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Proceedings of the regional peer review meeting to develop advice on fish swimming performance curves

February 9, 2011
Teleconference and WebEx

Chairperson: K.A. Martin and R. Wysocki
Editor: H. Cleator

Fisheries and Oceans Canada
Freshwater Institute
501 University Crescent
Winnipeg, Manitoba R3T 2N6
Canada

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Canada

Foreword

The purpose of these Proceedings is to document the activities and key discussions of the meeting. The Proceedings may include research recommendations, uncertainties, and the rationale for decisions made during the meeting. Proceedings may also document when data, analyses or interpretations were reviewed and rejected on scientific grounds, including the reason(s) for rejection. As such, interpretations and opinions presented in this report individually may be factually incorrect or misleading, but are included to record as faithfully as possible what was considered at the meeting. No statements are to be taken as reflecting the conclusions of the meeting unless they are clearly identified as such. Moreover, further review may result in a change of conclusions where additional information was identified as relevant to the topics being considered, but not available in the timeframe of the meeting. In the rare case when there are formal dissenting views, these are also archived as Annexes to the Proceedings.

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SUMMARY

A Fisheries and Oceans Canada (DFO) regional science peer review meeting was held on 9 February 2011 via WebEx and teleconference. The purpose of the meeting was to review a working paper that presented the results of analyses on fish swimming performance curves to determine;

(1) if the database used for the analyses was complete;

(2) the scientific validity of the analyses, results, and conclusions reached; and

(3) the limitations of the study.

Meeting participants included DFO Science (Central and Arctic, National Capital, and Gulf regions), Katopodis Ecohydraulics Ltd., North/South Consultants Inc., the U.S. Department of Energy Oak Ridge National Laboratory, U.S. Geological Survey S.O. Conte Anadromous Fish Research Center, and the universities of British Columbia, Michigan, and Leiden (Netherlands).

A working paper was drafted and distributed prior to the meeting. During the meeting, participants discussed the assumptions, analyses, uncertainties, and limitations of the database and study results.

This Proceedings report summarizes the relevant discussions and presents the key conclusions reached at the meeting. The swim performance methods and results are published as a Research Document and the advice from the meeting is published as a Science Advisory Report on the DFO Canadian Science Advisory Secretariat Website.

Compte rendu de la revue par les pairs régionale pour développer avis scientifique sur les courbes de performance natatoire des poissons

SOMMAIRE

Une réunion d'examen scientifique régional par les pairs de Pêches et Océans Canada (MPO) a eu lieu le 9 février 2011 par WebEx et par téléconférence. Elle avait pour but d'examiner un document de travail qui présentait les résultats des analyses à partir des courbes de performance natatoire des poissons afin de déterminer :

(1) si la base de données utilisée pour les analyses était complète;

(2) la validité scientifique des analyses, résultats et conclusions formulées;

(3) les limites de l'étude.

Ont participé à la réunion : le Secteur des sciences du MPO (région du Centre et de l'Arctique, région de la Capitale nationale et région du Golfe), Katopodis Ecohydraulics Ltd., North/South Consultants Inc., le U.S. Department of Energy Oak Ridge National Laboratory, le U.S. Geological Survey S.O. Conte Anadromous Fish Research Center, l'université de la Colombie-Britannique, l'université du Michigan et l'université de Leiden (Pays-Bas).

Un de document de travail a été préparé et distribué avant la réunion. Pendant la réunion, les participants ont discuté des hypothèses, des analyses, des incertitudes et des limites de la base de données et des résultats de l'étude.

