Advances and Challenges in Valuing the Benefits from Water Quality Improvements: Lessons from a Panel Data Set of Lake Usage

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Prepared for the Danish Environmental Economic Conference
Kurhotel Skodsborg
August 25, 2016

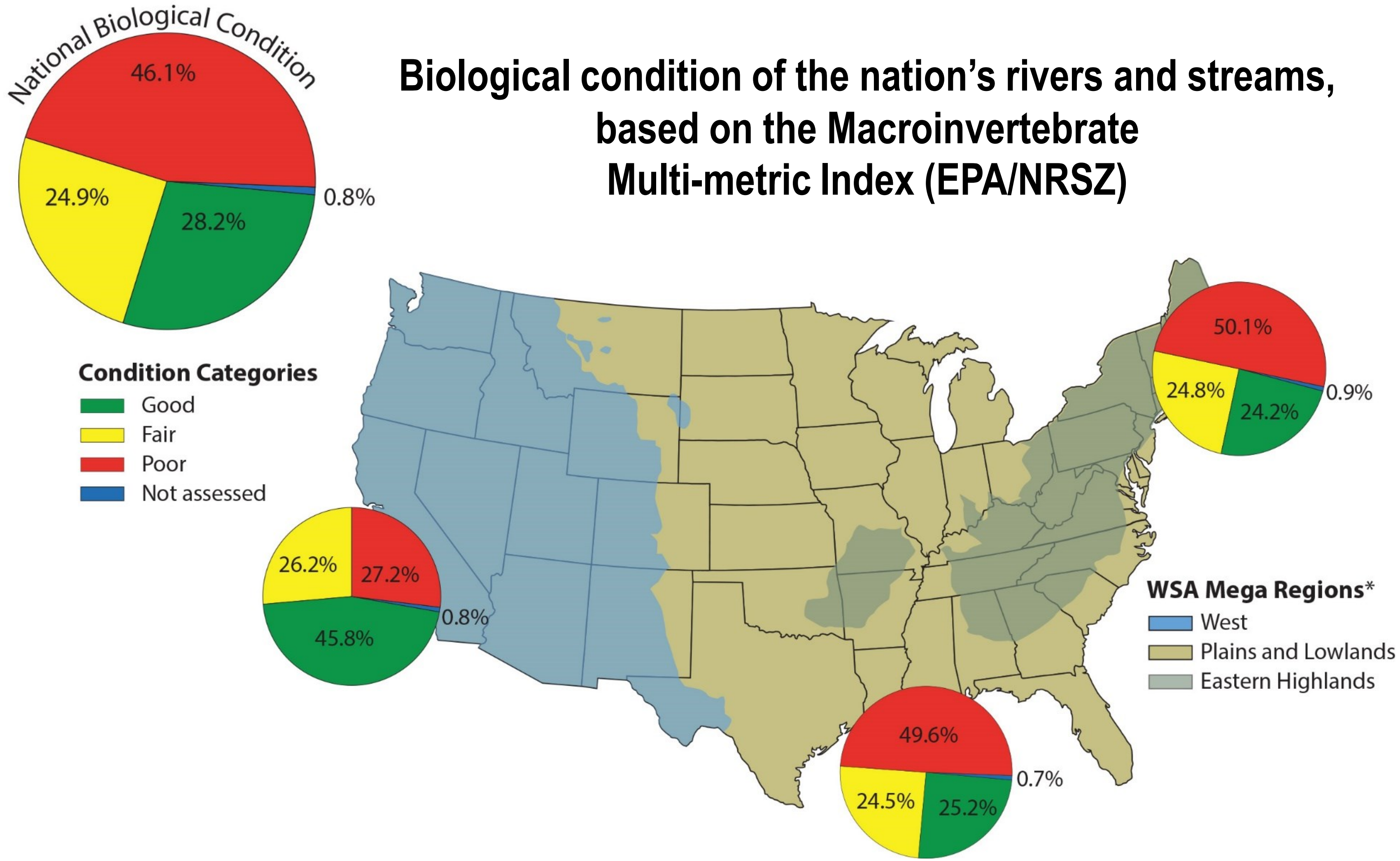
Introduction

- Overview of nutrient water quality problems
  - Nitrogen and phosphorus pollution
  - Agriculture, municipal waste, urban runoff
- The Iowa Lakes Project
- Some Findings

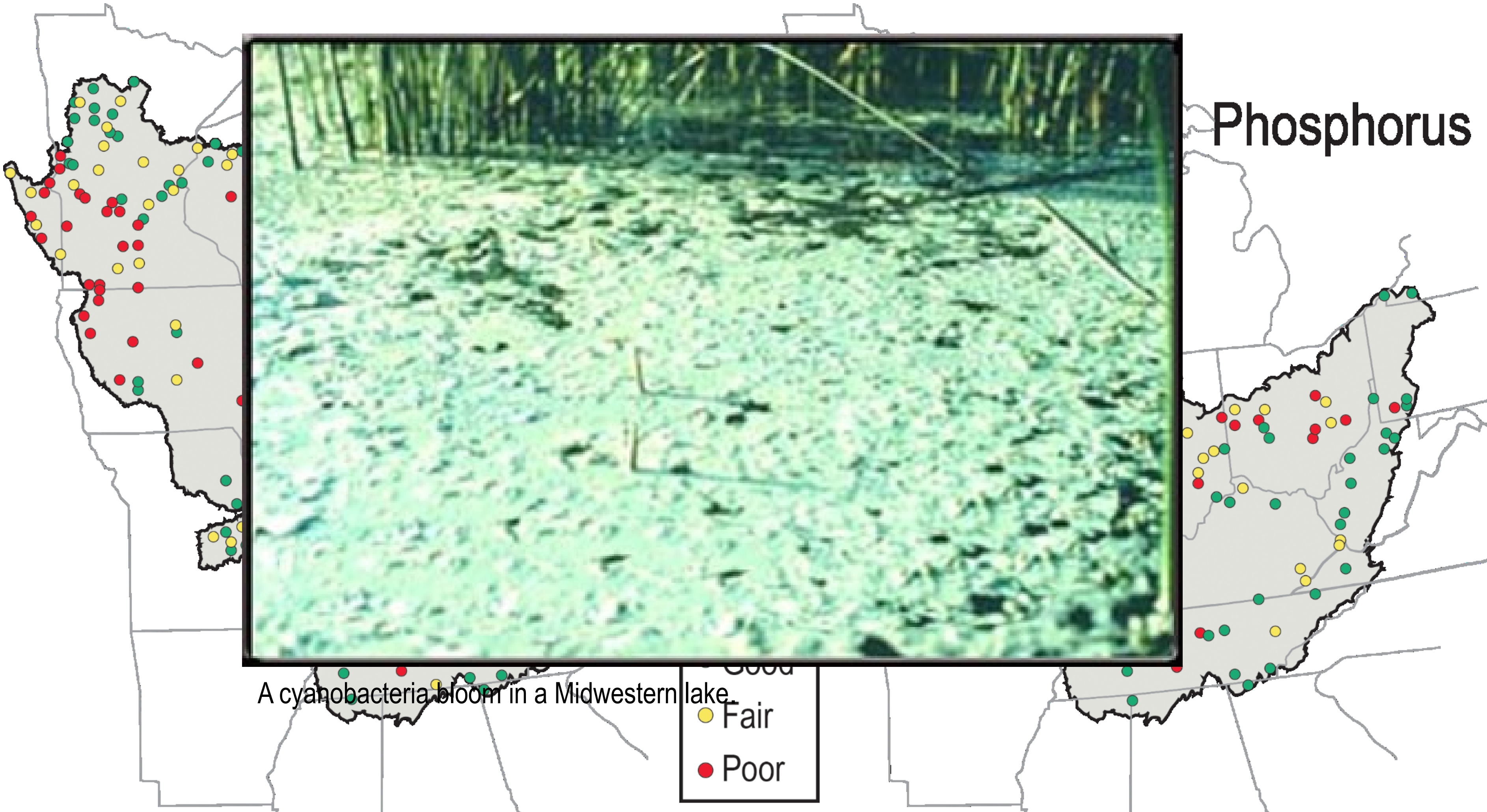
I. Overview of Water Quality Problems

Water Quality: Rivers and Streams (EPA NRSA)

Biological condition of the nation's rivers and streams, based on the Macroinvertebrate Multi-metric Index (EPA/NRSZ)



Water Quality: Lakes (EPA NLA)



A cyanobacteria bloom in a Midwestern lake.

Harmful algal blooms in Lake Erie can prompt beach closures. They also pose a threat to drinking water that is supplied from the lake. The two largest algal blooms ever recorded on Lake Erie occurred in the past five years.

Photo credit: Ohio Sea Grant and Stone Laboratory

Sandusky Bay, Erie County, Ohio

“Toledo bearing full brunt of Lake Erie algae

The Columbus Dispatch August 4, 2014

“Toxin leaves 500,000 in northwest Ohio without drinking water”

REUTERS August 2, 2014

Algae blooms in Lake Erie contaminate water in Ohio and Michigan”

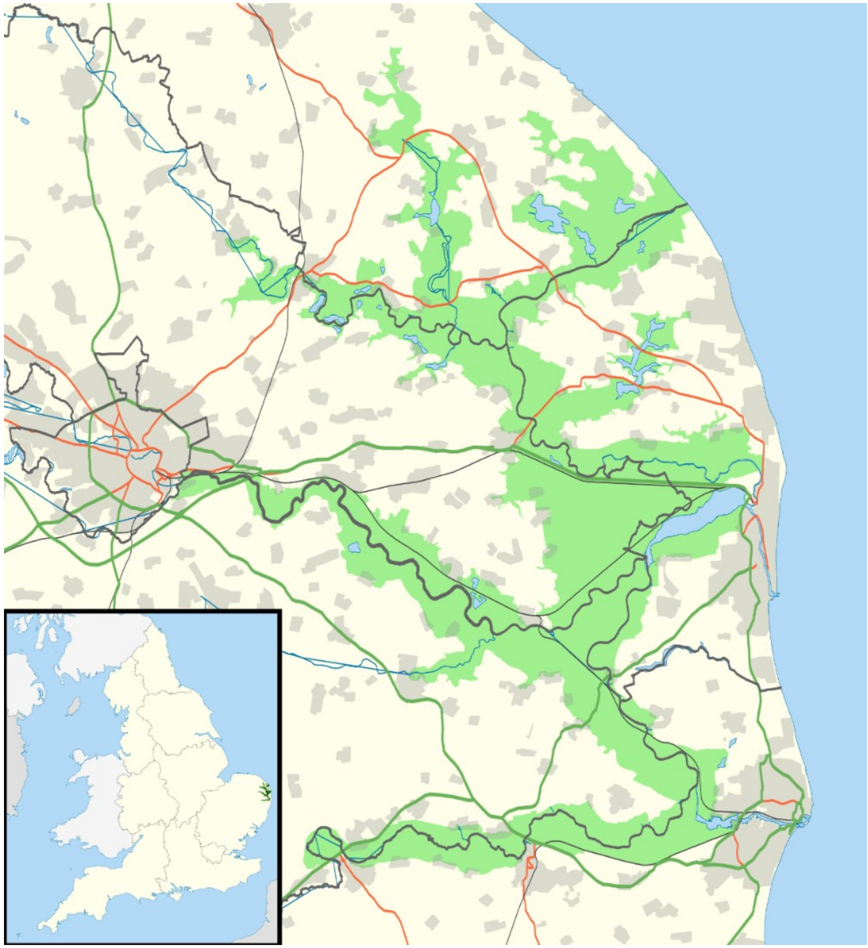
Pittsburgh Post-Gazette August 2, 2014

Toxic Algae Blooms Infesting Florida Beaches Are Putting a Damper on 4th of July Celebrations

