GREAT LAKES WIND COLLABORATIVE

OFFSHORE WIND ENERGY

Understanding Impacts on Great Lakes Fishery and Other Aquatic Resources

WORKSHOP SUMMARY

SPRING 2013

A product of the Great Lakes Commission and the Great Lakes Wind Collaborative based on the workshop held November 28-29, 2012, in Ann Arbor, Michigan.

Great Lakes Wind Collaborative

Great Lakes Commission des Grands Lacs

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1) Background and Introduction

Existing international studies have looked at local effects of offshore wind (OSW) farms, but very little is known about the cumulative effects on the larger ecosystem. It is recognized that the transition toward greater renewable energy sources, including offshore wind, has the potential to dramatically reduce carbon dioxide emissions, water usage by power plants and associated fish mortality within the Great Lakes. However, without adequate knowledge of potential impacts, both physical and biological, decisionmakers are poorly equipped to evaluate the extent to which OSW development might impact the fishery and ecosystem or to recommend appropriate mitigation measures to protect critical habitat and preserve self-sustaining fish populations.

This document summarizes discussions from the workshop *Offshore Wind Energy – Understanding Impacts on Great Lakes Fishery and Other Aquatic Resources.* Organized by the Great Lakes Commission, through the Great Lakes Wind Collaborative, the workshop took place on November 28-29, 2012, at the National Oceanic and Atmospheric Administration's Great Lakes Environmental Research Laboratory (GLERL) in Ann Arbor, Michigan. Primary funding support for the workshop came from the Great Lakes Fishery Trust.

The need for the workshop grew out of a 2011 report by the Great Lakes Wind Collaborative (*State of the Science Report: Ecological Impacts of Wind Energy in the Great Lakes Region*). That report noted that Great Lakes region-specific research, particularly as it relates to offshore wind, is notably lacking. Additional research and studies are needed to direct how wind projects are planned, sited and operated in the region.

As such, the November 2012 workshop aimed to build knowledge about the potential impacts of offshore wind energy on the Great Lakes fishery and related aquatic resources by

- sharing scientific and related policy and management information about what is known about the impacts of offshore wind farms on aquatic resources;
- identifying the most important questions that need to be addressed to effectively review permit applications for offshore wind development; and
- identifying knowledge gaps and priority areas for future research to answer the most important questions that decisionmakers face when determining whether and how wind projects are planned, sited and operated in the waters of the Great Lakes.

Approximately 40 individuals participated in the November 2012 *Fishery Impacts Workshop*, including fishery managers from most of the Great Lakes states, natural resource regulators and wind energy interests. Participants heard from experts on physical and biological aspects of the Great Lakes, and from researchers from outside the region. Importantly, the workshop featured research and environmental impact assessment case studies from two European offshore wind farms (see Box 1) one of which was the world's first OSW project in freshwater: Lake Vanern in Sweden (see Appendix A: Workshop Agenda). The workshop helped to minimize or eliminate some previously held concerns and identified knowledge gaps. Although the workshop did not produce definitive recommendations about offshore wind and related fishery impacts, it did elevate participant knowledge about potential impacts and which ones should be the focus of future research and management efforts. As such, the workshop findings presented here offer a step forward to advance the region's capacity, ensuring that public policy goals related to clean, renewable energy, are compatible with, and when possible, even mutually supportive of policy goals to protect and enhance fisheries and related natural resources. [1]

Box 1 – European Case Studies

Project: Lake Vanern

Åke Petersson Frykberg[2], and Tore Wizelius[3] presented on the construction and financing logistics, as well as environmental impacts, on the freshwater environment of the Lake Vanern wind farm. The pros of constructing a freshwater OSW farm were discussed: regular land turbines can be used since there's no risk of corrosion, which lowers costs, and deepwater turbine installation is more feasible. This wind farm was built with the support of local municipalities and private companies. The project was also a national pilot project, receiving 7 percent of total costs from the Swedish Government due to OSW construction technology needs. Construction costs were kept relatively low by using a unique "rock adaptor foundation" construction and retrofitting a barge with pontoons to accommodate a mobile crane. Their rock adaptor foundation, in contrast to a monopole foundation, uses vertical wires to attach the foundation to solid rock. Ten 3 MW wind turbines were installed in shallow waters (4-12 m depth) providing electricity for 20,000 households (90 GWh/year). The project became fully operational after 10 years in 2009.

Interesting Fact: Lake Vanern and the Great Lakes share several congeneric fish species such as the European zander (*Sander lucioperca*) and the American walleye (*Sander vitreus*).

Project: Egmond aan Zee

Dr. Erwin Winters[4] reviewed studies on potential impacts of OSW on fish, conducted in the context of the Dutch demonstration wind farm, Egmond aan Zee, which is located in the North Sea. Thirty-six 3 MW windmills have been installed in soft sediment at average depths of 20 meters and provide renewable electricity for at least 100,000 households. Egmond aan Zee receives a subsidy from the Ministry of Economic Affairs under the CO_2 Reduction Scheme of the Netherlands; part of the selection procedure for OSW developers was their ecological research study plan. To assess the impacts of the wind farm on fish (abundance, composition, length, behavior), both local (only inside the wind farm) and large-scale (outside and inside the farm) studies were conducted. However, GLERL's Ed Rutherford noted that although the studies were well designed and used a before/after control/ impact (BACI) design, they had relatively low statistical power of detecting an impact of wind farms.

