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DEVELOPMENT AND EVALUATION OF THE HABITAT ECOSYSTEM ASSESSMENT TOOL (HEAT)

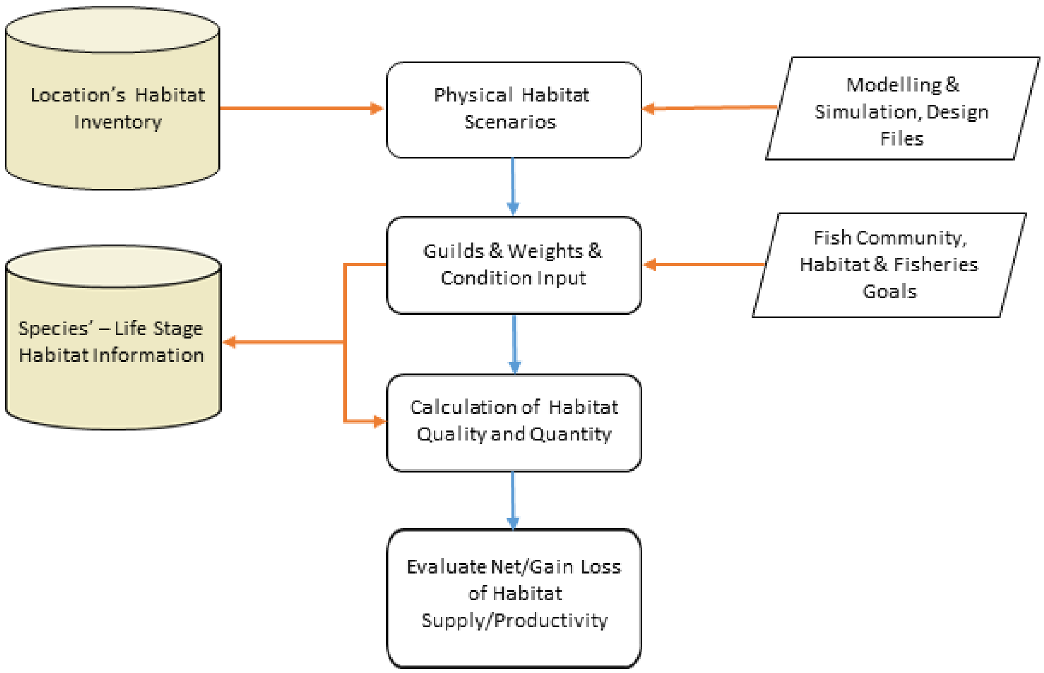

Figure 1. The conceptual framework for the Habitat Ecosystem Assessment Tool (HEAT): a scientifically-defensible method of assessing net change of habitat productivity, using habitat suitability as a surrogate.

Context:

Human activities in or around fish-bearing waters have the potential to affect the capability of aquatic habitats to support the production of fish. Activities are managed through the Fisheries Protection Provisions of the 2012 amendments to Canada's Fisheries Act*. The provisions and related policies specify that development projects that cause unavoidable serious harm to fish must provide offsets, such that the benefits from offsetting measures balance project effects or impacts. To balance the project effects the proponent must estimate the* serious harm to fish and potential benefits of the proposed offsets*. Some models and a variety of methods are available to quantify potential effects and offsets, including the Habitat Ecosystem Assessment Tool (HEAT).*

HEAT was developed to evaluate proposed development project effects on fish habitat and has primarily been applied in the Great Lakes region. Fisheries Protection Program has asked Science to review HEAT and determine if the tool could be applied to other regions.

A peer review meeting was held on January 27-29, 2016 to evaluate the HEAT Assessment Tool. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