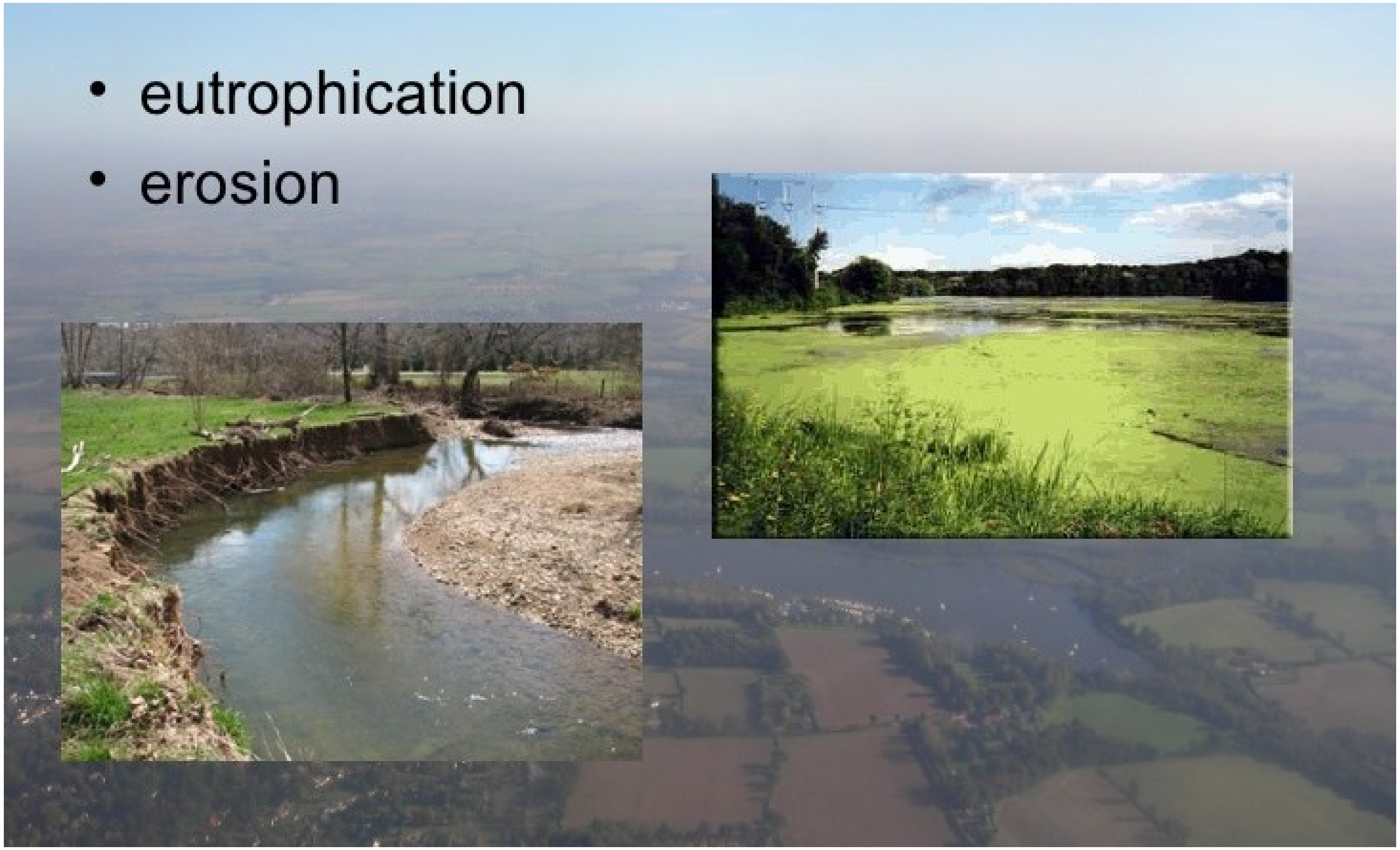
A dead walking catfish lays on the shore with algae Sewell's Point, Fla. on the St. Lucie River under an Ocean Boulevard bridge on June 27, 2016

http://abcnews.go.com/US/toxic-algae-blooms-infesting-florida-beaches-putting-damper/story?id=40326610

The Norfolk Broads

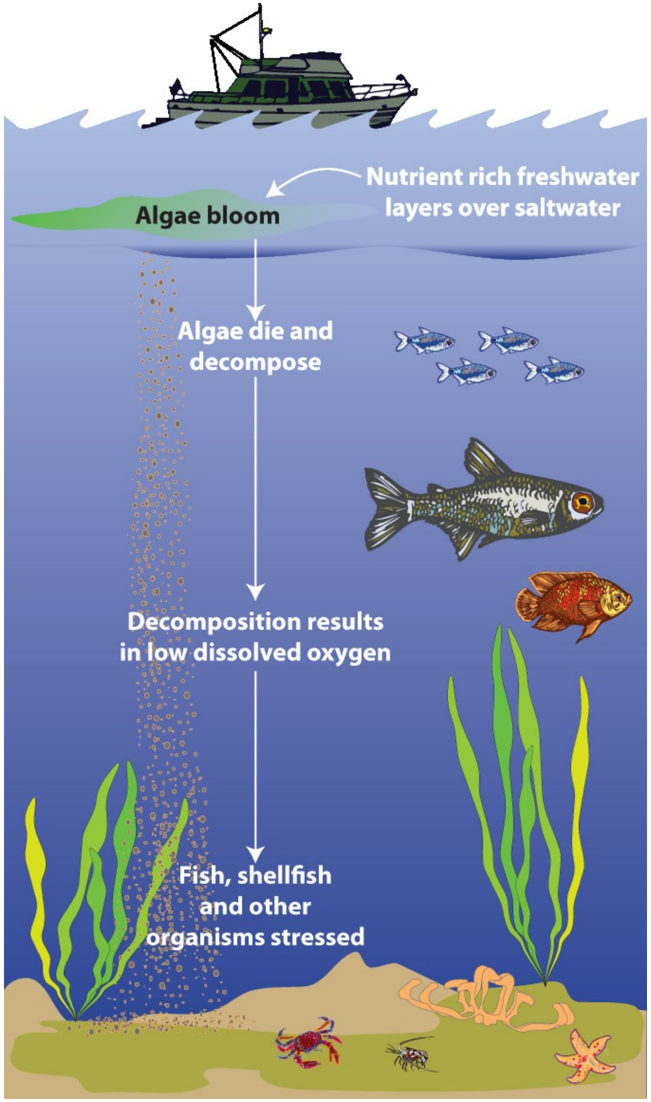


Human impact on the broads



http://www.slideshare.net/ecumene/9-norfolk-broads-tessa-1240600

Hypoxia = Dead Zone



- Depleted oxygen creates zones incapable of supporting most life
- Stressed marine and estuarine systems, mass mortality and dramatic changes in the structure of marine communities (Diaz and Rosenberg, 1995).

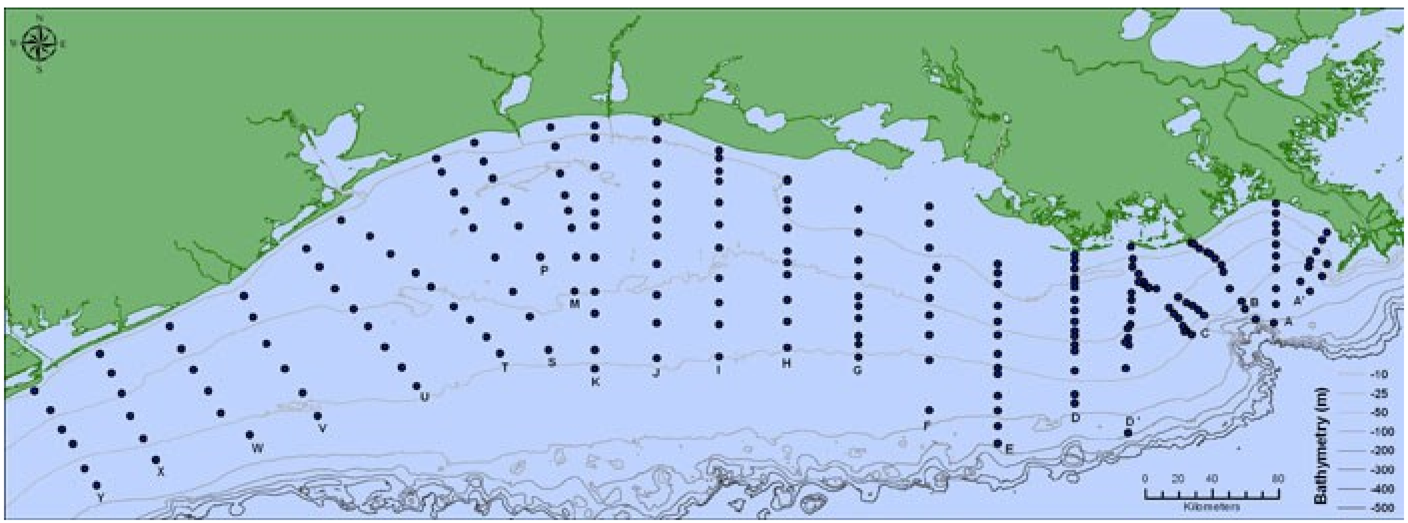
The Gulf of Mexico

http://www.umces.edu/people/boesch-gulf-mexico-hypoxia

The Gulf of Mexico

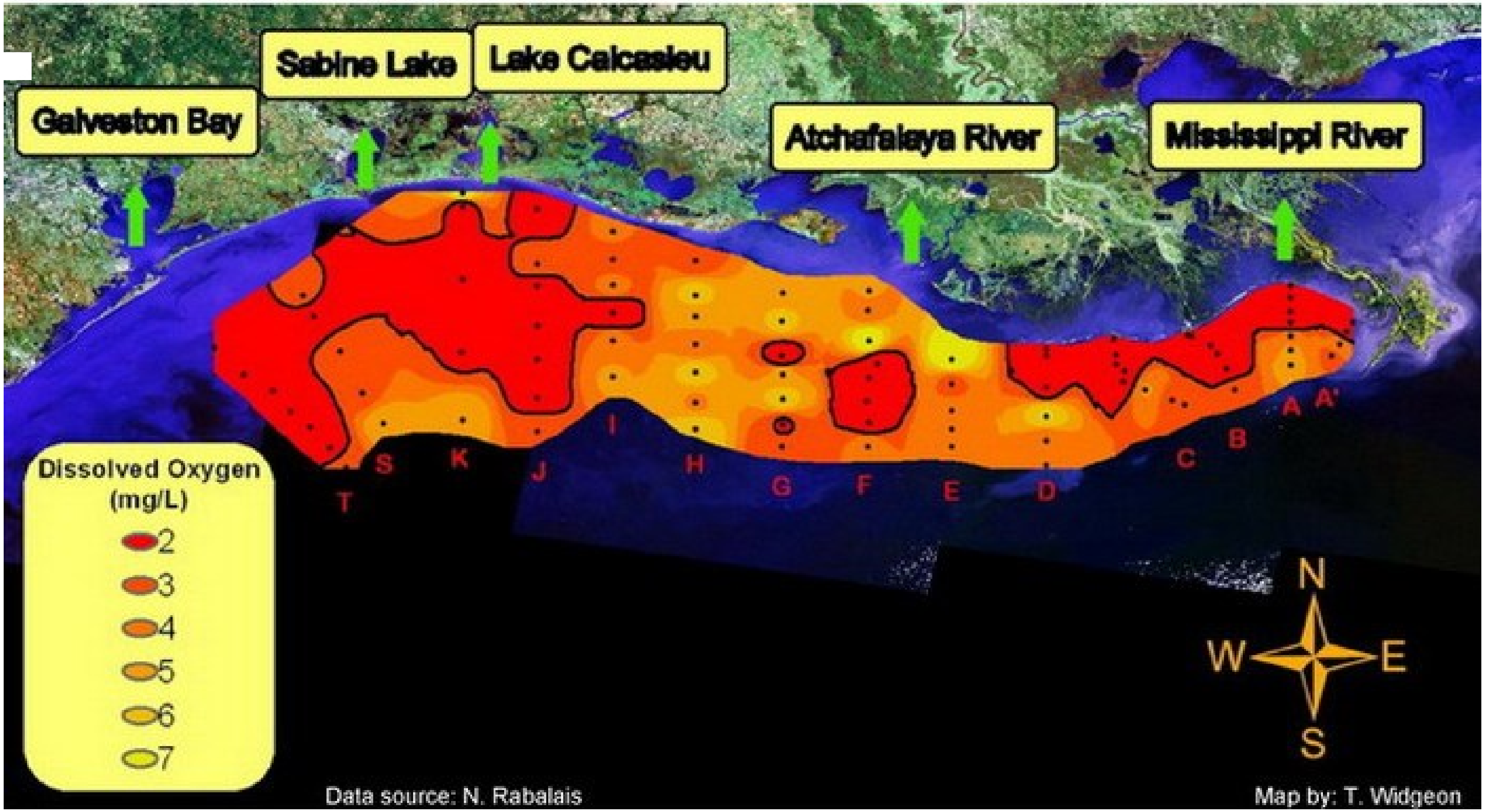
Image courtesy of Nancy Rabalais (Louisiana Universities Marine Consortium) and can be found on the Southern Regional Water Program web site.