2) Offshore Wind in the U.S. and Canada

Although no OSW turbines have been installed in U.S. or Canadian waters, the momentum for OSW is continuing to grow. The United States has no national renewable energy policy, but the Obama Administration has issued policy documents confirming the Administration's commitment to renewable energy. The 2011 *National Offshore Wind Strategy,* published in February 2011 by the U.S. Department of Energy (DOE) and U.S. Department of the Interior (DOI), calls for the development of a world-class OSW

[1] At the time this summary was being prepared, a new major report was released on the potential effects of offshore wind power projects on fish and fish habitat in the Great Lakes by Sarah Nienhuis and Erin S. Dunlop. See. Province of Ontario Aquatic Research Series 2011-01 at http://www.mnr.gov.on.ca/stdprodconsume/groups/lr/@mnr/@aquatics/documents/document/stdprod_103058.pdf

[2] Åke Petersson Frykberg: CEO of ReWind Offshore

[3] Tore Wizelius: a project manager with ReWind Offshore

[4] Dr. Erwin Winter is an ecologist at the Institute for Marine Sciences and Ecosystem Studies in the Netherlands

industry in the United States to achieve 54 GW of OSW deployment at a cost of energy of $0.07 / kWh by the year 2030, with an interim scenario of 10 GW at $0.10 / kWh by 2020 (DOE and DOI, 2011). More recently, In January 2013, the U.S. Congress extended the renewable energy Production Tax Credit (PTC) (AWEA, 2012). Additionally, and of particular relevance to the Great Lakes, the DOE announced funding of seven OSW advanced technology demonstration projects for offshore wind in December 2012.

The Canadian federal government has no policies to enable large-scale renewable energy adoption (DSF, no date); Ontario and Québec each have policies to promote renewable energy (Government of Ontario, 2010; Gouvernement du Québec, 2012).

In March 2012, the U.S. Fish & Wildlife Service released voluntary guidelines designed to help onshore wind energy project developers avoid and minimize impacts of land-based wind projects on wildlife and their habitats (USFWS, 2012). Similar federal, state or provincial guidelines do not exist for offshore wind. Although the Great Lakes Wind Collaborative's 2009 OSW guidelines offer a stopgap measure (GLC, 2009), more specific research and development of similar guidelines are needed for OSW.

3) Status of OSW in the Great Lakes

In the United States, the Great Lakes region has the greatest OSW potential, significantly dominating all the other regions when considering all depths in aggregate (Musial et al., 2010 in DOE and DOI, 2011). Also, all of the Great Lakes states and provinces have Renewable Portfolio Standards (RPS) or equivalent policies that promote renewable energy (IREC, 2012). Despite these renewable energy policies and the high quality wind resource over the Great Lakes, OSW has not been vigorously pursued for a variety of reasons including: 1) cost compared to other forms of energy (e.g., price of natural gas), 2) inconsistent public support, 3) incomplete federal and state permitting programs, and 4) a lack of knowledge about potential impacts to the Great Lakes aquatic resources.

Nonetheless, signs of continued interest in OSW remain. In March 2012, the bipartisan federal-state Memorandum of Understanding (MOU) for Offshore Wind in the Great Lakes[5] was signed by five Great Lakes governors (Illinois, Michigan, Minnesota, New York, Pennsylvania) and 10 federal agencies. More recently, in December 2012, DOE awarded $4 million to the Lake Erie Development Corporation[6] (LEEDCo) to advance their 27 MW OSW project, *Icebreaker,* which intends to install nine turbines seven miles off the coast of Cleveland (DOE, 2012). LEEDCo, a regional public-private partnership based in Cleveland, Ohio, was one of the seven recipients of the national OSW demonstration awards noted above.

4) Workshop Discussion and Findings

a. Physical and Biological Context

The Great Lakes basin is vast and climate, topography and soil types vary among regions. Hence, there are significant natural differences in the physical and biological features of each lake. Great Lakes ecosystems have been drastically altered over the past two centuries by human activities, including commercial logging and fishing, industrialization, hydrological alterations, agricultural intensification and expanding urbanization (US EPA & EC, 1995; Beeton, 2002). Resulting impacts such as pollution, habitat

[5] http://www1.eere.energy.gov/wind/pdfs/great_lakes_offshore_wind_energy_consortium_mou.pdf
[6] http://www.leedco.org/

degradation and destruction, and introductions of aquatic invasive species, have led to significant changes in aquatic ecosystem structure and function as well as species composition.

Among the most important physical aspects for siting offshore wind farms is depth. Lake Erie is the shallowest of all of the Great Lakes, a likely rationale for siting the first offshore Great Lakes wind farm in this lake. Lake Huron and Lake Ontario are the second and third shallowest lakes while Lake Michigan and Lake Superior are the deepest.

Lake Erie is the most productive of the Great Lakes and is generally classified as a mesotrophic system with some portions of the eastern basin considered oligotrophic and a few embayments in the western basin that are eutrophic (GLFC, 2009). The other lakes are less productive. Lake Huron is considered oligotrophic with the exception of Saginaw Bay and a few other nearshore areas (GLFC, 2009). Lake Ontario is the third deepest lake and generally considered oligotrophic; recent declines in productivity are primarily due to reductions in phosphorous loading in the system (GLFC, 2007). Lake Michigan, similar to Lake Huron, is mostly oligotrophic with some mesotrophic and eutrophic locations in Green Bay. Lake Superior is the deepest and largest of the Great Lakes.

Each of the Great Lakes supports commercial fishing. Fishing pressure will vary based on the habitats that each species prefers. Therefore, this report lists the species that are most often caught commercially for each lake to give a representation of the types of habitat that will be important to consider prior to wind farm construction. Lake Erie has a very valuable commercial fishery including, walleye, yellow perch, rainbow smelt, lake whitefish, white perch and white bass. Lake Ontario's commercial fishery is mainly walleye, yellow perch and lake whitefish. Lake Huron's commercial fishery is dominated by lake whitefish; lake trout and walleye are also important. Lake Superior's commercial fishery is dominated by lake whitefish; cisco and lake trout are also important. Lake Michigan's commercial fishery is dominated by lake whitefish with lake trout also being important. Limited fisheries exist for bloaters and yellow perch.