SUMMARY

- The Habitat Ecosystem Assessment Tool (HEAT) provides an accounting framework for assessing losses, gains, and modifications to habitat from development, offset, and restoration activities. HEAT is based on fish habitat suitabilities and can be used to predict the response of fish communities to development activities and mitigation options.
- HEAT is a mathematical model that assembles a series of tabular information in order to interpret impacts to fish based on an understanding of fish-habitat interactions. A model is a basic representation of our scientific understanding of system dynamics. HEAT links changes in habitat conditions or proposed management actions to habitat availability for fish. As such HEAT makes predictions about the relative state changes of the real system.
- HEAT provides an evidence-based assessment supported by quantitative analyses. The methods used for the quantitative analyses are supported by scientific evidence. Like all models and analyses there are uncertainties and assumptions associated with HEAT. The uncertainties and assumptions are explained in this document and some require further scientific work (e.g., sensitivity analyses). It is recommended that all the assumptions be clearly articulated and outlined in a guidance document.
- HEAT is a tool for the Fisheries Protection Program (FPP) that is defensible, evidence-based and consistent with the principles of the Fisheries Productivity Investment Policy, particularly the principle to balance the benefits from offsetting measures with a project's impacts as it provides a tool to quantify habitat losses and gains.
- HEAT was developed through consideration of the program needs within FPP and the previous Habitat Management program, ongoing engagement between Science and FPP is recommended to address future needs and maintain the applicability of the tool.
- The tool is currently being used in the Great Lakes basin; guidance material should primarily focus on the current use of the tool. The current advice provides guidance on updates needed for the tool's functionality in general.
- Applicability of HEAT could be expanded to apply in a broader context in terms of other regions, other ecosystems, other regulations related to changes in habitat, or other programs. However, further validation and review would be required prior to its use for these other purposes.

INTRODUCTION

Regulatory Context

In November 2013, the Fisheries Protection Provisions of the *Fisheries Act* came into force. Under the new provisions the Minister must consider the measures and standards to avoid, mitigate or offset serious harm to fish that are part of, or support a commercial, recreational or Aboriginal (CRA) fishery before authorizing a project that has the potential to cause serious harm to fish. In addition, as set out in the *Applications for Authorization under Paragraph 35(2)(b) of the Fisheries Act Regulations*, the proponent must include a plan to offset residual serious harm to fish as a regulatory requirement when submitting an application for authorization. This offsetting plan must include a description of the measures to offset serious harm to fish, supported by an analysis that should use scientifically defensible methods describing how the measures will meet the offsetting objective.

The Fisheries Productivity Investment Policy: A Proponent's Guide to Offsetting (the Offsetting Policy) provides guidance on developing offsetting measures when there is unavoidable serious harm to fish. Residual serious harm to fish is determined after all avoidance and mitigation measures have been applied. By understanding the nature of the residual serious harm to fish, it is possible to estimate the consequences on fisheries productivity and, in turn, to characterize the contribution of relevant fish to the ongoing productivity of commercial, recreational or Aboriginal fisheries (Paragraph 6(a) of the *Fisheries Act)*. The residual serious harm to fish is the loss that must be counterbalanced by the proposed offsetting measures.

Science advice on how to characterize serious harm to fish in the context of fisheries productivity and for the development of offset measures has been provided (DFO 2014a, DFO 2014b, DFO 2014c, DFO 2013, DFO 2017 with supporting documents; Randall et al. 2013, Bradford et al. 2014, Clarke and Bradford 2014, Bradford et al. 2016). Serious harm to fish has been categorized as impacts that have an effect on habitat quantity, habitat quality, and those that cause ecosystem transformations. For projects where the serious harm is localized and the proposed offsetting measures are designed to replace the productivity lost in the immediate area of the project's impacts, changes in habitat quantity or quality can be assessed by habitat-based measures. If the offset habitat is the same as that affected by the project, a simple evaluation of habitat area may be sufficient to determine offset requirements. In other cases, the function or capacity of the habitat to produce fish may need to be assessed. A habitat suitability index in relation to a quantitative habitat model is one way this can be achieved. Such a model can be used to compute weighted useable area (WUA) as recommended by Bradford et al. (2016). Science advice on the appropriate application of various equivalency metrics, including use of a habitat suitability index, and related assumptions has been previously provided (Bradford et al. 2014, DFO 2017).

HEAT Development and Use

The Habitat Ecosystem Assessment Tool (HEAT) is a tool that uses Habitat Suitability Indices (HSIs) to evaluate the effects of proposed development projects on fish habitat. Databases on fish species distributions in different regions, and their habitat needs or associations at different life stages, are used to determine the relative suitability of the available habitat at a location. HEAT is a web-based software tool that quantifies the suitability of an aquatic site or subarea for fishes and calculates a weighted habitat supply (weighted suitable or usable area) for one or more scenarios. These scenarios can include management options for offsetting projects to counter impacts of a proposed development project.