Gulf of Mexico Annual Cruise (Dr. Rabalais at LUMCON)

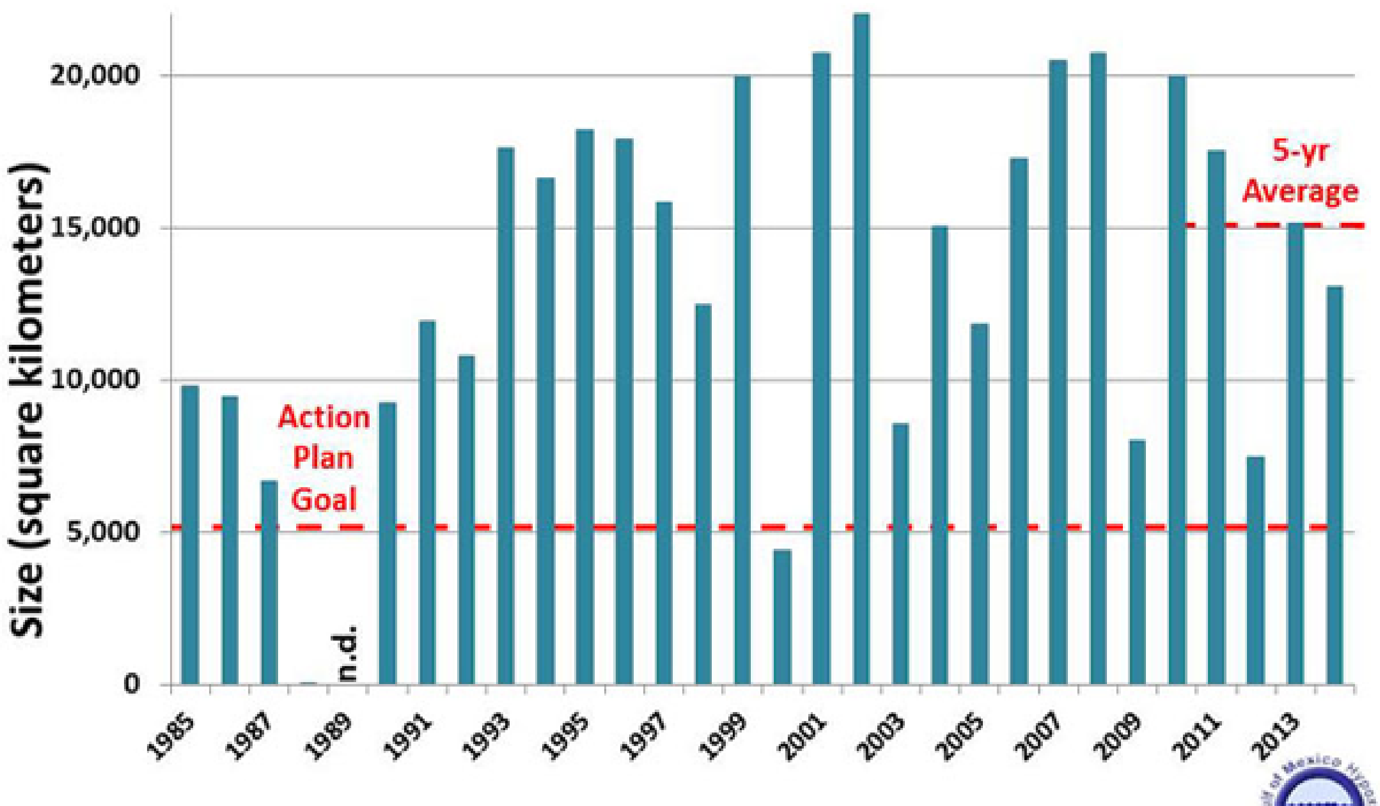


BOTTOM DISSOLVED OXYGEN (mg/L)

JULY 24-31, 2010



Size of bottom-water hypoxia in mid-summer

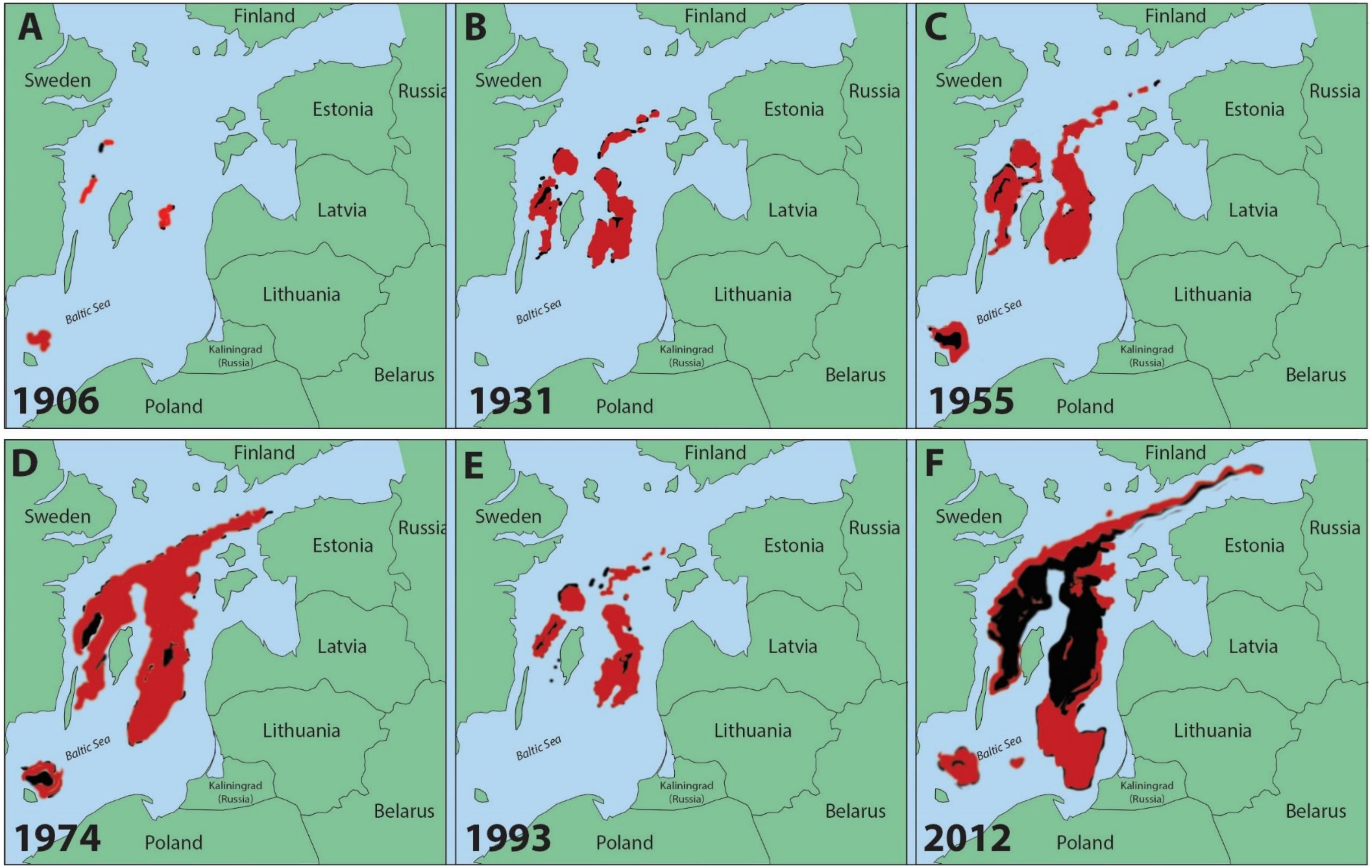


Data source: Nancy N. Rabalais, LUMCON, and R. Eugene Turner, LSU

Funding sources: NOAA Center for Sponsored Coastal Ocean Research and U.S. EPA Gulf of Mexico Program

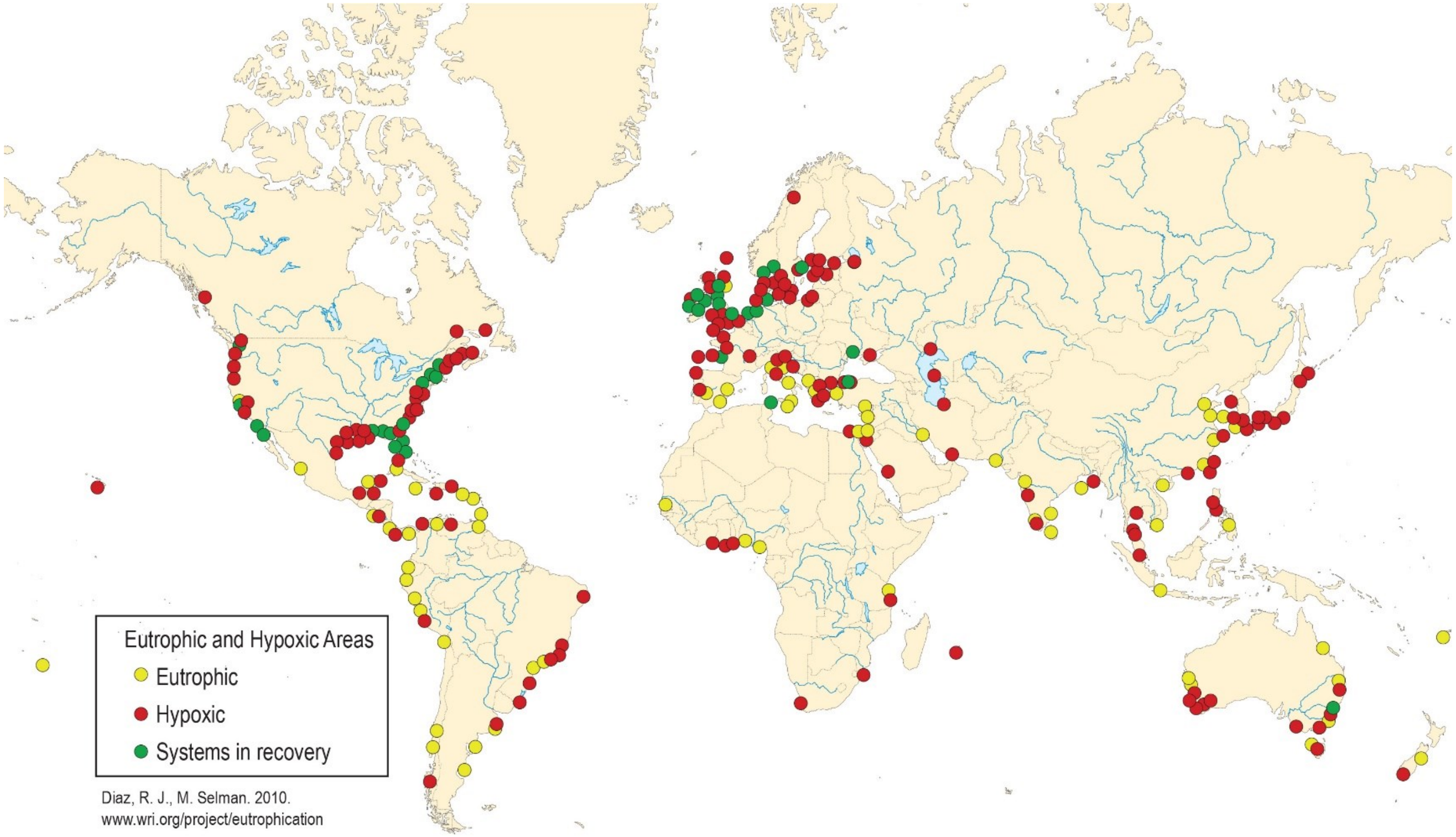
http://www.buzzle.com/articles/what-causes-dead-zones-in-oceans.html

Baltic Sea: Historical zone size



Carstensen, J. et al. "Deoxygenation of the Baltic Sea during the last century." PNAS. doi: 10.1073/pnas.1323156111

Hypoxia and eutrophication globally



From World Resources Institute at http://www.wri.org/map/world-hypoxic-and-eutrophic-coastal-areas

How does this harm ecosystem services?

Micro (species) level

- death,
- reduced reproductive success,
- interruptions of food webs,
- lost habitat,
- increased predation

Macro level (fish stock, catch etc.)