Invasive species including dreissenid mussels, round gobies, smelt, and alewives play substantial roles in restructuring Great Lakes ecosystems. The influence of wind turbines on distribution and abundance levels of invasive species will need consideration.

Restoration efforts for lake trout, lake sturgeon and cisco are occurring throughout the Great Lakes and these need to be recognized as species of concern when considering siting and mitigation actions for wind farms.

Box 2 – GIS-based Mapping as a Screening Tool

GIS mapping tools can help screen physical and biological criteria in support of siting decisions through the use of GIS mapping tools. Workshop participants learned about such a tool being developed for the Great Lakes: the Great Lakes Lakebed Alteration Decision Support tool. This interactive tool maps several key natural features of interest to fishery managers: known spawning and nursery sites, studied benthos species, substrate, ice, wind and waves, and circulation. See http://glgis.org/ladst.

b. Potential Impacts on Fish

1) Noise

Potential Impact

Anthropogenic noise in the marine environment often exceeds ambient noise from natural sources and is significant in the 10 Hz to 1 kHz range (Greene, 1987; Hildebrand, 2009 in Preston 2012). Continuous sound in the Great Lakes may be produced by machinery, ships and wind turbines. A second source of noise called impulsive noise is more extreme and may be derived from sources such as pile driving and air guns (Greene, 1987; Hildebrand, 2009 in Preston 2012) and could potentially compromise spawning, nursery or feeding area habitat, interrupt migratory patterns and/or relocate native and invasive species. Pile driving noise can also impact fish through auditory tissue damage and even mortality. Fish bladders are filled with gas and are particularly vulnerable to high noise levels (GLC, 2011; Winter, 2012b).

Discussion/Presentations

While anthropogenic noise was initially a topic of concern, presentations from the European speakers and Preston Wilson showed that noise issues were less critical than previously thought.

Dr. Winter and his colleagues conducted fish larvae studies to determine the lethal effect of noise from wind farm construction using a device named the “Larvaebrator” (Bolle *et al.*, 2012). This device re-created pile-driving sound typical for the Egmond aan Zee wind farm (i.e., 25 m depth, 4 m pile, sandy bottom) at representative distances from 100 meters to 2 km from the pile. The same sound metrics were used as in U.S. studies based on the Ainslie’s (2011) *Standard for measurement and monitoring of underwater noise*. Results showed no lethal effects to sole larvae but they concluded that interspecific differences in vulnerability to sound may occur so their results cannot be extrapolated to fish larvae in general. This study provided no information on sub-lethal effects and behavioral impacts of anthropogenic sound on fish remain unknown. A study on juvenile chinook salmon reported sound thresholds for injury being exceeded by wind farm construction noise (Halvorsen *et al.*, 2012).

Some researchers expressed the need for a framework to do targeted sound pilot studies on fish and microinvertebrates in the Great Lakes. Dr. Winter (2012b) insisted on not limiting research of impacts of anthropogenic sound to OSW but all anthropogenic noise sources. He also suggested considering noise impacts for all OSW farm phases. Some of Great Lakes fish experts agreed that fine-scale pilot studies of behavioral impacts (e.g., aversion and acclimatization) may be needed.

A novel approach for underwater noise mitigation was presented by Dr. Preston (University of Texas), based on the sound absorption properties of bubbles. Underwater bubbles absorb sound but freely rising bubbles do not mask continuous sound. Larger bubbles are able to absorb continuous sound due to larger amounts of attenuation.

Freely rising bubbles are the current industry standard for masking noise by pile driving but they are not very effective at low frequency noise mitigation. Research has been conducted on tethered encapsulated bubbles at the University of Texas and commercialization has recently begun (Preston 2012). There are multiple advantages of tethered encapsulated bubbles: 1) they allow for large stable bubbles, 2) their frequency and attenuation are adjustable, 3) continuous air supply is not required, and 4) they are not dispersed by currents (Preston 2012)[7].

Data Needs

Based on the presentations and discussions relating to the European case studies, there is less concern relating to continuous power production noise than was previously thought. Impacts from the potentially more harmful impulsive noise can be mitigated by the more efficient technologies discussed above.

Policy Recommendation

Dr. Winter explained that the U.S. noise criteria for deepwater construction are too conservative in his opinion based on the results of Bolle *et al.* (2012) on sole larvae and Halvorsen *et al.* (2012) on salmonids.

Mitigation Options

- Due to potential impacts to fish eggs, larvae and juveniles, developers and resource managers should work together to develop a construction schedule or mitigation strategies, which would minimize harmful impacts during biologically sensitive times/seasons.

- Due to potential impacts to migrating fish, major noise-generating construction activities should be minimized or mitigated in critical areas during migrating seasons.

- Sound attenuation devices should be used during OSW farm construction to minimize disruption and disturbance to aquatic life from sound, taking into account recent developments indicating large bubble sizes are necessary to attenuate low frequency noise and technology advances to enable their application (Preston 2012).

2) Electromagnetic Fields

Potential Impact

Submarine cables used for electric transmission create electromagnetic fields which can affect fishes, yet research on European eel in the Baltic Sea has only shown minor effects (Ohman *et al.*, 2007). The *State of Science Workshop* had identified that electromagnetic fields could impact fish by disorienting migration and prey and mate detection and that several Great Lakes species of conservation concern, including the American eel and the lake sturgeon, are particularly sensitive to electromagnetic fields. The following research priority had been identified: quantify thresholds for physiological or behavioral effects of noise and electromagnetic fields for representative Great Lakes fish taxa (GLC, 2011).