HEAT has evolved over the years to respond to the need to quantify impacts of development projects. Basic accounting equations for measuring net gain or loss were originally developed by Minns (1995, 1997) to describe changes in habitat areas via losses, modifications, and compensation actions (now offsets). The scientific tool was further developed and the approach was described by the term "Defensible Methods" (Minns et al. 2001). Later it was renamed the Habitat Alteration Assessment Tool (HAAT). More recently HAAT was re-implemented in a modern computing environment with the intention of expanding its capabilities to include more variables, and was renamed Habitat Ecosystem Assessment Tool (HEAT). There are both lake and river versions of HEAT. The river version is not as well advanced as the lake version and its regulatory application has been used less extensively than Lake HEAT. This report focuses on the lake version of HEAT as a starting point.

The Fisheries Protection Program (FPP) has asked Science to review the scientific underpinnings of HEAT, determine if the tool requires updating given changes to the *Fisheries Act,* and if HEAT could be applied to other regions. Presently this tool is used to quantify impacts of development projects and evaluate offsetting projects in the Great Lakes basin. To date, mainly development projects involving infills, including their offsets, or restoration/conservation projects have been assessed using HEAT for regulatory or scientific evaluation purposes.

ANALYSIS

HEAT Overview

HEAT relies on a number of inputs including habitat descriptions (pre and post development), species lists, and a pre-defined fish-habitat association database. All are used to quantify weighted suitable area of fish habitat to inform trade-offs and gains in offsetting and restoration (Figure 1). The output of HEAT is dependent on the reliability of the input files. Tables in the program are based on peer-reviewed habitat associations and are used to generate habitat suitability. Currently habitat suitabilities are linked to the variables of depth, substrate and vegetation, thermal guilds (e.g., cold water, warm water species) and the importance of fish in the diet; further details are provided below.

HEAT is an online software tool that estimates the suitability of a habitat based on local fish communities and their regional habitat needs or associations. It is coded in an R statistical language with instructions for users on how to use the tool. It is anticipated that if development continues, open distribution of the HEAT system R-code could be made available and would allow for development of new features and updates through collaboration of R community developers.

Design of the Tool

HEAT relies on two types of inputs, those that are defined by the user and information that has been pre-defined or is embedded in the code/programming of the model or the base tables.

Users provide inputs to describe the habitat features available to fish before and after a project in terms of the water depths (0-1, 1-2, 2-5, 5-10, and 10+ m classes), vegetation types (emergents, submergents, no cover) and substrate types (bedrock, boulder, cobble, rubble, gravel, sand, silt, clay, and hardpan-clay). The proportions of each depth strata, vegetation type and substrate type are described as patches within the site or project area that is to be directly or indirectly affected by a project (i.e., the Location’s Habitat Inventory, Figure 1). The user provides information on the habitat before and after the change(s) to create physical habitat scenarios (Figure 1). These scenarios describe the amount of habitat that is available to fish in the different categories of depth, vegetation type and substrate type under different management strategies. The study area should take into consideration the direct and indirect effects of a project and include the area of change due to offsetting. Other habitat variables of importance that are likely to be affected by the project or offset are currently considered in a habitat quality adjustment factor that can modify the output; this is discussed later (Condition Input, Figure 1).

The level of detail used to describe the basic habitat scenarios (e.g., 1 m grid versus 10 m grid versus larger homogenous patches) might influence the resultant output. More guidance is required from Science to determine how the scale and resolution of the data collected might influence the output. It is recommended that non-heterogeneous patches be used in scenario tables regardless of resolution for the time being.

In addition, users are required to provide a geographic location for project sites and their offsets. Currently all Canadian fish distributions by tertiary watershed are available within HEAT;

however, habitat associations by geographic region are only available for the Great Lakes. Based on the location of the project, a list of fishes is available for default use. Fish lists were compiled based on literature and expert knowledge (e.g., Scott & Crossman 1998). Fish can be added or removed from the default lists but this should be done only when there is a strong rationale to do so. There may be reasons that a waterbody may not contain all of the fish species present within a larger geography (e.g., barriers). However, one-time sampling is insufficient to generate a species list for any given waterbody. Reducing the species number to a very low number or focusing on a specific species is not suitable in HEAT as it is currently an analysis of community metrics and for many species habitat associations are not specifically known and therefore grouped with similar species.

