Ann Arbor)
  - Substrate, bathymetry, distance to tributaries, ice onset, ice duration, fetch, latitude
  - Based on historical spawning sites (Goodyear et al. 1982)

Spawning Habitat Models

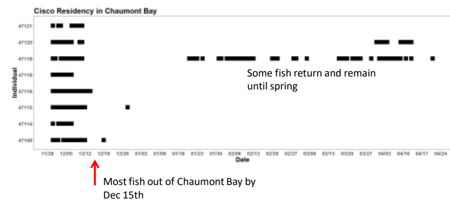
- Contrast between upper lakes and Lake Ontario (M. Paufve, Cornell)
  - Upper lakes: eggs found deep (>20m), even on silt.
  - Lake Ontario: highest egg deposition at shallowest site, shallow shoal habitat available that is not found at upper lake sites.
- Alternate spawning strategy (J. Jonas, MI DNR)
  - Hydroacoustics showed spawning-ready fish at surface over 100ft of water
  - M. Paufve collected coregonine eggs at this site (to be identified)


Spawning Migration Movements



Gorsky & Karboski et al. USFWS

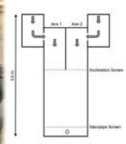
Residency in Chaumont Bay



Gorsky & Karboski et al. USFWS

Homing Behavior

- Grant Scholten, USGS Tunison
- Cisco imprinted with various chemical cues, double arm behavioral assessment.

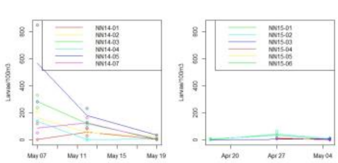


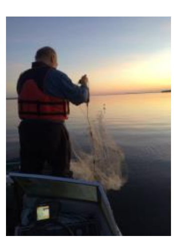
Reaching Out to Anglers

- Informational signs at boat launches from Rochester to Chaumont Bay (USGS Tunison)
- Ice fishing forums
- Other ways to crowdsource information?

Larval Year Class Strength

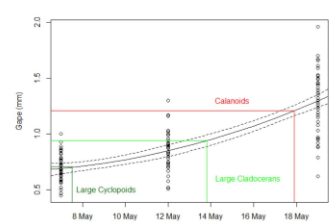
- Big fluctuations in larval densities
- Alewife? None in 2014 and 2015, but…





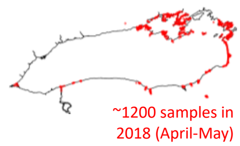
Larval Diet

- At beginning of sampling season preferred small cyclopoid copepods and nauplii
- By end of sampling season, preferred small cyclopoid copepods, large cyclopoids, and large cladocerans.



Larval Distribution at Lakewide Scale

- Honing in on other potential spawning sites
- Identifying predictors of larval distribution:
  - distance from overwintering Alewife
  - morphometry
  - substrate (e.g. % rock)
  - distance from historic spawning
  - total phosphorus
  - account for: wind, time, temp, depth, etc



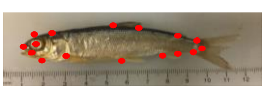
B. Weidel et al. USGS and many many more

Best Methods for Collecting?

- Egg stage
- Larval Stage
  - Little Traverse Bay Band trying different procedures for capturing larval cisco (pelagic vs. nearshore, night vs day)
- Juvenile stage "black box" – identified as research priority at Cisco workshop in Ashland, WI last fall.
  - MI DNR/USGS looking for young-of-year cisco with bottom trawls in Lake Michigan.

Identification Problems

- Genetic identification, especially for eggs (see George et al. 2017)
- Morphometric differences between Cisco, Lake Whitefish, and hybrid larvae (USGS Tunison)
- Development of meristics key for adults using landmark analysis (USGS Tunison)



Other early life history concerns?

- Spawning behavior
  - Bay of Quinte habitat and success?
- Egg stage
  - Ice cover duration?
- Larval stage
  - Competition?
  - Microplastics?

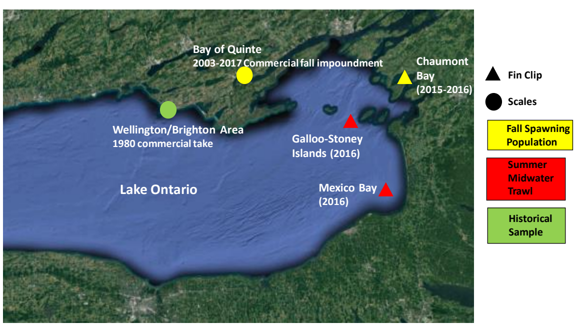
Thank you to all of YOU!

Lake Ontario Cisco, *Coregonus artedi*, Population Structure and Diversity

Ellen George, Matt Hare, Lars Rudstam
Cornell University

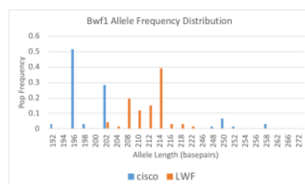
Measure genetic diversity of spawning populations and summer aggregations to inform Restoration/Management:

- Test for genetic bottleneck effects, estimate N_e
- Compare the status of two remnant spawning stocks
- Test for population substructure
- Develop markers for easy ID of cisco – whitefish hybrids