Le présent compte rendu résume les discussions pertinentes et présente les conclusions importantes tirées de la réunion. Les méthodes et les résultats relatifs à la performance natatoire sont publiés en tant que document de recherche et les conseils découlant de la réunion sont publiés en tant qu'avis scientifique sur le site Web du Secrétariat canadien de consultation scientifique du ministère des Pêches et des Océans

INTRODUCTION

The purpose of this meeting, as described in the Terms of Reference (Appendix 1), was to review a working paper on fish swimming performance to assess the completeness of the database used to develop the fish swimming performance curves; the scientific validity of the analysis, results and conclusions reached; and limitations of the study. Meeting participants (Appendix 2) included Fisheries and Oceans Canada (DFO) Science, Oceans and Habitat Management sectors from Central and Arctic, National Capital, and Gulf regions, and experts from North/South Consultants Inc., Oak Ridge National Laboratory, S.O. Conte Anadromous Fish Research Center, and the universities of British Columbia, Michigan and Leiden (Netherlands). The meeting was held on 9 February 2011 and generally followed the agenda outlined in Appendix 3.

This Proceedings report summarizes the relevant discussions and presents the key conclusions reached. Science advice resulting from this meeting is published in the Canadian Science Advisory Secretariat Science Advisory Report (SAR) series (DFO 2016). The swim performance methods and results are published in the Research Document series (Katopodis and Gervais 2016). The complete list of references for material cited in this report can be found in Katopodis and Gervais (2016).

PRESENTATION AND DISCUSSION

The co-chairs welcomed meeting participants and explained the DFO Canadian Science Advisory Secretariat (CSAS) science advisory process, how meeting discussions would be documented, and expected meeting products. After a round of introductions, the co-chairs provided an overview of the meeting objectives and agenda. It was noted that in addition to the objectives outlined in the meeting Terms of Reference, participants would also endeavour to identify and evaluate the sources of uncertainty and the assumptions used in the analysis. This was followed by a PowerPoint presentation of the working paper by the authors.

FISH SWIMMING PERFORMANCE DATABASE AND ANALYSES

Presenters: Chris Katopodis, Katopodis Ecohydraulics Ltd., and Richard Gervais, DFO Central and Arctic Region

The authors described the data sources and selection criteria they used to create the fish swimming performance database. The “ichthyomechanical database” was first generated in the late 1980s. Wide and comprehensive literature search efforts, intended to be as inclusive as possible, produced approximately 2300[1] references, published between 1945 and 2010. These were carefully scrutinized and 132 publications yielded relevant numerical data on freshwater species which included at least three variables: fish lengths, swim speeds, and swim times. The focus of the data collection process was on publications that contained swim time or swim distance measurements. Most data were obtained from peer-reviewed journal publications, though some were from the grey literature. Initial data collection included a variety of fish species; however, the final focus was on freshwater species and species that include freshwater in their life cycle (e.g., diadromous species).

[1] Additional analyses conducted since the meeting resulted in higher numbers of references, publications and samples sizes than those reported during the meeting and in this report. See Katopodis and Gervais (2016) for updated values.

The swim data came from forced swimming tests (e.g., stamina tunnel[2], rotating swim chamber) as well as volitional swimming tests. Many primary publications in the scientific literature are based on stamina tunnel tests. More recent research indicates that fish behaviour associated with gait transition may be restricted in critical swimming speed tests and may influence the interpretation of such data. Ground speed may affect a decision by fish to change "gears" or swimming gait. In volitional swimming tests, fish can move through an open channel, culvert or flume at their discretion. Swim distance or time, or both, can be measured. Within limits, flume length in volitional tests does not seem to affect gait transition speed or limit performance. While stamina tunnels are limited to fairly uniform flow conditions, open channel flumes provide more complex and more variable hydraulic conditions (e.g. water waves, turbulence, variations in water velocities and depths along their lengths or cross-sectional distributions) which may allow easier passage for fish, thereby overestimating swimming performance based on mean flume velocities. Fish in volitional tests often use energy-efficient burst-and-coast swimming when moving at speeds in the prolonged range, a behavior not possible in swim tunnels.

Much of the swim chamber research produces data in the prolonged range (i.e., generally for swim times of a few minutes to 30 minutes or greater), while volitional tests using a channel or culvert tend to be relatively short (< 100 m) and produce swim data mainly in the burst range (i.e. generally for swim times over a range of seconds to a few minutes). Both burst and prolonged swim data are needed to define the entire fatigue curve for a species. Sustained swim speeds are those beyond the prolonged range and usually change little with swim time, providing a cutoff for the lowest prolonged fish speeds.