Individual Species Habitat Suitability

HEAT contains a pre-defined habitat suitability database that defines habitat associations for fish species found in the Great Lakes (Species and Life Stage Habitat Information, Figure 1). The relative use of different habitat features (depth zones, bottom substrate type and vegetated cover) by fishes were assigned for three life-stages (spawning, nursery [i.e., young-of-year], and adult) based on literature evidence (Lane et al. 1996a, b and c). Preferences or evidence of usage or occupancy for bottom substrate and vegetated cover types were rated as no preference, low, medium and high preference. Depth range preferences often vary seasonally with thermal patterns and life history progressions and these were considered when assigning depth associations. Where no evidence was reported no preference was assumed across categories. Until clear statistical associations are available, then HEAT will use literature-based meta-analysis information to calculate guild based and life stage specific habitat suitability matrices.

The habitat suitability matrix (HSM) combines depth, substrate and vegetated cover probabilities using matrix algebra. These preferences were then assigned to all possible depth, substrate and cover combinations and the proportion of association calculated. Separate suitability matrices are calculated for all the species found in a particular location by life stage.

Group Habitat Suitabilities

HEAT combines species into guilds across three life stages (spawning, nursery and adult): currently the defaults are two feeding or trophic groups (piscivores and non-piscivores based on the importance of fish in the diet), and three adult thermal preference groups (cold, cool and warm water). This guild approach is used to minimize uncertainty related to habitat preferences or associations of individual species. HEAT relies on the cumulative weight of evidence among species to counter any data deficiencies present for individual species. HEAT is designed to assess community impacts; it does not have the capacity to weight a particular species of interest (e.g., SARA species, fisheries species, invasive species) more highly than others unless customized lists are created. Fish lists are provided by guild so the user can determine what species are included in the different groups. Currently, species-level considerations should be addressed using other more specific information separately, like critical habitat. Results for guild specific output could be considered if a particular group is the focus.

Across life stages (spawning, nursery and adult) and thermal/trophic guilds (warmwater piscivore, warmwater non-piscivore, coolwater piscivore, coolwater non-piscivore, coldwater piscivore, coldwater non-piscivore) the relative weights of these different groups are equal by default (Guilds and Weights, Figure 1). Weights (W) can be adjusted in the Tool, however, it is currently not recommended without formalization of methods. Sensitivity analysis is needed to determine whether the weighting of life stages and guilds should be changed and when it might be appropriate to do so without unforeseen effects on the output. Altering the weight of guilds would allow for consideration of fisheries management objectives directly in the output if standardized. In addition, there are most likely trade-offs in habitat supply with any alteration that are not reflected in the overall fish community gains and losses but are reflected at the life stage and guild levels before imposing values. Altering life stage weights could be used to reflect the relative importance of life stage contributions to the completion of life histories for all fish species or if specific habitat is desired for restoration or is deemed limiting (see Fish community, Habitat and Fisheries Goals, Figure 1).

Finally, the composite habitat suitability matrix for the whole fish community is calculated by combining the guild life stage group habitat suitability matrices.

Weighted Suitable Area

Using all the information above, HEAT calculates weighted suitable area for the habitat that is available to fish in the scenarios that are provided. Weighted Suitable Area (WSA) is a scaled measure of area units of fish habitat that can be considered a surrogate of productivity.

HEAT Output

The WSA outputs of Lake HEAT allow pre and post project comparisons of available habitat supply aggregated for the fish community at a site. At the time of this review, the habitat modification categories included in the assessment were: the area lost to the project (e.g., infill) (A_{Loss}), the area modified either directly (A_{ModD}) or indirectly (A_{ModI}) by the project, the area of compensation (A_{Comp}) gained through improvements of existing aquatic habitat or the creation of new habitat, and the area within a set project boundary that is unchanged by the project (A_{Unch}). Each patch in pre and post scenario tables is assigned to one of these categories. The term compensation is now referred to as offsetting in the *Fisheries Act* (subsection 6 c), Fisheries Protection Policy Statement (DFO 2013), Fisheries Productivity Investment Policy: A Proponent’s Guide to Offsetting (DFO 2013), it was recommended that the name of the A_{Comp} category be changed to A_{Offset} to reflect the current policy changes and avoid confusion.