Discussion/Presentations

Transmission cables were buried at both the Egmond aan Zee and Lake Vanern wind farms, and measurements have shown very weak electromagnetic fields close to buried cables. There were no observable impacts on fish in the North Sea case study. A study of the orientation ability of eels along an AC cable in Kalmar Strait, Sweden, showed that electromagnetic fields were of small or no concern. Cables wrapped in woven steel also reduced electromagnetic fields.

[7] This technology has some uncertainties for the Great Lakes: 1) local environment plays large role, noise abatement systems will need to be designed for their specific location and reduction needs; 2) water-column noise abatement may not be sufficient, coupling into lake bottom may re-radiate back into water column; 3) bottom treatment may be necessary in some cases; and 4) developers would have to incur the added cost of mitigation.

Data Needs

There seemed to be less concern from impacts of electromagnetic fields after hearing about these mitigation measures used in both European case studies. There was a suggestion to study impacts of existing submarine transmission lines in the Great Lakes to address this research need.

Mitigation Options

- Transmission cables should be wrapped in woven steel and buried to reduce electromagnetic fields and minimize impacts to fish and other aquatic resources.

3) Turbidity

Potential Impact

High turbidity occurs when sediments and other materials are re-suspended in the water, by natural or human forces, blocking the sunlight and thus decreasing the oxygen production of plants and algae. The suspended sediments also absorb heat from the sunlight leading to warmer water and reduced dissolved oxygen. This is harmful to fish and other aquatic organisms: fish gills can become damaged or clogged, filter-feeding invertebrates can be negatively affected, and fish eggs and insect larvae can be smothered (e.g., NERRS, n.d.). In the Great Lakes, resuspension of sediments, increasing turbidity, occurs commonly in depths up to 30 meters and perhaps up to 50 meters on rare occasions, with high wind speeds (Hawley 2012).

Discussion/Presentations

Sediment disturbance was observed during construction at Egmond aan Zee, which led to changes in phytoplankton biomass although effects on zooplankton were negligible. Fish and marine mammals seemed to avoid the area during construction activities but returned once the activities had ended.

In the Lake Vanern wind farm experience, informal visual observations during construction showed limited turbidity impacts to fish due to local hydrodynamic conditions (i.e., strong currents) quickly diluting suspended particles. However, construction took place outside spawning seasons of vendace[8] and pikeperch, two important fish species, as a precautionary measure (Frykberg and Wizelius, 2012).

Mitigation Options

- The mortality of certain fish eggs can be avoided if construction work that causes high turbidity is conducted outside the spawning and migrating seasons of important fish species.
- The use of turbidity curtains can localize sediment suspension around foundation structures during construction.

Policy Recommendation

Regulators should work to develop construction schedules that are informed by biological priorities to minimize ecological impacts.

4) Fish Movement

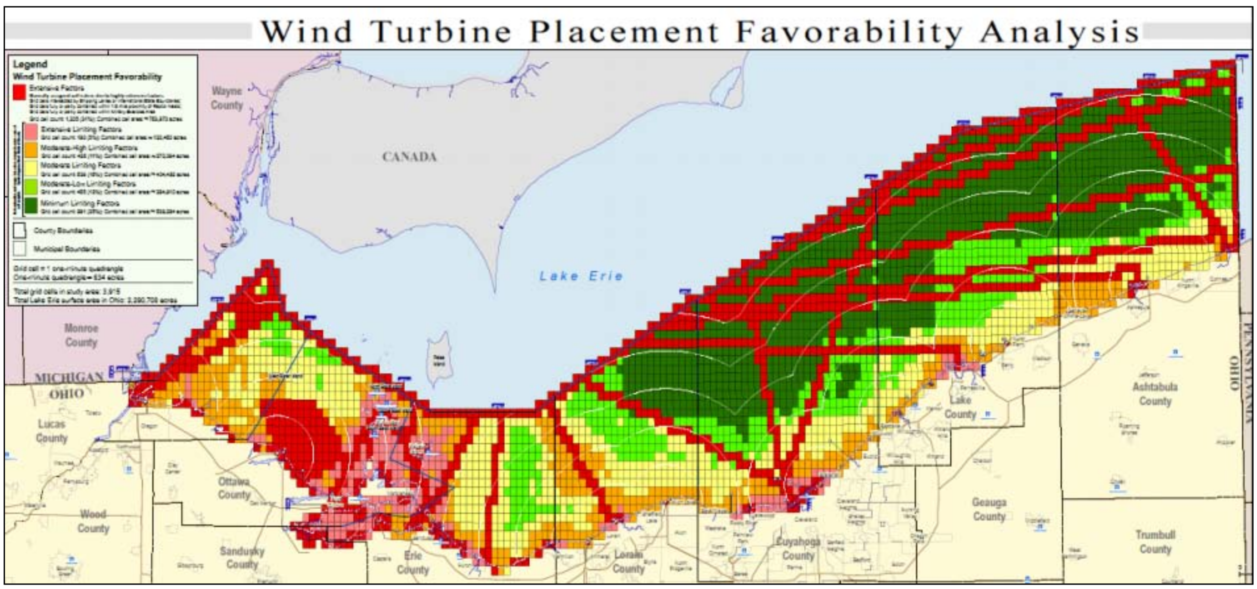
Potential Impact

There is a lot of uncertainty regarding the impacts of wind turbines on fish movement, and influences will likely be different for migratory and non-migratory fish species. It will take time to understand the long-term consequences of wind turbines. We have a limited knowledge of a few select species in a few lakes

[8] Vendace is a member of the coregonid family including lake whitefish and cisco.

and very little open-lake data (e.g., swimways). A review article looking at all fish movement studies in the Great Lakes between 1952 and 2000 found that the majority of studies were related to non-native salmonids and a few on trout, walleye and sturgeon. Most of these are mark-recapture estimates or use radio telemetry (Landsman *et al.*, 2011; VanderGroot, 2012).