Microsatellites

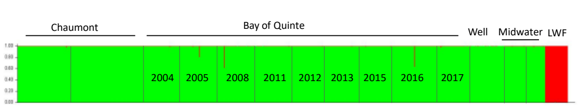
- 8 markers
  - from Patton et al. 1997, Turgeon et al. 1999, Fave & Turgeon 2008



		n = 29 Allelic Richness	
Locus	Source	cisco	Lake whitefish
Bwf1	*Coregonus nasus*	7.9	8.7
C2-157	W. Stott	10.0	15.2
Bwf2	*Coregonus nasus*	5.0	6.8
Cisco90	*Coregonus* spp.	4.0	5.0
Cisco181	*Coregonus* spp.	32.4	16.6
Cisco200	*Coregonus* spp.	16.8	16.4
Cisco106	*Coregonus* spp.	18.8	22.7
Cisco179	*Coregonus* spp.	7.9	5.9

Population Structure

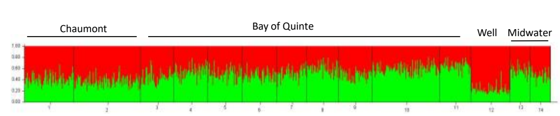
- Bayesian clustering of multilocus genotypes using admixture model
  - Program STRUCTURE
- All populations, Cisco (CIS) and Lake Whitefish (LWF)
- Best support for two differentiated populations, CIS ⟷ LWF (F_{ST} = 0.21)
- Three potential hybrids?



Cisco Only (no LWF)

- Single population is model with highest support (K = 2 shown anyway)
- Wellington most different, but also had highest genotyping error rate

⟷ Average F_{ST} = 0.03



Genetic Diversity

- High allelic richness – no support for hypothesis of recent bottleneck
- Low F_{IS} for all populations and loci – no deviation from random

	Chaumont 2015	Chaumont 2016	Quinte 2004	Quinte 2005	Quinte 2008	Quinte 2011	Quinte 2012	Quinte 2013	Quinte 2015	Quinte 2016	Quinte 2017	Wellington 1980	Galloo-Stony Midwater	Mexico Midwater	Lake Whitefish
Allelic Richness	12.5	12.3	11.9	13.1	12.6	12.4	12.4	13.3	12.4	12.8	13.4	11.3	13.8	12.8	12.2
F_{IS}	-0.006	0.013	0.031	0.025	0.058	0.012	-0.007	0.01	-0.008	0.031	-0.001	0.12	0.057	0.012	0.16

- High expected heterozygosity across all loci, 0.57 – 0.97

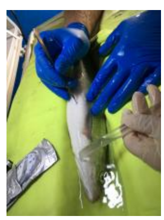
Effective Population Size, N_e

- An index inversely related to the strength of genetic drift
- Contemporary estimator based on allelic correlations
- All cisco samples combined except Wellington/Brighton (n = 698)
- Rare alleles (< 0.02) ignored

Ne = 5618 (95% CI 2233 - infinity)

Conclusions for Cisco Management:

- No apparent population structure in Lake Ontario cisco; some population exchange is occurring
- Cisco and whitefish are both genetically diverse with no obvious bottleneck effect
- Effective population size suggests that genetic drift is not an overly strong force
- Adaptive capacity is likely



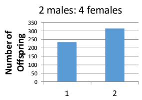
FWS Cisco & Bloater Genetic Analyses

- Monitoring genetic diversity of broodstock:
  - Wild Cisco broodstock for Lake Ontario
    - Chaumont Bay collections (2011, 2015, 2016, 2017)
  - Bloater broodstock from Lake Michigan
    - Wild adults used for Lake Ontario starting with 2018
    - Wild collection for captive broodstock establishment at FWS Jordan River NFH
- Proposed research to evaluate temporal and spatial distribution of larval and juvenile Cisco in Chamont Bay

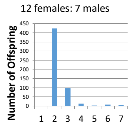
Cisco Workshop, May 31, 2018

Evaluation of reproductive variance

2 males: 4 females



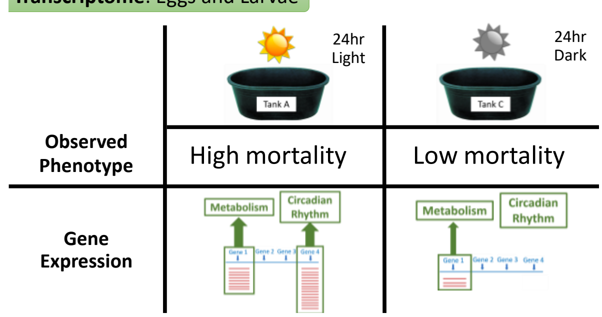
12 females: 7 males



	Female		Male			N_e	
Ratio	average	variance	average	variance	# spawners	Est.	Obs.
2:4	137.5	30505	275	3362	6	5.33	3.41
12:7	45.83	1271.97	78.57	24371.62	19	17.68	4.77
Average (16 spawns)					247	213.47	101.13

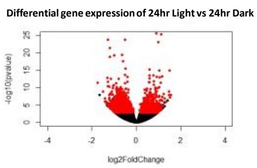
Cisco Workshop, May 31, 2018

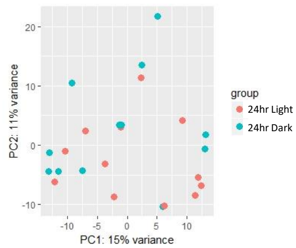
Transcriptome: Eggs and Larvae



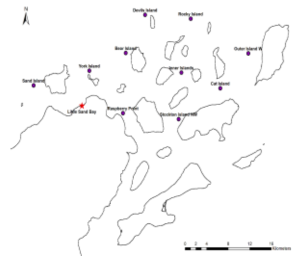
Transcriptome: Eggs and Larvae

24hr light treatment reached 50% hatch **7 days** before other treatments





Single Generation Selection: Larvae



Determine if **genetic selection** is occurring through **time** and **space** during the larval stage

Thank you!