Other Habitat Features

In the existing model, a condition factor is available to modify the quality of a habitat patch to reflect other variables that may affect its suitability. Upon review it was recommended to change the name of this factor to a quality adjustment factor (QAF) (see Condition Input, Figure 1). The QAF can be applied to patches of habitat to represent degraded habitat conditions. For example, it has been used to reduce the quality of degraded areas where there are water or sediment quality issues due to contamination or eutrophication. The use of a QAF needs to be applied when the factor is different in pre and post conditions. The QAF must be supported by literature or data on habitat use or fish productivity; ideally in the localized area. QAFs are conditions or states that depress the productivity value of habitat patches and are applied at the patch level for other physical (e.g., high wave energy or active siltation) or biochemical (e.g., anoxia) characteristics. QAF is scaled from 0-1 (applied to scale down the suitability of a patch) and is therefore used as a modifier on the final composite suitabilities after group/life stage weighted summations have been completed for each patch. It is important to note that the use of QAF requires a documented rationale for its use and specific application. Further guidance is required on when it is appropriate to use this function under different circumstances.

Value of the Tool

There was consensus at the meeting that HEAT is a valuable tool for proponents and FPP for assessing losses, gains and modifications to habitat from development, offsets and restoration activities. There was also consensus that the approach used in HEAT has broader application to assess other changes to a habitat.

Moving forward, some additional requirements and documentation were identified by participants, including a clear, documented description of the science and equations underlying HEAT calculations and the central assumptions involved in the estimations of Weighted Suitable Areas; an updated guidance document to support HEAT's continued use, and changes to the outputs to reflect changes in Fisheries Protection policy and ongoing revisions to the *Fisheries Act*. Currently information on the science underlying HEAT is available in a variety of peer-reviewed documents and this information has been summarized in a single research document (Abdel-Fattah et al. 2019). The model's application, using the program defaults, is supported by peer-reviewed information or expert opinion so any changes to the defaults need to be supported by further supporting evidence. Ongoing collaboration between Science, FPP and other users of HEAT is recommended to use the tool appropriately and to continue to make improvements.

Future Use

A number of different updates to HEAT and alterations for its future use were reviewed. Participants agreed that the existing capabilities of HEAT need to be maintained as a priority (i.e., basic habitat variables, Great Lakes data tables). In addition, the capacity of HEAT algorithms to modify inputs needs to be tested further to understand the implications on resultant outputs. Following this work, additional guidance for the use of HEAT and any modifications suggested could be developed. Science should continue to work closely with FPP to ensure that the model output reflects current policy and aides in consistent decision-making with metric standards. It was agreed that extensions of the model are possible including broadening the regional coverage of the model and adding variables that further explain fish habitat use and its relative suitability. Some work is already underway in this regard with the inclusion of temperature as a variable and continued base information gathering within select biogeographic regions of Canada.

The core databases containing habitat preferences and fish lists in HEAT require regular updates with new information. In particular species distribution lists need to be updated to address the introduction of new species within a region (e.g., invasive species, such as Round Goby in the Great Lakes list of species), or the loss of species (e.g., some ciscoes, minnows that are now considered extinct or extirpated in some areas). Work will be required on a regular basis to update the core data tables with new information from standardized literature reviews. In this way, uncertainties can be addressed as new information becomes available. In addition, the reviews of fish habitat preferences or associations could examine the potential for adding uncertainty into the habitat preference data and refining algorithms.

Through a review of case studies and discussions of the HEAT assumptions, a number of areas where additional guidance is required were identified. In most cases the guidance would need to be informed by a sensitivity analysis. For example, sensitivity analysis is needed to determine how sensitive the output is subject to the weighting of life stages and guilds and whether they should be changed from default levels (i.e., from equal weighting). In addition, further guidance is required to inform the impact of patch size and habitat heterogeneity in patches. Sensitivity analysis could also be conducted on suitabilities to determine how patch size or resolution affects the outcomes of the model. Thresholds of patch heterogeneity could be established within the model to establish quality checks before scenarios are run.

Further guidance on approaches to substrate type weightings or input specificity for sediment mixtures found in different areas is required. For example, sediments in wetlands and open coasts are difficult to describe using the current substrates in HEAT and how they are specified was shown to impact the output likely because of the disaggregation in matrix calculations. The sensitivity of the model to substrate composition and the number of classes should be investigated. Finally, further technical guidance is required to inform substitutions of habitat features into the existing HEAT habitat classes, especially those for cover other than vegetation. For example, guidance on how to deal with woody debris or manmade structures is needed.