The authors showed a break-down of the database in terms of a number of parameters (e.g., data source; fish and species counts; test method and apparatus). The pre-processed database contained data for 131 fish species, which was reduced to 122 species after applying a swim time criterion of ≤ 30 minutes. It was a practical decision to cut it off at 30 minutes because;

(1) it provides sufficient time for a fish to travel through a culvert, in front of a fish screen or other artificial or natural passage areas, and

(2) beyond 30 minutes fish perform at low sustained velocities that, theoretically at least, could be maintained for an indefinite period of time.

The processed swim speed and endurance time data collection used to derive the performance curves presented in this analysis, consisted of 2,045 data points obtained from swimming performance measurements from 22,506 fish. Of the 2,045 data points: 261 (13%) were from volitional open-channel tests; and 751 (37%) and 853 (42%) where from fixed and increasing velocity stamina tunnel forced swim tests, respectively. In the literature, data were usually grouped into subsets according to logical features such as fish length. The authors used a similar approach with the raw data. For example, fish tested at similar water temperatures and velocities were grouped together. Many publications were not included in the database because they contained background information but no swim performance data. Participants asked the report authors to describe in the Research Document how they grouped the data.

Participants asked what criteria were used to decide what data to include in the database. The authors said that if the swim data were based on unusual conditions, such as water temperatures at which the test species would not naturally occur, they were screened out. If the publication or other experts reported that swimming performance may have been compromised in a particular study, those data were also excluded. They also noted the twenty-fold reduction

[2] A stamina tunnel is where a fish is constrained in a water-filled tunnel to test its ability to swim against a current of known velocity for a given period of time.

in the number of publications scrutinized (~ 2,300) compared to the number that yielded relevant data (132). The authors indicated that literature searches were wide and captured many publications which either did not contain numerical data, only included graphs or were devoted to theoretical aspects of fish swimming. Furthermore, marine species were excluded from this analysis as the focus was on diadromous species. The authors noted that more fine-scaled screening of the database may be possible though it may have little impact on the overall results. The authors felt that overall they had been more inclusive than exclusive when screening the data[3]. Participants asked the authors to describe in the Research Document the decision pathways, they used to select data so that it is clear to the reader that the screening process was based on scientific rigour rather than "cherry picking" data to suit pre-determined conclusions. It was suggested these details be added to the appendices where appropriate. (See Katopodis and Gervais 2016 for a full explanation of the data selection process.)

It was agreed that the database should indicate whether the fish included in the database had undergone surgery or tests for pollution effects. The authors concurred though they noted that only the control fish used for pollution tests were screened in. It was thought that a quality control field in the database would be useful. The authors reported the database currently has flags so it is possible to highlight specific information of interest (e.g., recent surgery, tagging).

Participants asked if DFO would make database publicly available. The co-chairs will investigate that possibility.

Many sources of data reported their results based on grouped data only (e.g., the mean endurance time for a group of fish), so the database contains a mix of group and individual swimming performance data. For consistency, data for individual fish from a specific source were grouped when the test method and species were the same and a difference of ten percent or less existed in fish length, water temperature, swim speed or time.

The authors presented graphs showing fish swim time versus swim speed for the pre-processed data (swim times of less than 150 minutes). Swim speed was generally higher for volitional test data, since they most often represent burst speeds.

Participants asked whether mean or median values were presented for grouped data. The authors said that in most cases mean values were given for the grouped data. Median values were used for censored data (i.e., when the fish performance values occurred outside the range of the measuring instrument). For example, if some test fish were still swimming at the conclusion of the test then median values were used for grouping the data because it is unknown when those fish would have stopped swimming. (See Katopodis and Gervais 2016 for a full explanation of the grouping process.)