- Mobile species exit zone, move outside,
- "A number of compensatory mechanisms limit the translation of local scale effects of hypoxia to the scale of the whole system" Breitburg, et al. Annual Review of Marine Science, 2009
- Concerns: long run effects, hysteresis effects, different equilibrium ecosystem
- Much remains unknown

Pathways for water quality to affect utility

1. Recreation – swimming, boating, fishing, nature viewing
2. Local Amenity- housing values
3. Drinking water/household use
4. Input into production of private goods - commercial fisheries
5. Existence value - passive use, nonuse

Methods and degree of knowledge

1. Recreation – recreation demand, stated preference, many good local studies, aggregate values not well known (US)

2. Local Amenity- hedonics, stated preference, many good local and improving regional

3. Drinking water/household use – avoidance costs, good for perfect substitutes, little known for continuing health effects,

4. Input into production of private goods - hypoxic conditions, little known for at least some systems, US Gulf and Baltic

5. Existence value - ?,

II. The Iowa Lakes Project

With Joseph Herriges, Yongjie Ji, Hocheol Jeon and many graduate students and post docs

Funding from the U.S. Environmental Protection Agency and the State of Iowa, Department of Natural Resources

Iowa (~3 million people, 56K sq mi: Denmark 6 million, 16K sq mi)

Iowa Lakes Project

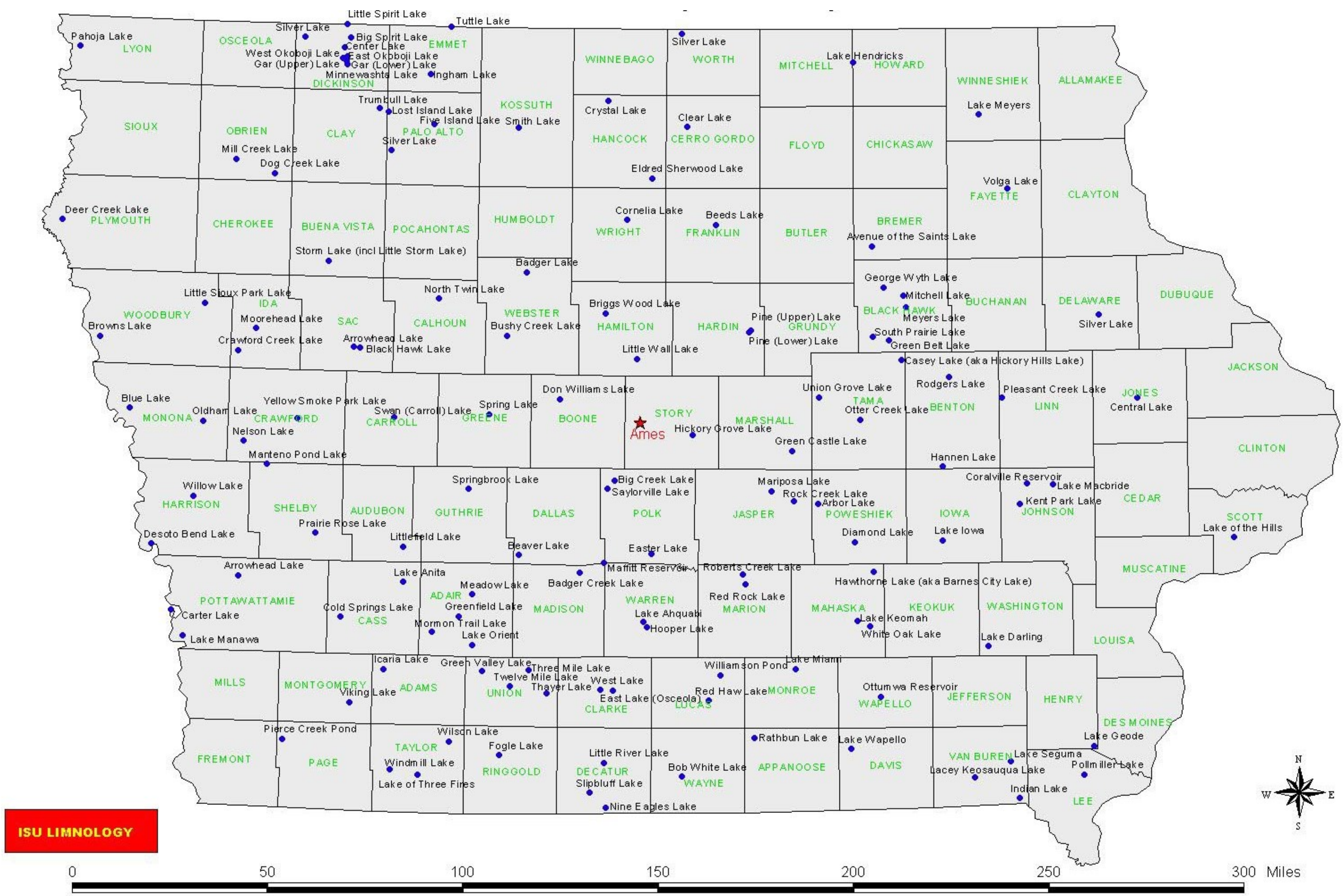
Four years initially, Iowans usage of lakes

- Surveyed 8000 Iowans, random population sample
- Actual trip behavior and future expected trips, years 2001-2006
- Stated Preference scenarios at several target lakes
- Knowledge and perceptions regarding lake quality

Data linked to limnological measurements (Downing) at 130 primary lakes in Iowa (Nitrogen, Phosphorous, Dissolved Oxygen, turbidity, etc)

Two additional years: 2009 and 2014, 6 years of panel information

Iowa State University lake study sites



CARD
Center for Agricultural and Rural Development

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Baseline survey

- Random sample of Iowa households

- Survey collected
  - trip data for 132 lakes
  - attitudes regarding lake quality
  - Socio-demographic data

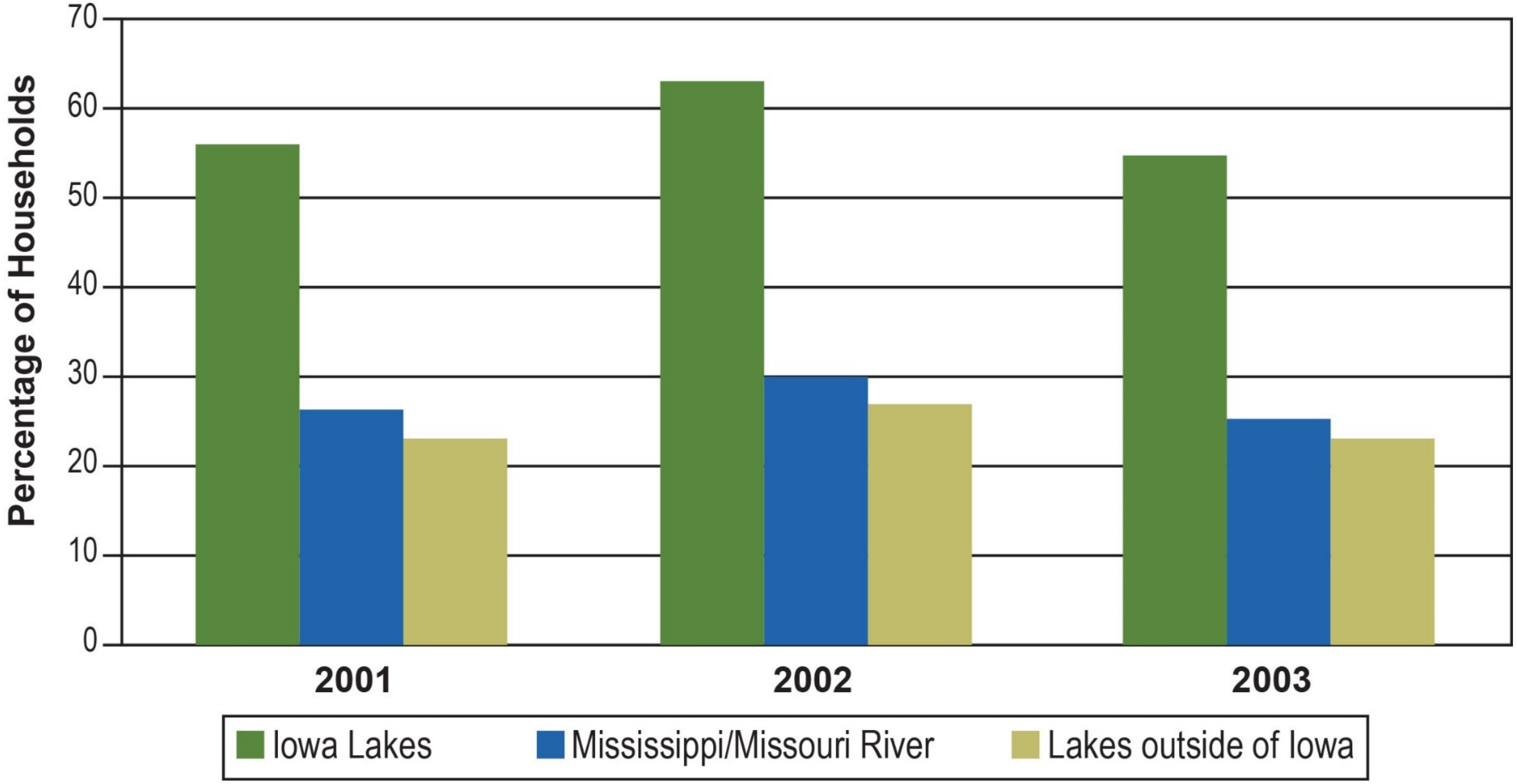
- ~62% response rate, first year; lower in later years

Summary Socioeconomic Data

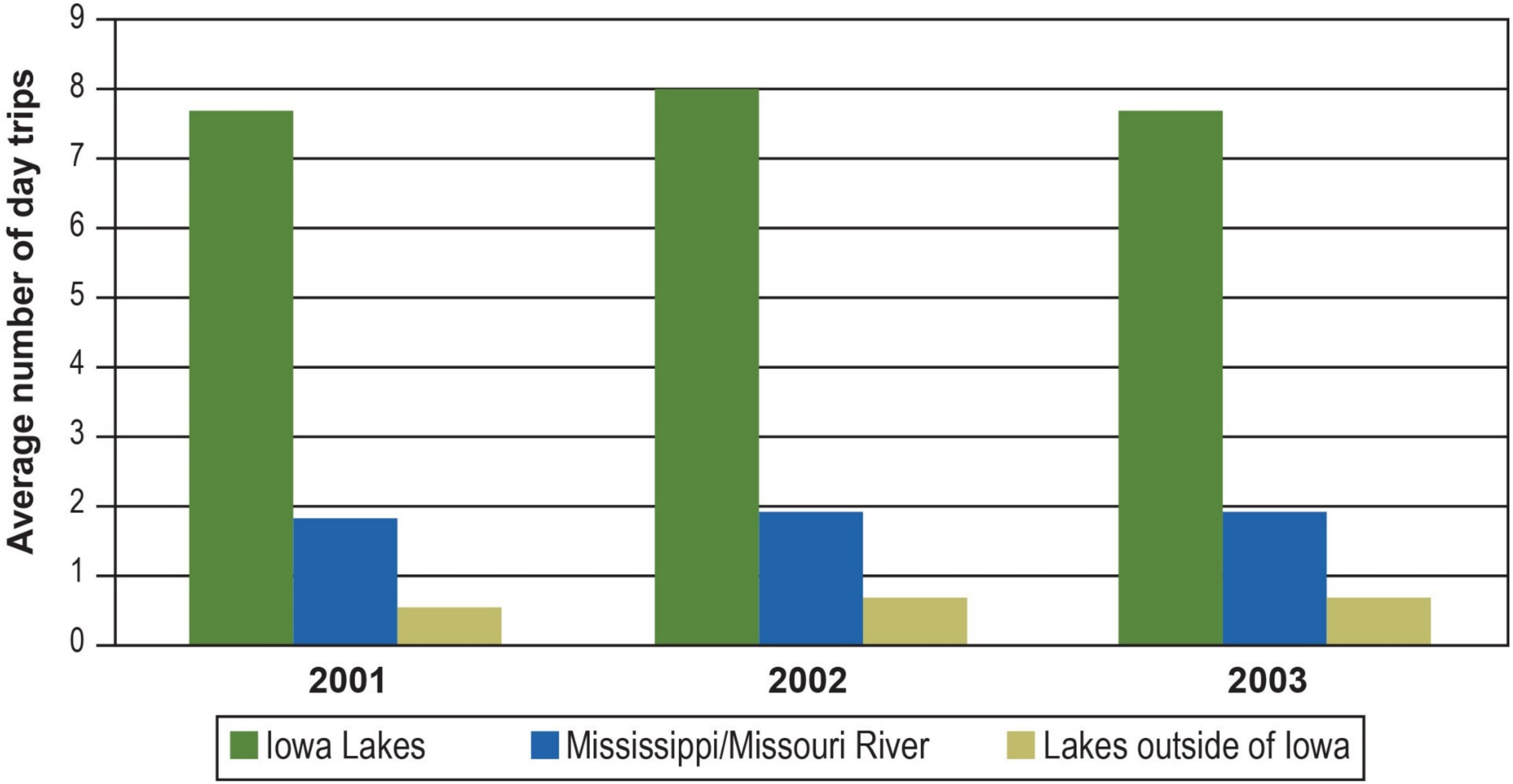
	2002	2003	2004	2005	2009	2014
Average visits	8.52	9.07	8.30	8.19	5.7	8.57
Income	$55K	$55K	$58K	$59K	$64K	$72K
Age	51.2	52.3	53.7	54.4	56.0	57.4
Travel costs	$209	$167	$236	$224	$239	$187
- Real trips	$56	$50	$75	$67	$72	$50
Sample size	3317	4296	3554	3151	5352	3055
Complete panel	3317	2290	1763	1349	611	605

- Income and Age are elicited with intervals, we take the middle point of each interval as the point value.
- Travel costs are calculated between each household home location and each lake centroid. The travel cost for real trips is corresponding to households' single day trips to each visited lake, weighted by the number of trips taken in that year.