Ongoing science work to provide additional functionality and upgrades to HEAT were described for two significant extensions; the inclusion of temperature as a habitat variable, and the ability to incorporate different water level comparisons (e.g., low water, average water, 80^{th} percentile, high water) for pre and post evaluations. As more habitat layers and features are added to the system, the associated guidance material will require updating.

The current HEAT computer program could be updated to include tables that apply to other biogeographic regions of Canada; however, considerations of the current state of habitat knowledge should inform the design for a national approach to HEAT. This includes an examination of seasonal habitat use, substrate types, water levels, depth classes and overwintering habitat usage in all regions. Other development needs of interest included regional habitat association datasets for the rest of Canada. In some cases that may only require gap filling for some species with some new ecological information generated in the interim.

Before expanding HEAT to other ecosystem types like rivers, other available tools might need to be considered. For example, there is a number of functioning riverine habitat models available that produce similar outputs (e.g., Physical Habitat Simulation System (PHABSIM) as part of the Instream Flow Incremental Methodology (IFIM), River2D).

Sources of Uncertainty

A model is a basic representation of our scientific understanding of system dynamics. All models make decisions on what to include based on an understanding of the system and through testing; ultimately all models (including statistical) are simplifications of the real dynamics they are meant to represent. Currently habitat suitabilities are linked to the habitat variables of depth, substrate and vegetation and how fish species use them. That information is lumped or aggregated based on thermal guild assignments (e.g., coldwater or warmwater species) and feeding guild (e.g., piscivorous or fish-eating species). Other variables are known to influence habitat use by fishes, which are not included in HEAT at this time but can be accommodated with the use of the quality adjustment factor.

Knowing and understanding the assumptions, uncertainties, sensitivities, accuracy and precision of the model are essential for HEAT to meet user expectations. Some basic core assumptions of the model include the following:

- If a species has not been observed using specific habitat features as defined in the habitat classes, then it was assumed to not use that habitat (by negative inference); this observation is predicated on the theory of the ideal free distribution of species (Tyler and Rose 1994).
- The major habitat axes (depth, substrate and vegetated cover) are currently evaluated as if independent of each other. The implications of this assumption were qualitatively tested by confirming that the model produced acceptable habitat suitability values given expert

knowledge of the relative productivity and diversity of select areas within the Great Lakes drainage.

- Large areas of low-suitability habitat are equivalent to small areas of high suitability habitat (i.e., as defined by carrying capacity) in calculations because their WSAs would be equivalent. This may undervalue the importance of high quality but small habitats if this is not true.
- The basic net change equation (Minns 1997) is based on the underlying assumption that fisheries productivity is linearly related to the suitability of those areas for the fishes present. This linearity assumption has been qualified as a result of the theoretical science advice regarding fisheries productivity curves and the cumulative role of habitat/ecosystem features under different conditions (DFO 2014d). The assumption of linearity has the benefit of providing a precautionary approach since it assumes that any decrease in habitat suitability or the area of suitable habitat leads to decreases in fisheries productivity.

Confidence and understanding of the sensitivities of the model to changes in the input data can allow FPP staff to ensure the model is being run and interpreted in a clear and consistent manner. A systematic sensitivity analysis should be conducted in order to assign uncertainty at each step in the calculations. Precision of the input data may influence resulting calculations and more guidance from science on how the scale or precision at which the data is collected influences the output. Other considerations of how input variables might influence output that would benefit from sensitivity analyses include; how water depths are determined for fish use (for example are they determined based on average levels, seasonal lows, seasonal highs, etc.), how fish association data is assigned to substrate categories in base suitability tables, and how to account for substrate or other cover types not currently included in the input. In addition, further review of the functional use of different substrates by fishes during their various life histories could be conducted to strengthen the link with fisheries productivity. Changes in substrate tend to have a larger influence on the output values than other variables in preliminary testing, thus indicating the importance of examining the sensitivity of the model to substrate composition input.

A systematic evaluation of case study results could be carried out to explore the underlying data decisions and application of the WSA approach. Sensitivity analyses are needed to determine what the effect of differential weighting of life stages and guilds has on the output. This is important because altering the weight of guilds would allow consideration of specific fish community objectives within the assessments. Altering life stage weights could be used to reflect the relative importance of life stage contributions to the completion of life cycles in all fish species (Fish community, Habitat and Fisheries Goals, Figure 1).