<u>Discussion/Presentations</u>
The Lake Erie Walleye Tagging Program (in Ohio) estimates gross migration routes; the data is not designed to be fine. It was initiated in 1990 with 117,000 fish released to date looking at migration and survival. The center of Lake Erie has no tag returns most likely because fishermen are less active in these areas rather than because fish are not there. The most favorable areas for OSW development, as defined by the Ohio Wind Turbine Placement Favorability Analysis (See green squares on Map 1), are where there is less fishing effort.



Map 1 – Ohio Wind Turbine Placement Favorability Analysis (source: Ohio Department of Natural Resources[9]).

<u>Data Needs</u>
There's limited knowledge of a select species in a few lakes and very little open-lake data. Although some migratory fish may use areas that have been identified as favorable for wind turbine placement, it is unknown how the fish will behave if turbines are in place. It is not known how fish will adapt to turbines. Will they be displaced? Migrate around structures? Key in on structures as desirable? Or will species differ in their response? While additional data on fish distributions and migratory behavior in the presence of wind turbines is desirable, the potential location of fish migratory routes should not prevent siting of offshore wind turbines.

<u>Policy Recommendation</u>
A precautionary approach should be adopted when siting OSW in relation to threatened and endangered migratory fish species (e.g., lake sturgeon) because all the required information is not available. However, when considering impacts to migratory species with more robust populations an adaptive approach should be adopted where data is collected prior to and during operation, which can be incorporated into

[9] http://www.ohiodnr.com/tabid/21234/Default.aspx

future decisionmaking. For example, if migratory routes are disturbed by construction, it is advisable to ensure that active construction does not coincide with migration.

5) Lakebed Habitat

Potential Impact

The lakebed provides habitat to a range of aquatic species that contribute to the Great Lakes ecosystem. Long-term disruption to sensitive lakebed habitats may influence densities of benthic invertebrates as well as fish spawning or nursery habitats.

Discussion/Presentations

Different construction techniques have varying degrees of impact on lakebed habitat, and basal scouring may be an attractive nuisance. For example, invasive dreissenid mussel populations could increase in those areas as they prefer hard substrates (Janssen 2012; Jones and Ricciardi, 2005). Impacts to lakebed fauna and vegetation were observed during the construction of the Egmond aan Zee wind farm but not afterward. Study results showed some fish species (e.g., cod and crabs) were attracted to scour bed habitats created by currents swirling around the foundations while demersal fish avoided such areas (Winter, 2012a).

Blasting can be particularly harmful to lakebed habitat and, as a mitigation measure, it was not used during the Lake Vanern wind farm construction. Rather, their rock adaptor foundations were attached using vertical wires that were drilled into the bedrock, which greatly minimized impacts to lakebed habitats (Frykberg and Wizelius, 2012). If using the foundation technology from Lake Vanern, hard substrates – either bedrock outcroppings, limestone reefs or hard compacted clays – are likely favorable for wind farm siting in the Great Lakes. However, hard substrates are also the favored substrates for spawning by some native Great Lakes fishes and interactions will need to be examined.

Dr. Janssen, University of Wisconsin at Milwaukee, and his team have been using a highly modified, tethered Remotely Operated Vehicle (ROV) to collect lake trout eggs and sac fry around deep reefs. The ROV can be tracked along a bathymetry map in real time and eggs and sac fry have been found in cobble at and adjacent to drop-offs and at ridges (Janssen *et al.,* 2006). Lake trout reefs also concentrate fish prey such as microzooplankton and mesozooplankton (Houghton *et al.,* 2009). Monitoring data will help to determine and evaluate specific fish habitat localization and protection issues (Janssen, 2012).

Data Needs

1) Substrate and bathymetric data for the Great Lakes is coarse and – especially in the case of the substrate data – outdated, but would allow for general fish habitat identification with tools such as the Lakebed Alteration Tool. More detailed site assessments of lakebed habitat would be necessary prior to any project.
2) More recent and comprehensive substrate data would greatly assist with the accuracy of tools such as the Great Lakes Lakebed Alteration Decision Support Tool, which can support the siting of OSW farms.

Policy Recommendation

Local bathymetry data, site-specific (geophysical, biological and archaeological) and surficial mapping could help to avoid the destruction of prime fish habitat. For example, very detailed mapping of reef areas is required when working to avoid preferred lake trout, lake herring or lake whitefish spawning habitats, which can be quite small. Sediment transport will also need to be taken into consideration.

Mitigation Options

- Lakebed disturbance can be minimized during construction of OSW foundations and installation of underwater cables. For example, building foundation structures in hard substrate types that are not biologically significant for spawning can greatly minimize impacts to fish and aquatic habitats as was learned from the Lake Vanern case study. It is also feasible to increase reef habitat by encouraging suitable rock substrate and structural designs if pilings are required.
- The timing and duration of OSW farm construction can be modified to reduce the period of disturbance to fish and other aquatic species. For example, a modular approach to installation where all underwater construction is completed prior to tower installation could reduce the period of underwater construction.

6) Fishing

Potential Impact

Both commercial and recreational fisheries are active in the Great Lakes. Wind turbine structures could act as aggregating devices in attracting a variety of fish species. Anglers and fishers may key in on these structures as desired fishing locations.

Alternatively, in some situations the area surrounding OSW foundations and buried cables may require restrictions on fishing or fishing methods (e.g., trawling). In situations such as this it may be desirable to place a buffer around OSW farms to limit negative impacts and avoid conflict fisheries.