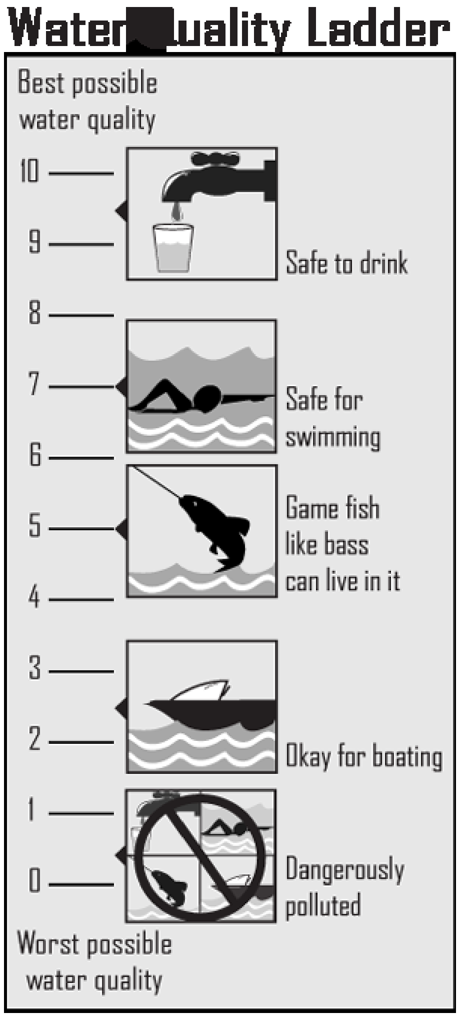
Percentage of respondents who took at least one trip



Average number of day trips



National Sanitation Foundation Water quality index

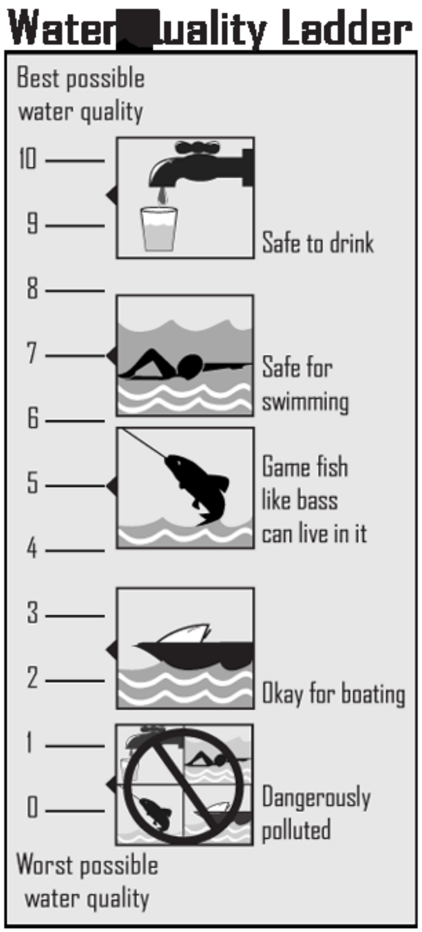


Indicators	Weight
Dissolved Oxygen	0.17
Fecal Coliform	0.16
pH	0.11
BOD	0.11
Temperature Change	0.1
Total phosphate	0.1
Nitrates	0.1
Turbidity	0.08
Total Solids	0.07
	1

- Indicators are first converted to the sub-indices (Q-value) q_i, then weigh… $\sum w_i * q_i$.
- Since we only have 6 out of 9 indicators, the weights are adjusted by w_i'…

Water Quality data: National Sanitation Foundation Water quality index

WQI	2002	2003	2004	2005	2009
Average of All Lakes	78	78	74	76	78
1st Visited Lake	65	69	62	63	80
2nd Visited Lake	81	63	73	77	86
3rd Visited Lake	78	77	72	62	64
4th Visited Lake	72	84	86	73	71
5th Visited Lake	67	81	63	62	81
6th Visited Lake	91	91	62	90	86
7th Visited Lake	85	67	83	81	75
8th Visited Lake	84	86	86	88	68
9th Visited Lake	88	80	80	87	82
10th Visited Lake	80	90	87	81	71