The 30-minutes cutoff was discussed further. The time limit was selected based on fish passage design criteria where the cost and complexity of passage works are significantly higher, and the effectiveness of fish passage lower, when velocity criteria based on continuous swimming is greater than 30 minutes. For that reason, passage is typically broken down into a series of steps, each requiring no more than 30 minutes of passage, with opportunities for rest between steps. As fatigue curves[4] level off for swim times of 30 minutes or more, this means that large increases in swim time are needed to change the fish swim speed significantly. Participants

[3] Since the meeting, the authors obtained more available data to include in the database and revised Research Document (see Katopodis and Gervais 2016).

[4] Fatigue curves are a graphical presentation of the relationship between swimming speed and time to fatigue (endurance time); they define the performance capacity for given fish size and species.

noted that fish swim capacity is not independent of BL. A small fish will swim relatively slowly compared to a fish two orders of magnitude larger, yet the authors used the same time constraint for all fish species. The document should be explicit about the limits of the data. For example, it could specify that for the smallest fish, the 30-minutes cutoff may exceed the application of the data. Or, put another way, data from the smallest fish may not apply for culverts longer than a specified length. The authors noted that their analysis shows that fish swim capacity depends on fish length, and that the longest swim performance distance curve estimated for any size fish will be limited to that corresponding to the 30-minute swim time limit.

One traditional way of analyzing fish swimming speed is in terms of BL/s. The authors found a relatively weak relationship (R^2=0.244) between swim time and swim speed by species using regression analysis for both un-weighted and weighted (by sample size) points. Re-analysis of the data using dimensionless analysis produced a much higher R^2 value (0.617).

There are insufficient swim performance data available for many species to derive individual fatigue curves. An ecohydraulic approach[5] using dimensionless variables allows more global data analyses for groups of fish species and the ability to use limited datasets, compared to individual curves with limited data. Dimensionless variables are commonly used for hydraulics and, more recently, in hydrodynamics (e.g., sediment transport, bankfull discharges). Reynolds and Froude numbers are also examples of dimensionless variables. The authors explained how they used dimensionless analysis to calculate water velocity for an imagined water wave in a channel. Assuming the length of the water wave is equal to the length of a fish, they calculated dimensionless fish swim speed and the water velocity fish swim against. Thinking of the period of the water wave as a characteristic of time, they calculated dimensionless fish swim time and swim distance fish achieved. Gravity was used as a constant in the analysis. It is a fairly universal constant and important in terms of wave period.

Participants raised questions and made points related to the dimensionless analysis. It was noted that expressing absolute swim speed as a function of fish BL was developed some time ago. Since then, math has become more sophisticated and our knowledge of scaling has improved immeasurably. Dimensionless analysis normalizes swim speed to the square root of BL. That is closer to what is expected from a scaling effect on locomotion, based on what we know about fish physiology, and is reflected by the higher R^2 value. However, the equation used to calculate dimensionless fish swim speed produces a crude number from a hydraulic perspective. Perhaps another dimensionless parameter might be more appropriate where water waves do not necessarily dominate water flows. The variables used may fit data obtained from wave-type dominated flow environments but not the entire range of conditions under which swim performance data have been collected. The authors acknowledged that much of the swim performance data are not from open channels with waves but from swimming chambers that may not have surface waves. However, they used this approach to treat all data in a consistent way and the wave analogy was used strictly for the purposes of conceptualization, better understanding and improved interdisciplinary communication. One participant felt that from an engineering perspective, the limitation of this approach for some types of data should be highlighted in the Research Document. (See Katopodis and Gervais 2016 for a more complete explanation of dimensionless analysis and its relevance to swim performance.)

In the dimensionless analysis, the speed of the wave (i.e., celerity), is proportional to the square root of gravity multiplied by wave length. A participant asked if there is a physical speed

[5] Ecohydraulics is an interdisciplinary field studying the interactions between water and ecology. In the case of this study, a hydrodynamically-based approach was used to analyze biological and hydraulic data to address information gaps related to swimming performance.

associated with the water wave speed equation. The authors said that when a fish is swimming in a channel with a surface wave it may be easier to represent the physics than when the fish is in a swim chamber without surface waves. The water wave speed variable may be thought of as a characteristic speed of that fish length.