Discussion/Presentations

The Lake Vanern case study provided a positive example of collaboration among the fishing community and developers to find compromise in the use of the shared resource. The developer reduced the restricted area greatly by altering the layout of the transmission cables. In the Great Lakes, OSW farms could serve to enhance fishing opportunities by aggregating fish populations. When restrictions are required, anglers and developers should work together to establish desirable outcomes.

Policy Recommendations

Developers should work with stakeholders to develop consensus on the use of OSW farms to protect the interests of both parties.

7) Artificial Reefs

Potential Impact

The underwater hard surfaces of wind turbine foundations can attract fish and act as artificial reefs providing new habitat for aquatic invertebrate species (Langhamer, 2012). Some studies have found that these artificial reefs increase fish biodiversity (e.g. Ambrose and Anderson, 1990) while other studies have found no significant difference as compared to surrounding areas (e.g. McGlennon and Branden, 1994). One potential negative impact might be the increased colonization of invasive species such as dreissenid mussels and round gobies or alewives, which may also benefit from additional hard substrate or structures to aggregate around (Bulleri and L. Airoldi, 2005; GLC, 2011). The *State of the Science Workshop* identified that native species such as lake trout could also benefit from reef-like habitats created by wind turbine foundations (GLC, 2011).

Discussion/Presentation

In the freshwater case study of the Lake Vanern wind farm, many small fish have been observed around the operating foundations including certain species of sculpin (European bullhead). Furthermore, plankton is congregating in whirls near the foundations and algae have grown on the upper parts of the foundations providing food for fish and marine fauna (Frykberg and Wizelius, 2012). In regard to the North Sea case study, the newly created hard-substrate habitats around monopoles had higher abundance of some fish, but lower abundance of sand-dwelling species. Habituation may play a role in the potential fish congregating effect around the foundations, yet there is currently no data on the behavior of migratory fish species when they encounter an OSW farm (Winter, 2012a).

Data Needs

It is not known if there could be a congregating or avoidance effect of fish around monopiles in the Great Lakes. Pilot projects would provide beneficial information on aggregation patterns and fish behaviors throughout the water column around turbine structures in the Great Lakes.

c. Potential Impacts on Other Aquatic Resources

During the workshop there were several other topics that were discussed. These presentations increased the group's awareness of the current state of understanding about these important physical processes; however, no major concerns rose to the top. The following section provides a brief overview of information covered and table 1 details the anticipated impacts of OSW on these resources overall and at a local scale.

8) Ice

Potential Impact

The Great Lakes ice cover has large interannual variability which affects regional economy, ecosystems and water balance (see Box 3). There is an increased potential for ice formation around OSW foundations, creating islands of piled up ice at a very local scale which may impact the structures as well as local ice patterns. However, ice has put extreme pressure on the Lake Vanern foundations and there have been no observed structural impacts (Frykberg and Wizleius, 2012; Wang, 2012).

Data Needs

More research must be conducted on potential ice formation and depth around OSW foundations, as well as resulting changes to the ecosystem.

Policy Recommendation

There can be ice scour up to 20 meters in the Great Lakes, which means cables in the nearshore would likely need to be buried, especially in Lake Erie (Hawley, 2012).

9) Bathymetry

Potential Impact

The Great Lakes are deep, with average depths being greater than 50 meters except for Lake Erie, yet most of them have several distinct basins separated by shallower areas. The construction of OSW farms would cause local scour and deposition but nothing substantial, meaning that there could be very minor

Box 3 – Great Lakes Ice Cover

Great Lakes ice cover has large interannual variability which affects regional economy, ecosystems and water balance; however, there has been a warming since the early 1970s. Ice reduction decreased at a rate of -2.05%/year on average from 1970-2008. The El Niño/La Niña–Southern Oscillation (ENSO) and Arctic/North Atlantic Oscillations (NAO/AO) have impacts on year-to-year Great Lakes ice cover. Since 1973, there have been 11 ice minimum winters of which five can be attributed to strong El Nino events, and four can be explained by the joint strong +NAO and La Nina events. Two of the minimum winters occurred for unexplained reasons (Wang *et al.*, 2012).

Low ice cover leads to greater exposure to atmospheric/weather patterns, resulting in greater evaporation and reduced lake levels (predicted). There was an ice cover record low in the 2011-12 winter with approximately 5 percent coverage due to lack of sustained cold (Bai *et al.*, submitted). This led to early harmful algal blooms and early disturbed sediment in Lake Erie.

A decreasing trend of ice coverage may lead to more lake-effect snow or rain, and more evaporation may bring about lower water levels and warmer water temperatures. There may be a disruption of quagga mussels that will have to filter for a longer period of time. Furthermore, more storm stirring and mixing could lead to more suspended sediments, lessening the light intensity and plankton blooms. Longer periods with wave action will enhance coastal erosion (Wang, 2012).

changes in bathymetry at a local scale (Hawley, 2012). The *State of the Science Workshop* identified coastal morphology as being potentially altered by the presence of OSW farms (GLC, 2011).

10) Wind Climate

Potential Impact
There is a high level of uncertainty surrounding the impacts of OSW on wind climate or wind patterns. It is not anticipated that an overall change to wind climate would be observed, but it is less certain what might occur at the local level (Hawley, 2012).

Data Needs
Precise wind stress reduction patterns are unknown and should be predicted accurately in each OSW project (Hawley, 2012) to advance understanding of these processes as well as to increase efficiency of siting.

11) Waves

Potential Impact
Impacts of OSW farms on wave patterns would be very localized (Hawley, 2012); however, it is unclear how OSW installations may impact wave patterns or how waves may impact the installations.