GLOSSARY OF TERMS

Fisheries management objectives – are the stated socio-economic, biological, and ecological goals for a fishery that are typically established by federal, provincial or territorial fishery managers. Other entities, including wildlife co-management boards established under land claims agreements may also set fisheries management objectives (Fisheries Protection Policy Statement).

Habitat Patch – a defined spatial area that is unique in composition to its neighboring parts (a way of designating parcels of area within the model**.**

Offsetting – measures to counterbalance *serious harm to fish* by maintaining or improving fisheries productivity after all feasible measures to avoid and mitigate impacts have been undertaken. Previously termed ‘compensation’.

Quality Adjustment Factor – are conditions or states that depress the productivity value of habitat patches and are applied at the patch level for other non-physical characteristics. QAF are scaled from 0-1 (to scale down the suitability of the patch) and applied as modifiers on the final composite suitabilities after group/life stage weighted summations have been completed. QAF for loss patches are always 1.

CONCLUSIONS AND ADVICE

- HEAT can be used to quantify the impacts of development projects and the benefits of proposed offsetting.
- Currently the model applies to freshwater lakes in the primary watershed of the Great Lakes area, including the Great Lakes proper and all inland lakes in the Great Lakes basin; however, it could be expanded to include other regions and habitats.
- HEAT provides a basis for quantitative analysis of harm and offsetting that increases consistency in proposals by proponents and their review by regulators.
- The output of HEAT is dependent on the reliability of the input files, default base tables in the HEAT program are based on peer reviewed habitat associations or suitabilities. Currently habitat suitabilities are linked to the habitat variables of depth, substrate and vegetation, and the assignment of fish to thermal and trophic guilds. Changing or adding any variables will require new habitat suitabilities to be defined in order for the model to provide reliable and consistent output.
- The base information of the tool requires periodic review to reflect current species distributions and updated knowledge of habitat use by fish and the interrelationships between variables.
- HEAT includes a pre-defined species pool from which the species in the broad lake environment of the project can be selected. A species list selected for a location should include species that could potentially use the location and not just those that have been sampled there unless there is adequate sampling effort across all life stages.
- HEAT has a number of defaults that should not be adjusted without sensitivity analysis and evidence supporting those adjustments, including;
    - Differential weightings of life stages (spawning, nursery and adult) and thermal guilds (e.g., cold water, warm water),
    - The quality adjustment factor (i.e., the condition factor)
- HEAT is designed to assess community level impacts; it should not currently be used to evaluate a particular species of interest (e.g., SARA species, single fisheries species, invasive species).
- Operational validation of offsetting projects that have used HEAT/HAAT to estimate impact and offsetting is recommended to test assumptions and uncertainties with field data outcomes. This could include post hoc testing of existing projects with monitoring data or using an experimental approach to future projects for validation.

- To support the current use of HEAT several resources were identified that would be of use including a supporting science research document describing in greater detail the science underlying HEAT and the central assumptions and key uncertainties of the model (Abdel-Fattah et al. 2019), a guidance document for online computer program users, and updates to output names to reflect the changes in policy and the *Fisheries Act*.
- In addition, there is a need for standard protocols and guidelines to be established to ensure the use of HEAT is consistently applied within FPP. Ongoing collaboration between Science, FPP and users is recommended to use the tool appropriately for periodic review and refinement of the model and program.
- Open distribution of the HEAT system R-code and supporting databases would allow for shared development and research in the continued development of HEAT and its use in offsetting or evaluation of broader habitat changes.
- A number of improvements to HEAT and its documentation were identified; however, no recommendations were made on their relative importance. Possible improvements to HEAT included:
  - The development of spatial input tools like linking with GIS layers for location and patch level information as well as GIS-based outputs to visualize suitabilities.
  - The addition of temperature as a variable influencing habitat suitability, temperature is functionally important in fish habitat associations. Adding temperature would require further testing and validation of the new tool components and their impact on output.
- Development of technical guidance to inform substitutions for vegetated cover (e.g., how to input woody debris or manmade structures).
- The current structure of HEAT may apply to other regions; however, a consideration of the current state of knowledge should inform expansion to a national approach to HEAT, including further examination of seasonal habitat use, substrate types, water levels and depth classes.
- Before expanding the HEAT approach to rivers, other available tools might need to be considered for use as existing standards. For example, there is a number of functioning riverine habitat models available to use to produce similar outputs – e.g., PHABSIM part of IFIM, River2D whose output could be standardized for evaluations / assessments that span both aquatic systems.
- HEAT could be used to quantify impacts of other changes to fish habitat suitability, for example changes in habitat availability due to climate change. However, this is beyond the scope of development project evaluation unless climate scenarios are used in comparing future project states.