A participant wondered if the role of fish BL (i.e., ***l***) in the analysis was to reduce the variance or increase the R^2. If it was for a better R^2, that was achieved but it wasn't clear why it was needed. If it was to reduce variance for a specific dataset then that should be clarified in the Research Document. The authors suggested that better statistics were needed for developing more robust fatigue curves, particularly where significant limitations in datasets were apparent. For example, extrapolating fatigue curves derived only from volitional channel data would underestimate prolonged performance because they are characterized by steep slopes. The reverse is also true. Fatigue curves based on data collected only from swim tunnels tend to be flatter, therefore would underestimate the burst performance end of the swim data spectrum. For this reason, the authors used dimensionless analysis to try to find more robust fatigue curves which use both prolonged and burst data together. Some participants thought it might be useful to explore using the square root of BL/s, instead of dimensionless analysis, as the adjustment to see if it provides similar R^2 and variance values. Other participants did not agree with removing the gravitational constant because they preferred the rigour associated with dimensional homogeneity. Participants recommended the authors compare the two approaches and present the results in the Research Document.

A participant wanted to know the purpose of the dimensionless analysis in terms of its operational value. The authors had wanted to develop full fatigue curves for individual species but insufficient published literature was available to do that. So instead they decided to combine all available swim performance data to build a general fatigue curve that would tell us something about the swimming speed of a fish over the entire curve. Participants recommended the authors provide a better explanation in the Research Document for why dimensionless analysis is useful for practical applications, particularly for species for which data are not available. It was noted by the authors that if the results of this review suggest the analysis and results are valid, then it would be possible to derive specific distance or endurance curves for specific lengths or groups of fish that can be applied in a practical way.

While dimensionless analysis can be used as a tool for analyzing swim performance data, a participant noted there are probably other ways of deriving even better relationships to account for more of the variability in the model. For example, the information theoretic approach could be used to build regression models that would potentially find better parameters for estimating the scale effect. Optimizing the model should be the goal rather than removing dimensions. The method used here is moving in the right direction but has some limitations. There are other techniques that could produce better results. It is not necessary to use them in this document but if the database is available for others who want to explore other questions (e.g., the relationship of Froude number in hydraulics to fish swimming performance), that would be helpful. One of the biggest limitations of the database was that the authors did not have access to some datasets that are detailed and well done, thereby preventing more in-depth analysis.

A suggestion was made to replace the analogy of using the relationship of a circle's circumference to its diameter (i.e., $\boldsymbol{\pi}$) to help explain dimensionless analysis to the relationship between drag coefficient and Reynolds Number. For example, if velocity is plotted against drag force (*x* and *y* axes, respectively) it would yield a family of curves for different diameters of a shape such as a cylinder. The value of this analogy is that once the drag coefficient and Reynolds Number have been calculated, all the data reduce down to a single line. The authors chose not to use this analogy because it might be too technical for biologists to understand. Participants thought the fluid dynamics example would be clear enough for biologists to follow and more appropriate for its application to dimensionless analysis given its relevance to water and fish movement. The authors agreed to include another analogy in the Research Document if it would help to explain the concept.

During their analyses, the authors tried various dimensionless parameters and presented the combination that best reduced the scatter in the graphical representation of the data as the model was refined. Participants thought it would be useful to summarize in the Research Document what parameters were tried and what did and did not work as well. It is not necessary to include graphs showing the results of the combinations tried. A participant asked how gravity operates on swim speed given that fish are not really affected by this force. The authors said that gravity was used as a dimensionless variable for providing a characteristic scale in terms of speed. Reynolds Number and other variables were also tried but found to produce poorer results than those obtained using gravitation acceleration.