12) Sediment Transport

Potential Impact
Bathymetry, wind climate, waves and the type of bottom sediments drive sediment transport, which can lead to different sediment transport potentials within and among the lakes. However, since good substrate data is lacking it may be hard to predict how an area may act. Fortunately, as OSW foundation construction will be very localized and relatively brief, impacts to sediment transport, which may be relatively great, should be short-lived and impact small geographic areas (Hawley, 2012).

13) Circulation Patterns

Potential Impact
Since there are no tides in the Great Lakes, the four main factors that affect circulation are wind stress, bottom topography, temperature gradients and the Earth's rotation (Beletsky, 2012). Wind has the potential to alter horizontal and vertical circulation due to the Ekman transport mechanism: cyclonic and anticyclonic winds can create upwellings and downwellings (Colling, 2001). While there is uncertainty, it is possible that an OSW farm could create a wind stress deficit and disturb the upper water layer due to wind farm-induced Ekman pumping (Broström, 2008).

Discussion/Presentations
Potential risks of OSW farms on Great Lake currents are 1) changes in circulation patterns, 2) creation of localized upwelling and downwelling patterns, and 3) change in thermocline position.

Data Needs
Studies conducted on existing structures in the lakes may be useful, and there are many opportunities to look at these localized shifts at initial OSW farms.

Table 1 Possible effects of wind farms on Great Lakes physical properties (adapted from Hawley, 2012)

Parameter	Overall impact	Local impact
Bathymetry	None	Small
Wind	None	Unknown
Waves	None	Small
Sediment transport	Small	Unknown
Circulation patterns	Unknown	Unknown

5) Research Needs

Throughout the workshop, several areas for future Great Lakes fishery research were identified but three rose to the top: 1) detailed knowledge of substrate types and the location of spawning areas for valuable species; 2) potential impacts to migratory fishes(e.g., lake sturgeon); and 3) recommended best practices to avoid or mitigate impacts to spawning areas and migratory fish species.

Additionally, the need for integrated assessments was mentioned on numerous occasions. The idea of a pilot turbine foundation study was embraced by both physical and biological experts to gain comprehensive knowledge of potential physical and biological impacts. It would provide an instrumented footprint that could be moved to different locations in the five lakes. More physical research, mostly modeling, is needed to better understand wind stress and changes in circulation and ice patterns brought on by OSW farms, as well as resulting changes to the ecosystem. Indeed, there was a general consensus at the end of the workshop that the participation of physical scientists will be crucial in future discussions.

OSW power generation within the Great Lakes has the potential to be implemented with minimal impacts on the aquatic ecosystem if adequate mitigation options are adopted (GLC, 2011). Numerous mitigation practices were discussed during the workshop. However, these must be further investigated to develop best practices that can be communicated to regulators and resource managers in order to minimize impacts to fish and aquatic resources.

6) Summary and Conclusions

In spite of relatively extensive OSW development in some parts of the world, including northern Europe, the cumulative effects of OSW are not well understood, yet are crucial to minimize potential impacts on Great Lakes fish and other aquatic resources, as well as other ecosystem components such as birds and bats, from future OSW developments. Renewable forms of energy such as OSW are not without negative impacts but, cradle to grave, renewable energy, including wind, has several inherent environmental advantages over non-renewable energy resources. One prominent Great Lakes fishery biologist commented at the workshop: "If we don't address climate change, we may not have any fish to worry about." However simplistic, this reflects a sentiment among many at the workshop of the need for a comprehensive and integrated approach to evaluating energy choices that considers the full range of impacts and enables policymakers to make comparisons among them. Although the Great Lakes states and provinces have a suite of environmental management laws, none currently has a framework (e.g., legislation or regulations) designed to evaluate offshore wind projects for their potential impacts on the environment or the economy. States and provinces can address this through a combination of regulatory and administrative rulemaking, legislation, guidance documents and decision support tools. Whatever the approach, state and provincial legislation and associated regulatory programs for offshore wind should consider the full range of impacts, both positive and negative, of OSW energy projects on quality of life and the environment in comparison to equivalent power generation from fossil fuel sources over the life of the project.

This Workshop Summary begins to delve into information needs required by regulators and resource managers to determine whether a proposed wind farm site will have a significant or unacceptable impact on fish and other aquatic resources. It also presents crucial mitigation measures as well as strategies to coordinate research needs into the future. The physical and biological experts at the workshop agreed that there is a need to continue the dialogue around fish and OSW energy. Some initial priorities were identified but there was a general sense that more discussion could have refined the findings. There are many forums looking at Great Lakes fish from many perspectives such as the Great Lakes Fishery Commission Lake Committees, but not specifically evaluating the potential impacts of OSW. Participants agreed that a longer workshop would have been helpful to allow more time to discuss and refine research priorities. Nonetheless, three main options were identified during the workshop to coordinate research needs into the future:

1) Since there has been a resurgence of OSW interest in the Great Lakes with LEEDCo's award, it would be timely to organize a second workshop that would bring together fishery experts. This would refine priorities identified at the November 2012 workshop and develop research and management roadmaps for use by fishery researchers, funders and managers to fill key knowledge gaps and support informed decisions about OSW while managing the Great Lakes ecosystem for sustainable production of valuable species. It would also allow full scoping of the specific research needs for the priorities identified.

2) The European presenters agreed that it is also important to have timely sharing of research results. Dr. Winter advocated for sharing among researchers and developers within and among countries. The

fruitful workshop discussions and conclusions can attest to this. For example, participants learned that research in Lake Vanern is of even greater value for informing Great Lakes research because Lake Vanern and the Great Lakes share several congeneric fish species.

3) It was suggested that an advisory committee be put together with physical and biological scientists to advise regulators and resource managers that will potentially be involved with OSW siting decisions and processes. As of now, more discussion is needed on how to incorporate priority research needs into regulatory programs and processes (e.g., pre- and post-construction monitoring could be part of the regulatory requirements).