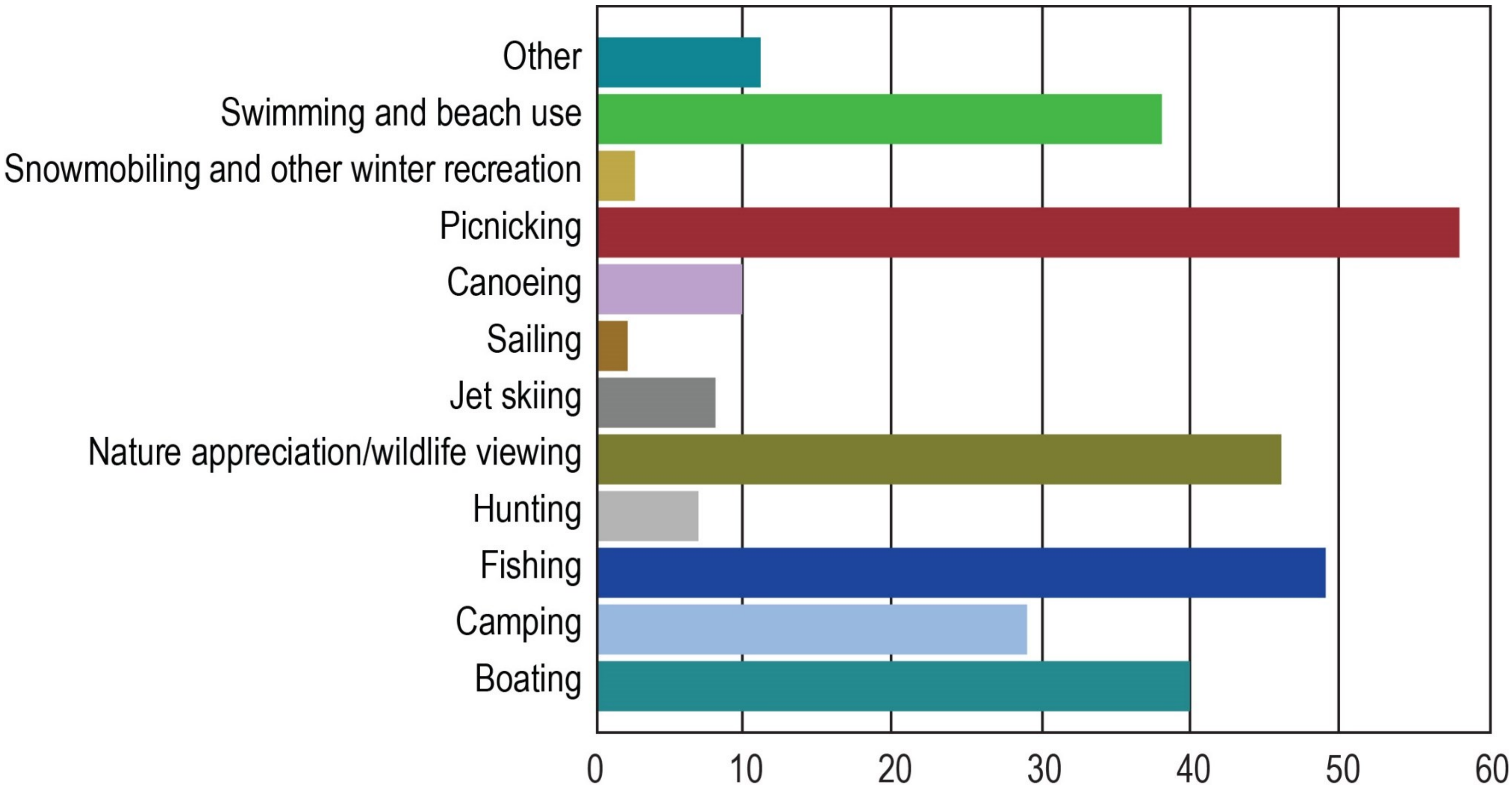


Silver Lake

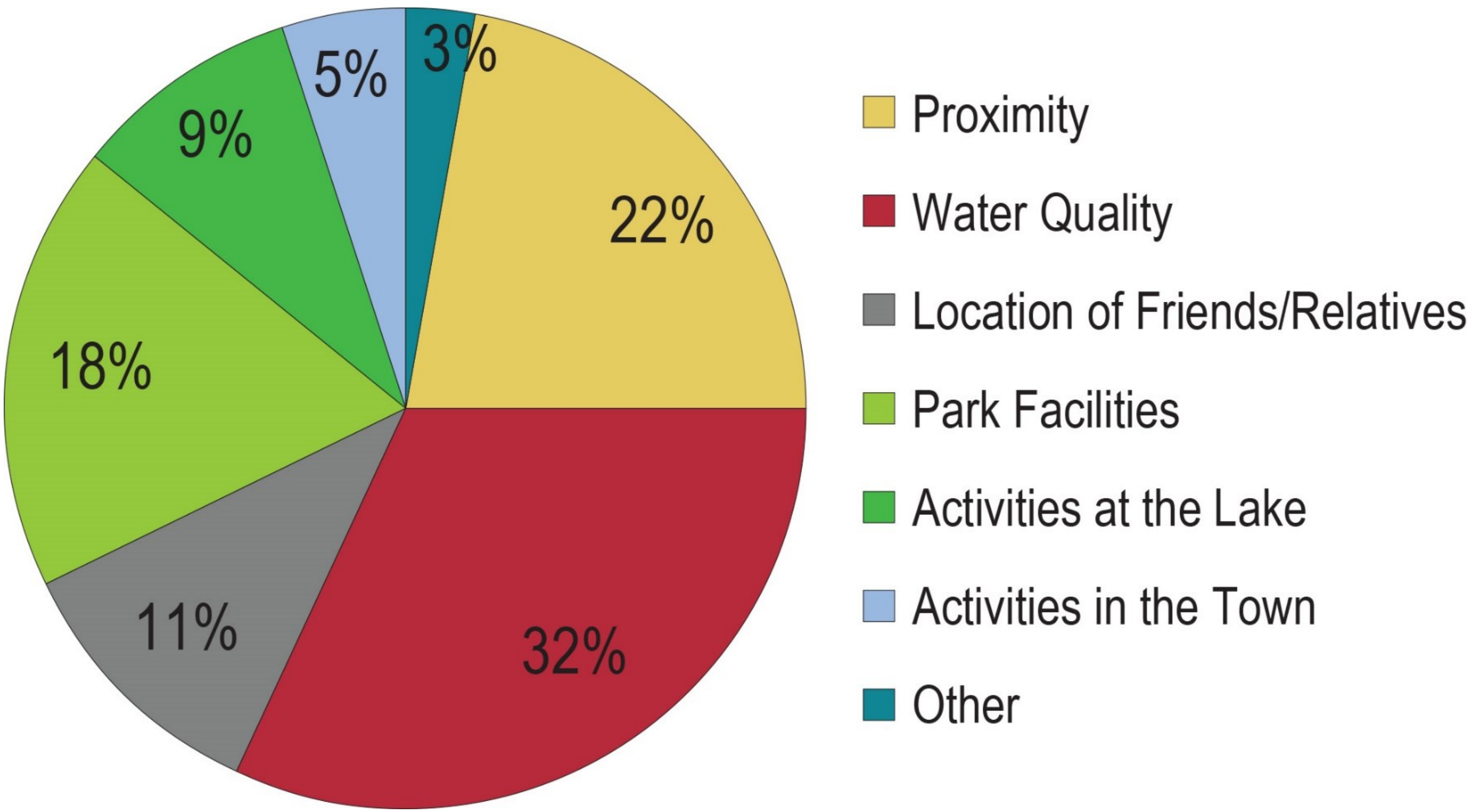
Rathbun Lake

West Okoboji Lake

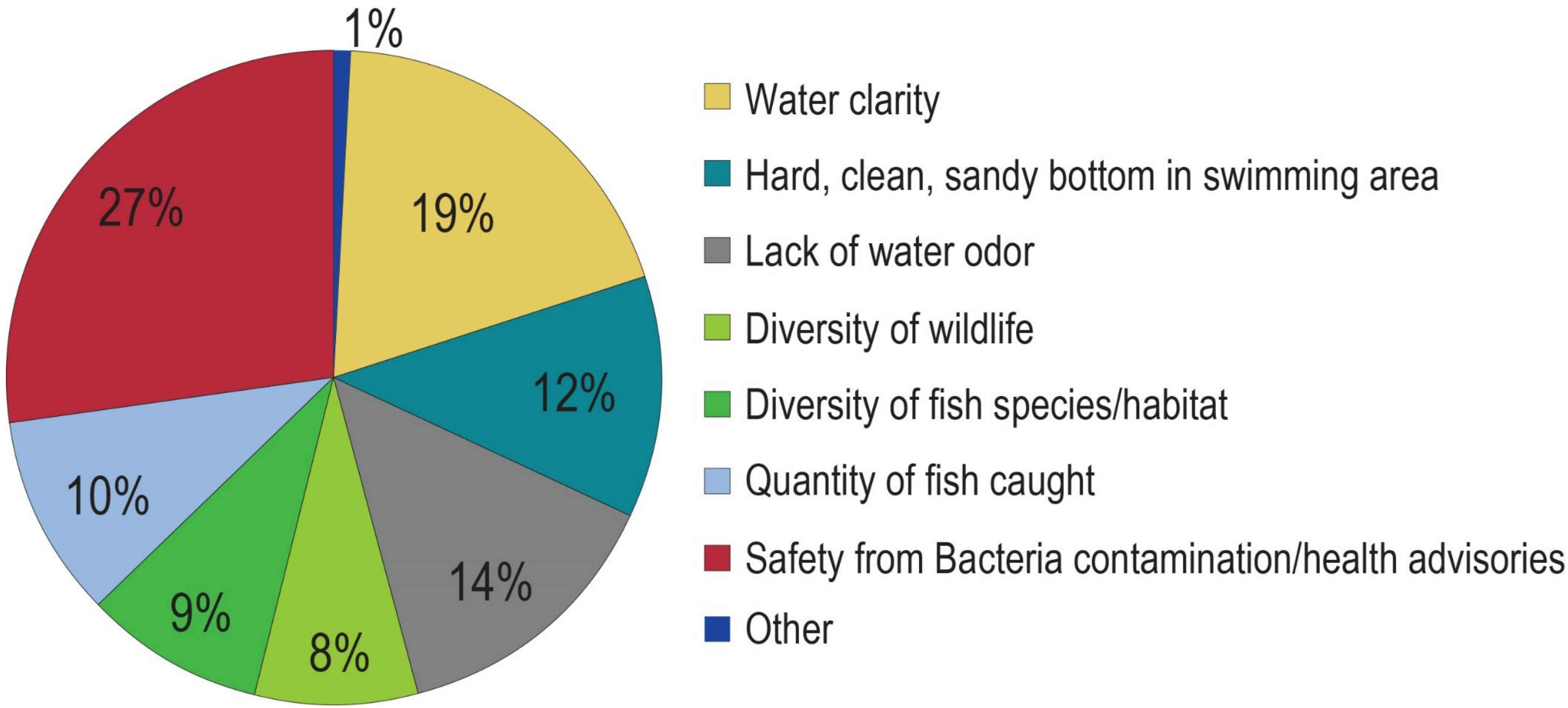
Activities engaged in by respondents



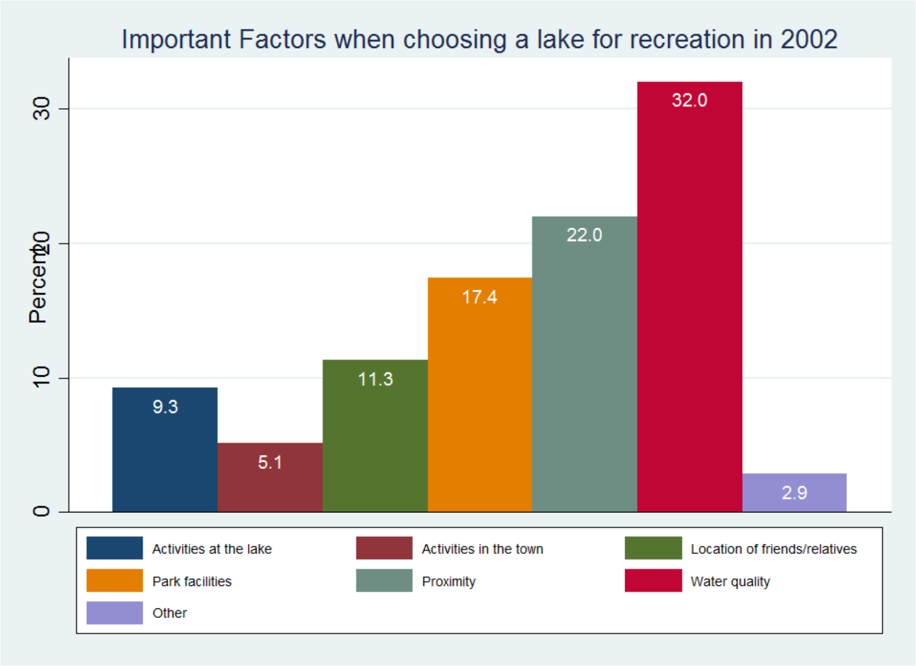
Average allocation of importance points to factors important in Choosing a lake for recreation

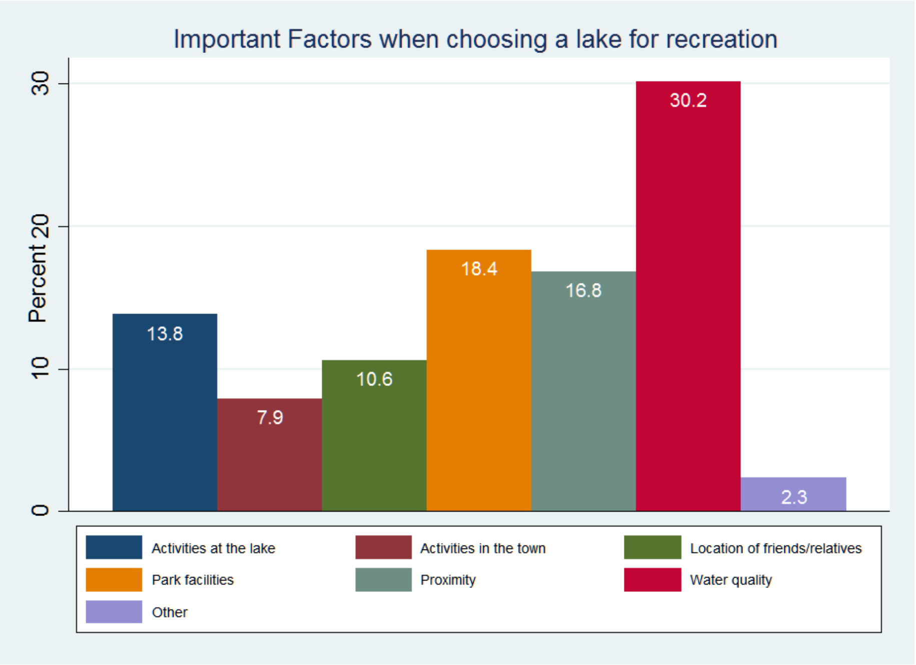


Average allocation of importance points to lake characteristics

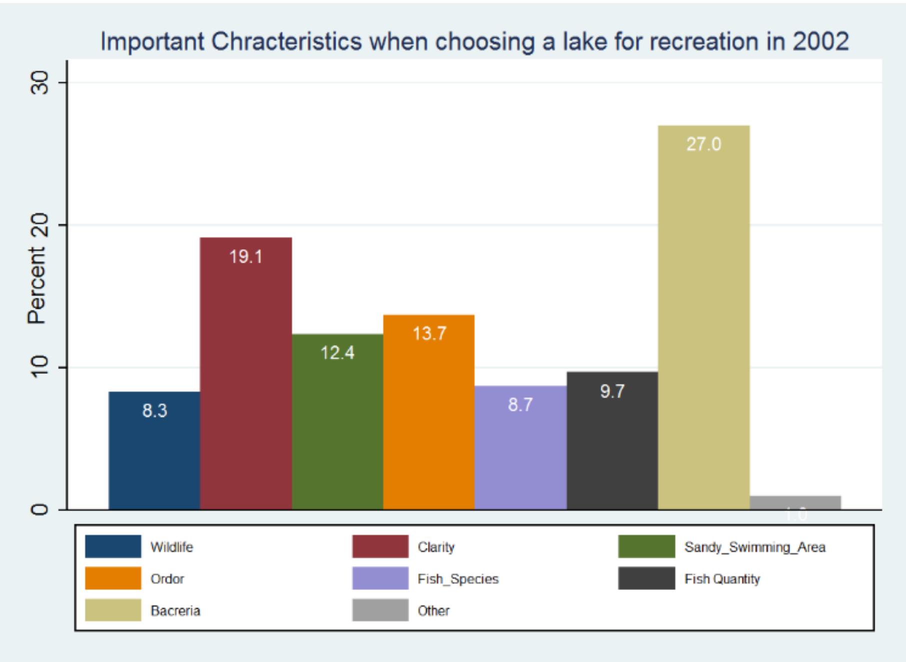


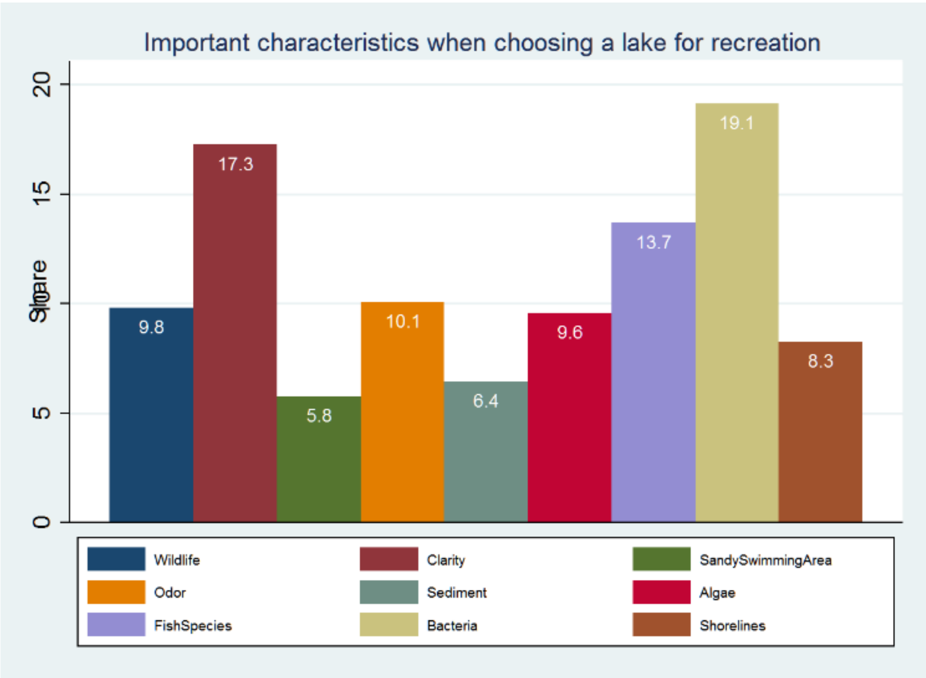
Factors when choosing a lake for recreation in 2002 vs 2014