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SOURCES OF INFORMATION

This Science Advisory Report is from the January 27-29, 2016 Habitat Ecosystem Assessment Tool (HEAT) Software Development and Evaluation. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

Abdel-Fattah, S., Minns, K., Doka, S., and Doherty, A. 2019. Science and Foundation of the Habitat Ecosystem Assessment Tool (HEAT). DFO Can. Sci. Advis. Sec. Res. Doc. 2019/060. *In press*.

Bradford, M.J., Randall, R.G., Smokorowski, K.E., Keatley, B.E., and Clarke, K.D. 2014. A framework for assessing fisheries productivity for the Fisheries Protection Program. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/067. v +25 p.

Bradford, M.J., Smokorowski, K.E. Clarke, K.D., Keatley, B.E. and Wong, M.C. 2016. Equivalency metrics for the determination of offset requirements for the Fisheries Protection Program. DFO Can. Sci. Advis. Sec. Res. Doc. 2016/046. vi + 32 p.

Clarke, K.D. and Bradford, M.J. 2014. A Review of Equivalency in Offsetting Policies. DFO Can. Sci. Advis. Sec. Res. Doc. 2014/109. v +18 p.

DFO. 2013. Fisheries Productivity Investment Policy: A Proponent's Guide to Offsetting. Fisheries and Oceans Canada, Ottawa, Ontario. 19 p.

DFO. 2014a. A science-based framework for assessing changes in productivity, within the context of the amended Fisheries Act. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2013/071.

DFO. 2014b. Science Advice for Managing Risk and Uncertainty in Operational Decisions of the Fisheries Protection Program. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2014/015.

DFO. 2014c. Science Advice on Offsetting Techniques for Managing the Productivity of Freshwater Fisheries. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2013/074.

DFO. 2014d. A Science-Based Framework for Assessing the Response of Fisheries Productivity to State of Species or Habitats. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2013/067.

DFO. 2017. Science Advice on the Determination of Offset Requirements for the Fisheries Protection Program. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2017/009.

Lane, J.A., Portt, C.B., and Minns, C.K. 1996a. Nursery habitat characteristics of Great Lakes fishes. Can. Manuscr. Rep. Fish. Aquat. Sci. 2338: 42 p.

Lane, J.A., Portt, C.B., and Minns, C.K. 1996b. Adult habitat characteristics of Great Lakes fishes. Can. Manuscr. Rep. Fish. Aquat. Sci. 2358: 43 p.

Lane, J.A., Portt, C.B., and Minns, C.K. 1996c. Spawning habitat characteristics of Great Lakes fishes. Can. Manuscr. Rep. Fish. Aquat. Sci. 2368: 48 p.

Minns, C.K. 1995. Calculating net change of productivity of fish habitats. Can. Manuscr. Rep. Fish. Aquat. Sci. 2282: vi + 37 p.

Minns, C.K. 1997. Quantifying “no net loss” of productivity of fish habitats. Can. J. Fish. Aquat. Sci. 54: 2463–2473.

Minns, C.K., J.E. Moore, M. Stoneman, and B. Cudmore-Vokey. 2001. Defensible Methods of Assessing Fish Habitat: Lacustrine Habitats in the Great Lakes Basin – Conceptual Basis and Approach Using a Habitat Suitability Matrix (HSM) Method. Can. Manuscr. Rep. Fish. Aquat. Sci. 2559: viii + 70 p.

Randall, R.G., Bradford, M.J., Clarke, K.D., and Rice, J.C. 2013. A science-based interpretation of ongoing productivity of commercial, recreational or Aboriginal fisheries. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/112. iv + 26 p.

Scott, W.B., and Crossman, E.J. 1973. Freshwater fishes of Canada. Fish. Res. Board Can. Bull. 184: 966 p.

Tyler, J.A., and Rose, K.A., 1994. Individual variability and spatial heterogeneity in fish population models. Rev. Fish Biol. Fish 4: 91–123.

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