7) Appendix A - Workshop Agenda

Offshore Wind Energy – Understanding Impacts on Great Lakes Fishery and other Aquatic Resources

Agenda

November 28-29, 2012
Great Lakes Environmental Research Laboratory
4840 S. State Rd., Ann Arbor, MI 48108-9719
(734) 741-2235

Wednesday, November 28

12:00 p.m.	Registration
12:30	Welcome and introductions, review agenda and workshop objectives –John Gannon, Ph.D., International Joint Commission (*retired*)
1:00	Case Study 1: Lake Vanern, the only operational offshore wind farm in a freshwater environment – Tore Wizelius and Åke Pettersson Frykberg, ReWind Offshore AB, Sweden
2:00	Case Study 2: The Dutch demonstration of the Egmond aan Zee offshore wind farm – Erwin Winter, Ph.D., Institute for Marine Sciences and Ecosystem Studies, Wageningen University and Research Center
3:00	Break
3:15	Facilitated Discussion of Case Studies and Their Relevance to Great Lakes Ecosystem – Michael Murray, National Wildlife Federation (*moderator*)
4:45	Day 1 wrap-up and overview of Day 2 – Amanda Sweetman, Great Lakes Commission
5:30 - 7:00	Happy Hour at Sava's Restaurant (upstairs), 216 S. State, Ann Arbor, Michigan

Thursday, November 29

7:30 a.m.	Continental breakfast
8:00	Summary of Day 1 outcomes and Day 2 overview – Amanda Sweetman
8:15	Turbines in the Great Lakes: Where Might They Be? – Ed Rutherford, Ph.D., NOAA Great Lakes Environmental Research Laboratory (GLERL) and Jason Break, University of Michigan
9:00	Physical/limnological effects of offshore wind power on the Great Lakes *Presentations & Discussion* – Jennifer Boehme, Ph.D., International Joint Commission (*moderator*) • Currents – Dmitry Beletsky, Ph.D., University of Michigan • Wind, waves, sediment transport & bathymetry – Nathan Hawley, Ph.D., GLERL • Ice formation and icing patterns – Jia Wang, Ph.D., GLERL
10:15	Break
10:30	Biological effects of offshore wind on fisheries in the Great Lakes *Presentations & Discussion* – Jory Jonas, Michigan Dept. of Natural Resources (*moderator*) • Impacts of anthropogenic sound on aquatic organisms – Erwin Winters • Fish & habitat: offshore deep reefs – John Janssen, Ph.D., University of Wisconsin, Milwaukee • Impacts to fish movement in the Great Lakes—Chris Vandergoot, Ph.D., Ohio DNR • Identifying mitigation activities – Preston Wilson, Ph.D., University of Texas at Austin
Noon	Workshop wrap up & research priorities – Victoria Pebbles, Great Lakes Commission
12:30	Adjourn

8) Attendee list

Jonathon Beard
Grant Manager
Great Lakes Fishery Trust

Dmitry Beletsky
Associate Research Scientist
University of Michigan
CILER - School of Natural Resources and the Environment

James Boase
Fish Biologist
U.S. Fish and Wildlife Service

Jennifer Boehme
Physical Scientist
International Joint Commission

Jason Breck
Computer Specialist
University of Michigan

Charles Bronte
Fishery Biologist
U.S. Fish and Wildlife Service

Mark Clevey
Manager
Michigan Energy Office

Margaret Dochoda
Proxy
Big Sandy Bay Management Committee

Carlos Fetterolf
Great Lakes Fishery Commission (Retired)

John Gannon
International Joint Commission (Retired)

Tom Graf
MI Dept. of Environmental Quality
Water Resources Division

Christina Haska
Fishery Management Associate
Great Lakes Fishery Commission

Nathan Hawley
Oceanographer
NOAA GLERL

Dr. John Janssen
University of Wisconsin-Milwaukee

Jory Jonas
Research Biologist
Michigan Department of Natural Resources

Kevin Kayle
Fish Biology Supervisor
OH Dept. of Natural Resources
Division of Wildlife

Brian Klatt
Director
Michigan State University
Michigan Natural Features Inventory

Genevieve Layton-Cartier
Government of Québec Intern
Great Lakes Commission

Regina McCormack
University of Delaware

Sarah Mullkoff
Energy/Climate Policy Coord.
National Wildlife Federation

Michael Murray
Staff Scientist
National Wildlife Federation

Carlyn Osborn
The John Hopkins University

Becky Pearson
Project Manager
Great Lakes Commission

Victoria Pebbles
Program Director
Great Lakes Commission

Åke Pettersson Frykberg
ReWind Offshore AB

Stephen Porter
Co-Chair
NWPAGE

Catherine Riseng
Research Scientist
University of Michigan

Ed Rutherford
Research Fishery Biologist
NOAA GLERL

Daniel Ryan
Fisheries Biologist
Pennsylvania Fish and Boat Commission

Victor Santucci
Lake Michigan Program Manager
IL Dept. of Natural Resources

Amanda Sweetman
Sea Grant Fellow
Great Lakes Commission

Katie Trachsel
Michigan Public Service Commission

Christopher S. Vandergoot
Ohio Department of Natural Resources
Sandusky Fisheries Research Station

Matt Wagner
DTE Energy

Jia Wang
Research Ice Climatologist
NOAA GLERL

Preston Wilson
Associate Professor
University of Texas at Austin
Dept. of Machanical Engineering

Erwin Winter
Institute for Marine Sciences and Ecosystem Studies
Wageningen University and Research Center

Tore Wizelius
ReWind Offshore AB

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