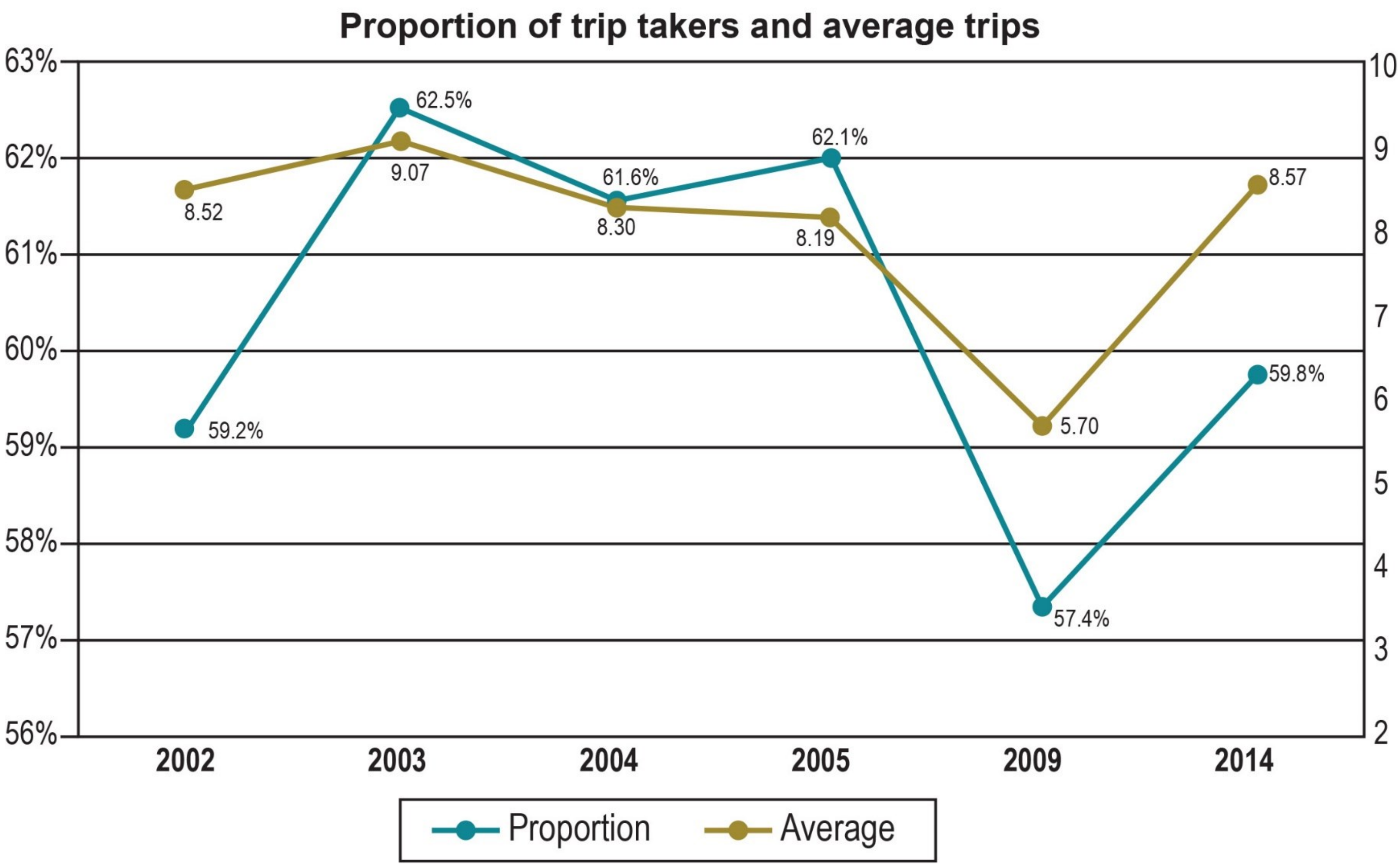


Lake characteristics when choosing a lake for recreation in 2002 vs 2014





Comparison of proportion of trip takers over the years



Recreation Demand Modeling

1. Random Utility Maximization (RUM) Model – current “workhorse”

   - Based on McFadden, applied extensively (both recreation and elsewhere)
   - Morey et al, repeated logit model, important insight for extending to recreation data
   - Strengths: deals with discrete nature of choices, relatively easy to estimate even for large choice ocassions
   - Weaknesses: each trip is independent, no diminishing marginal utility of trips, arbitrary number of choice ocassions

2. Kuhn-Tucker Model

   - Based on Wales and Woodland, derives estimating equation from Kuhn-Tucker conditions for utility maximization
   - Strengths: fully utility theoretic r.e. both site choice and number of trips
   - Weaknesses: Difficult to estimate for large number of choice occasions, limited functional forms that are estimable

RUM Model specification

$$U_{ijt} = \begin{cases} \beta^z z_i + \epsilon_{iot}, & j = 0 \\ -\beta^p P_{ij} + \beta_i^q Q_j + \beta^a A_j + \epsilon_{ijt}, & j = 1, \dots, J \end{cases}$$

Where j=0, stay home option

- z_i is a vector of social –demographic data
- P_{ij} represents the computed travel cost or "price" of the recreation trip calculated as: $P_{ij} = 2 * (0.25 * distance + \frac{1}{3} * travel\ time\ * wage)$
- Q_j represents the physical water quality measures for each lake
- A_j represents non-water quality attributes for each lake
- βs are unknown parameters, the subscript i indicates that parameter is a random parameter.

Water Quality and welfare aside: Choice of water quality measures

- Q_j is a vector of water quality variables, what are they?
  - Physical measurements of biological and chemical components: Nitrogen, Phosphorus, suspended solids, etc
  - Water quality indices, water quality ladder
  - Descriptions of related attributes: catch rates, clarity (Secchi depth), odor, species richness
- How do we decide? Here, use model fit

1. Five water quality variables, fit model using 2002 data for each combination of log vs linear inclusion of variable, N=2^5=32 combinations

2. Within-Sample fit = lowest log likelihood value.

RUM Model welfare measures, 2002 data

Annual WTP	***All lakes improved to West Okoboji***	***Nine focus lakes improved to West Okoboji***	***Loss of Lake West Okoboji***
Average WTP per Iowa household	$229.81	$78.87	$17.22
Total WTP for all Iowa households	$264,115,000	$90,643,000	$19,791,000

- WTP is measured by the compensating variation
- The considered water quality improvement is to improve focus lakes' water quality to the level of Lake West Okoboji in 2002
- Total WTP for all Iowa Households is calculated as the average WTP times the number of households in 2000 US census, and rounded to the nearest thousand

Sensitivity of findings

- How stable are parameter and welfare estimates from one year of data? Can we be confident that estimates from a single year of data collection can be applied to other years?
  - Estimate models using 2002 data,
  - search for best fit,
  - examine how well the model predicts other years

- How stable are welfare estimates using a different model structure altogether? Kuhn-Tucker model

Within-Sample Fit vs Out-of-Sample Prediction

1. Five water quality variables, fit model using 2002 data for each combination of log vs linear inclusion of variable, N=2^5=32 combinations

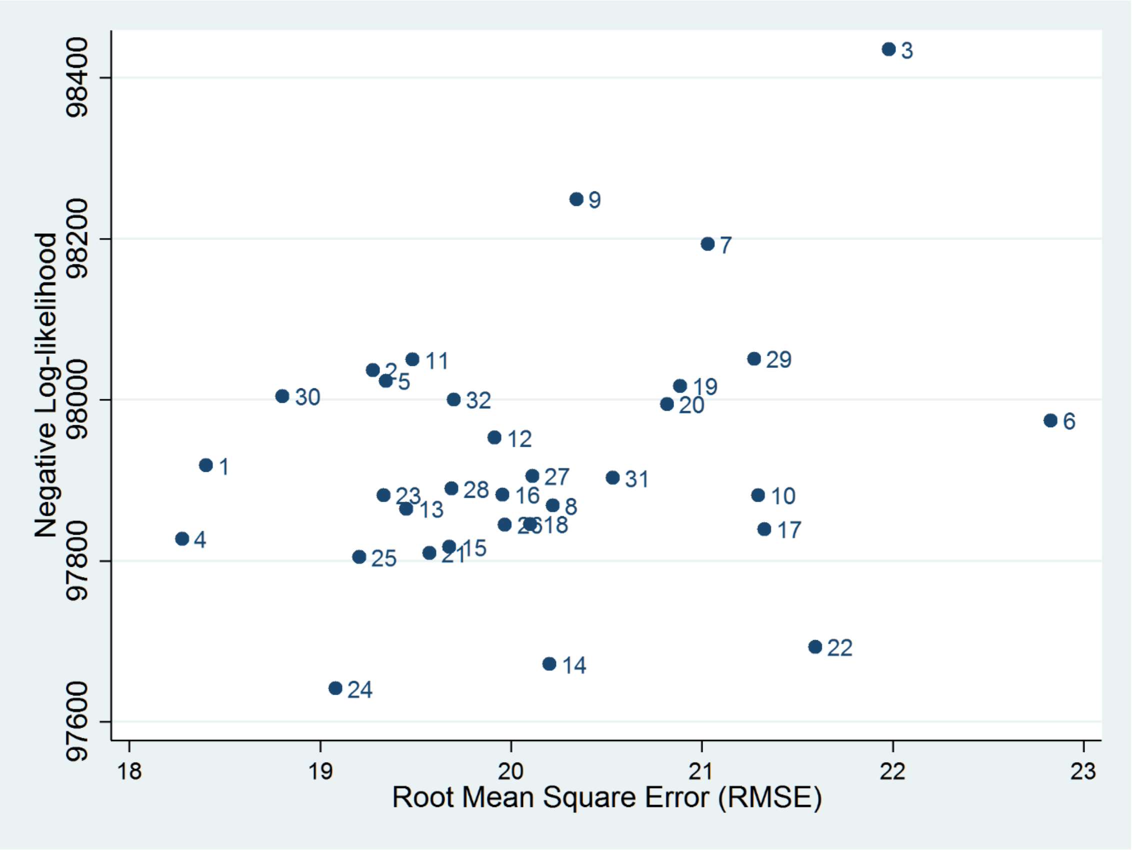
2. Within-Sample fit = lowest log likelihood value.

3. Out-of-sample fit, compute Root Mean Square Error for trips prediction between 2002 and 2003

$$\text{RMSE} = \sqrt{N^{-1}\left(\sum_{i=1}^{N}(y_i - \widehat{y_i}\right)},$$

where y_i and $\widehat{y_i}$ are household i's reported recreation trips and predicted trips in 2003 with parameter estimates from 2002 data, respectively.

Within-Sample Fit vs Out-of-Sample Prediction



RMSE is defined as $\sqrt{N^{-1}(\sum_{i=1}^{N}(y_i - \hat{y}_i)}$. y_i and $\hat{y}_i$ are household i's reported recreation trips and predicted trips in 2003 with parameter estimates from 2002 data, respectively.

Most favored RUM specifications

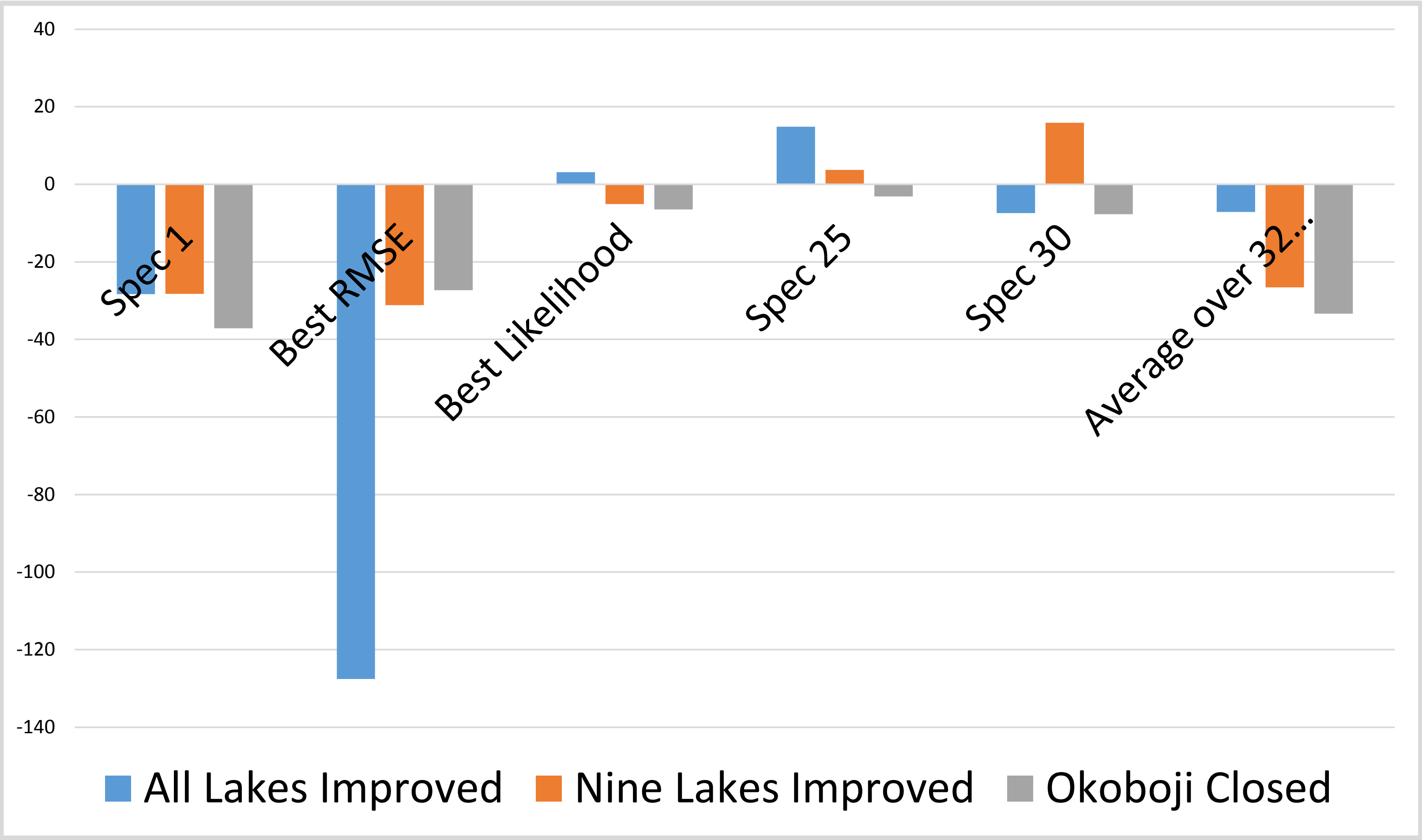
Spec	Secchi	Chlorophyll	TN	TP	DO
1	Linear	Log	Log	Linear	Log
4	Log	Log	Log	Linear	Log
24	Linear	Linear	Log	Log	Linear
25	Linear	Linear	Log	Linear	Linear
27	Log	Log	Linear	Log	Linear
30	Log	Linear	Log	Log	Linear

Willingness to Pay estimates—from most favored RUM specifications

Specifications	2002			2003-predicted I			2003-predicted II			2003		
1	$267	$109	$21	$532	$286	$62	$530	$245	$48	$413	$191	$35
4	$187	$59	$12	$274	$104	$18	$264	$80	$14	$116	$61	$11
24	$230	$79	$17	$206	$193	$42	$370	$164	$33	$382	$156	$31
25	$174	$75	$18	$264	$184	$42	$315	$157	$33	$370	$163	$32
30	$239	$59	$15	$416	$92	$17	$260	$74	$14	$242	$88	$13
Average	$203	$79	$17	$315	$165	$35	$315	$143	$28	$294	$113	$21
CV (coefficient of variation)	0.37	0.36	0.26	0.45	0.53	0.59	0.46	0.55	0.56	0.41	0.46	0.48

2002: estimated coefficients with 2002 data, water quality data and household information also from 2002 data.
2003-predicted I: coefficients from 2002 data, water quality data and household information from 2003 survey.
2003-predicted II: coefficients from 2002 data, household information from 2002 data, water quality data from 2003.
2003: estimated coefficients with 2003 data, water quality data and household information also from 2003 data.

Percentage Difference: 2003 Fitted model and 2002 Prediction



More to come

- Extend to all years, 2002 – 2014
- Consider alternative variable choices,
  - Water quality index
  - Lagged water quality
  - Panel estimates
- How stable are welfare estimates using a different model structure altogether? Kuhn-Tucker model

Thank you!

Tusind Tak

Fortsat god dag!

This research was supported by the US Environmental Protection Agency, the Iowa Department of Natural Resources, and the Center for Agricultural and Rural Development at Iowa State University.

Kuhn-Tucker Model

$$U = \sum_{j=1}^{M} \Psi_j \ln(\phi_j x_j + \theta) + \frac{1}{\rho} z^{\rho}$$

$$\ln \Psi_j = \delta^T s + \mu \varepsilon_j,$$

$$\ln \phi_j = \gamma^T q_j$$

$s =$ socioeconomic variables

$x_j =$ visits to site $j = 1, \ldots, J$

$q_j =$ vector of water quality variables

$z =$ numeraire

$\varepsilon =$ random term

$\Psi_j, \delta, \mu, \phi_j, \gamma, \rho =$ parameters to be estimated

Willingness to Pay estimates—KT Model

Annual WTP	***All lakes improved to West Okoboji***	***Nine focus lakes improved to West Okoboji***	***Loss of Lake West Okoboji***
Average WTP per Iowa household	$129.39	$17.20	$28.09
Total WTP for all Iowa households	$148,708,000	$19,762,000	$32,286,000

- WTP is measured by the compensating variation

- The considered water quality improvement is to improve focus lakes' water quality to the level of Lake West Okoboji in 2002

- Total WTP for all Iowa Households is calculated as the average WTP times the number of households in 2000 US census, and rounded to the nearest thousand

Willingness to Pay estimates comparison—average WTP per Iowa household

	All lakes improved to West Okoboji		Nine focus lakes improved to West Okoboji		Loss of Lake West Okoboji	
	RUM	KT	RUM	KT	RUM	KT
1st favorable model	$229.81	$129.39	$78.87	$17.20	$17.22	$28.09
2nd	$196.82	$126.15	$88.58	$16.91	$22.96	$30.61
3rd	$70.26	$128.97	$71.42	$17.31	$14.26	$28.83
4th	$174.32	$129.00	$74.97	$17.31	$17.63	$28.83
5th	$167.28	$193.33	$82.27	$26.69	$15.77	$32.53
Mean (32 models)	$202.77		$78.77		$17.24	
CV (coefficient of variation)	0.37		0.36		0.26	

The favorability of each model specification is judged by its log-likelihood values. Best fit for RUM is 24, best fit for KT is 27

What are the Consequences of Consequentiality?

The Impact of Consequential Surveys on Stated Preference Responses

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Department of Economics
Iowa State University

Motivation

- Carson, Groves, and Machina (2000): If respondents believe the result of the survey might influence an outcome they care about, dominant strategy to answer CV questions truthfully
- Provision and payment consequentiality both important
- Want to value water quality improvements inclusive of all values (not just recreation) and want to consider role of consequentiality

Sample survey pages

In the following sections we will ask you some questions about potential changes to the water quality of Rathbun Lake located in Appanoose County. First, however, we will give you some information on the current condition of the lake. Please read this information carefully before answering the questions that follow.

Rathbun Lake's Current Condition

The quality of a lake can be described in many ways. One measure of water quality is the clarity of the lake water. Water clarity is usually described in terms of how far down into the water an object remains visible. The clarity of Rathbun Lake is currently between 2 to 4 feet. This means that objects are visible down to about 2 to 4 feet under the surface of the water.

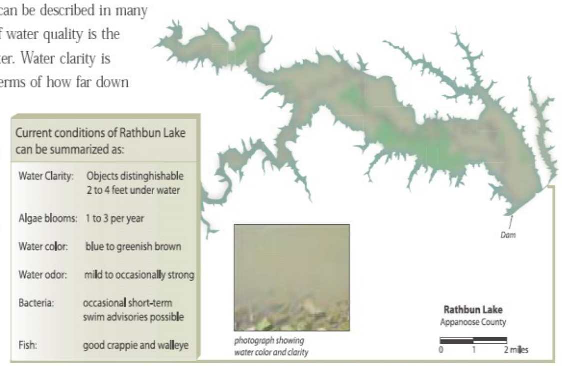


Figure 1. Current conditions of Rathbun Lake

Another measure of water quality is the amount of nutrients and other contaminants contained in the water. Water degradation can result from a number of sources, including urban runoff, fertilizers used in agriculture, motor vehicles, and others. Currently nutrients contribute to the occurrence of algae blooms in the lake, usually 1 to 3 times per year. Under some circumstances these blooms can be a health concern, causing skin rashes and allergic reactions. While Rathbun Lake is currently not regularly monitored, lakes with water quality measurements similar to those of Rathbun Lake had "Swimming is Not Recommended" signs posted by the Iowa Department of Natural Resources for anywhere from 6 to 8 weeks during a typical summer.

The overall quality of the water can affect other conditions of the lake. Poor water quality can result in an undesirable color and odor to the lake water. Currently, the color of Rathbun Lake varies between blue and greenish brown. The water usually has a mild to occasionally strong odor that many describe as "fishy."

Finally, the quality of the water affects the variety and quantity of fish in the lake. Rathbun Lake is a popular fishing lake for crappie and walleye. Catch rates for crappies are typically very good (about 120,000 annually) while walleye catches are more variable, but Rathbun Lake is the best walleye fishery in southern Iowa (about 2,000 annually). Large mouth bass and bluegill are not important sportfish species at Rathbun Lake.

4. During the course of the next year (2004), how many trips do you expect to take to Rathbun Lake?
   _____trips in 2004.

In the next question, we will be asking you how you would vote on a special ballot regarding the water quality of Rathbun Lake. While there is currently no such ballot initiative, we would like you to respond as if you were actually voting on the initiative and as if this were the only alternative available for improving water quality in the lake. (In particular, assume that no state action will be undertaken unless the referendum passes.)

When you think about your answer, it is important to keep in mind that people may indicate that they would be willing to pay more money when payment is hypothetical than when they are immediately expected to pay. It may be easy for people to say that they support a project when they are not sure they will ever have to pay any money based on their response. However, if the proposed payments are real and immediate, people may be more inclined to think about other options and what things they would have to give up to make this payment. So in answering the following questions, please keep in mind both the benefits of the water quality improvement and the impact that passage of such a referendum would have on your finances. In other words, **please answer as if this were a real referendum.**

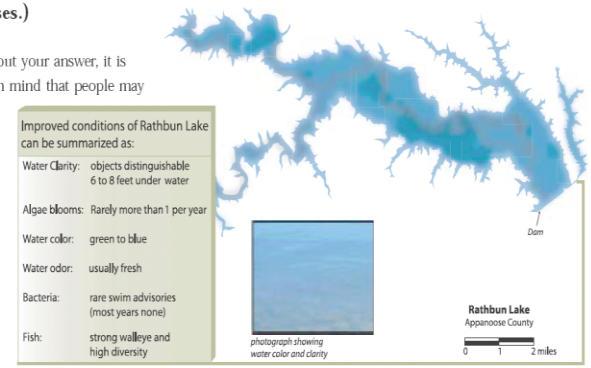


Figure 2. Conditions of Rathbun Lake following an improvement

Suppose that investments could be made to actually improve the quality of Rathbun Lake. These investments might include dredging, building protection strips along the edge of the lake to reduce runoff from the surrounding watershed or other structural changes to the lake and watershed. These changes would improve the lake over the next 5 years to the conditions described in Figure 2.

5. Would you vote "yes" on a referendum to improve the water quality in Rathbun Lake to the level described here? The proposed project would cost you $«CV BID» (payable in five $«Bid div 5» installments over a five year period.)

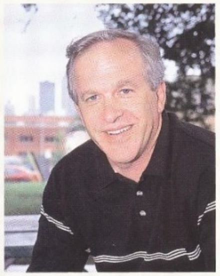
   ❑no ❑yes

6. How sure are you of this answer?

   1 (not sure at all) 2 3 4 5 (certain)

Excerpt from the Iowa Conservationist January/February 2005

FROM THE DIRECTOR



Bob Castelline

A Road Map To Lake Improvement

Here's a fascinating passage in the *Iowa Conservation Plan* that I think is worth sharing:

"The natural lakes of Iowa constitute one of the state's most wonderful assets. They are of incomparable value for recreational purposes. They offer the finest fishing and the finest refuges for water birds. They serve as storage to equalize stream flow. They are enormously interesting from the biological standpoint and they comprise one of the loveliest features in the landscape."

The report continues:

"They (Iowa's lakes) have been greatly damaged. Uncontrolled erosion of banks and on drainage areas has deposited silt on the bottoms of most of the lakes and this has been aggravated by such heedless acts as taking natural rock protection barriers away from the shores. The silt deposits are in no small measure responsible for the unbalanced biologic condition and growth of algae. The intensive occupation of adjoining lands has cut the public off from access to these finest public playgrounds."

What's interesting about this assessment of Iowa's lakes is that it was done more than 70 years ago in the *Iowa Conservation Plan* of 1933. We still face many of the same challenges today in protecting and improving the water quality in our lakes.

This issue of the *Iowa Conservationist* examines two critical studies currently being done by Iowa State University. The first study is the completion of a five-year effort assessing the water quality in the lakes. The second study is a look at the economic value of our lakes.

Make no mistake, water quality and the economic value of our lakes are closely linked. The information from these two studies is going to be critical in prioritizing lake restoration projects not only from an environmental perspective, but from a return on investment standpoint.

While this additional research from Iowa State University will undoubtedly help us in our effort to improve the quality of water in our lakes, I believe the biggest challenge we face in improving water quality lies more on the social aspect. We need for our citizens to value water quality and recognize it as a fundamental requirement to the long-term future of our state. In many cases, we can identify sources of water quality problems and there may be financial programs available to provide assistance, but it still takes willing participants to make the changes necessary to improve water quality.

This issue of the *Iowa Conservationist* contains a number of success stories. The common thread linking these successes has been the interest and initiative local residents have taken to spearhead restoration efforts in their own communities.

One of the best examples we have to illustrate local leadership driving a successful lake restoration effort has been Storm Lake, which recently saw its hard work pay off in the form of an $8 million Vision Iowa grant.

The leaders in Storm Lake have recognized the importance that improving water quality means for the economic well being of their region.

For those not familiar with the efforts in Storm Lake, you are missing a truly remarkable story of a community that has the vision to recognize its strengths and improve on them. Not only are locally led efforts being made to improve the water quality in the lake, but also of developing the additional amenities such as parks and green spaces that will allow their community to flourish.

Iowans must come to accept that water quality is not just an

Director's Message

cont. on page 4

Director Vonk agrees that your input is important in prioritizing restoration projects!

Results: Consequentiality and WTP

- Found that respondents who believed consequential surveys were different than those who did not, consistent with underlying theory

- Benefits function findings:

  - Wtp is increasing in income, education, and female

  - Average willingness to pay for improvements about $160/household