Participants agreed the text in the Research Document needs to provide better explanations of the methods used and results obtained. The text needs to be more expansive on how the analysis moved from one step to the next and how that relates to application of the results. Better explanations are needed for any data excluded and the criteria used to screen the original 131 species down to 122 (e.g., 30-minutes swim time). The graph from the PowerPoint presentation that shows the processed dataset, expressed in terms of BL/s, by species and its associated R^2 and variance values should be included in the Research Document, as should the comparable graph using the dimensionless approach. Limitations of the methods and analyses should be discussed as well as possible solutions. It would be useful to justify the use of dimensionless variables for extrapolating to situations where good quality data are not available.

The authors continued with their presentation. Recognizing that pooling all fish species together as a single group may not provide the desired results, they examined the efficacy of grouping species within the database based on a relevant characteristic. Swimming mode was chosen as a defining feature, although overall taxonomy and similarity was also considered. The authors presented a series of fatigue curves, subdivided according to type of locomotion (e.g., anguilliform, sub-carangiform, carangiform), generated using two approaches:

(1) normalized swim speed in BL/s against swim time and

(2) dimensionless analysis. They began by comparing swim performance for the eel and trout groups.

Significant speed-time regressions were developed for the two fish groups. Overall, the BL/s analysis revealed the eel group had lower swim speeds than the trout group, suggesting there is value in developing fatigue curves for these two fish groups. The dimensionless analysis provided a better explanation and more robust regressions than the BL/s method of the scaling effects related to fish size.

Fish species were grouped together based on characteristics that suggested they had a similar swimming mode. For example, the eel group contains those species in the database that swim in a manner similar to eels (e.g., lamprey), not just members of the eel order. The same is true for the trout group. This needs to be clearly explained in the Research Document. Participants thought it was inappropriate to use a name (e.g., eel) that, from a scientific perspective, does not apply to all members in the group, even though it is commonly used by the public to describe all species that look and move like it. Describing a wide range of species under one name is likely to cause confusion. For example, it doesn't make sense to group pike and muskellunge with eels because they use drag-base propulsion and are not good at eel-like swimming. Participants discussed alternate terminology for the eel and trout groups. As the authors had divided species into two groups on the basis of their swim performance, participants thought that it made the most sense to call the groups “weak” and “strong” swim performers. The authors suggested that this would limit the choice to two groups only, which may not be warranted, as more than two groups may emerge from further analysis or additional data. One participant suggested that species could be grouped on the basis of kinematics, which requires only two values (wave length and BL), according to the number of waves per BL. The authors agreed that would be reasonable so long as that information was available.

The objective of dividing the database from one large group into smaller groups was to show that there is some gain in terms of statistics (i.e., R^2 and the standard error of estimate) but after some point there is no further gain given the limitations of the dataset. It was recommended that the authors clearly state in the Research Document, in a step-by-step fashion, how they analyzed the data and the corresponding results. Acronyms used in the document to describe the different fish swimming forms should also be explained.

The authors concluded that although variability in swimming performance exists between species and individuals within a species, their data analyses indicate broad similarities in relative performance within the two groups of species. Participants pointed out that in the data plots presented for the eel group, the data points do not appear to visually fit their associated regression lines or the confidence intervals for the regression lines in the BL/s or dimensionless scatter diagrams. That needs to be resolved if the objective is to make the point that these lines work well for the two sets of data. If not, then the regression lines can be left off the graphs.

Further investigation of the eel group led the authors to compare the swim speed-time regressions between the eel group and a subset of it, the Anguilliform group, using dimensionless analysis. They found only minor improvement in R^2 and the standard error of estimate by narrowing the eel group down to just the Anguillid species. A participant indicated that R^2 values should not be used as a measure of reliability in these circumstances. The sturgeon species included in the eel group have a much shallower regression slope than the Anguillids and for that reason probably should not have been included in the eel group. However, sturgeons were included, thus, they had to fall within the variance of the Anguillids. Therefore, it is not unexpected that the R^2 values changed little between the eel group and Anguilliform group regressions. The approach used to analyze the data is somewhat backwards. The participant thought that a better approach would be to separate species a priori and then ask if the slopes are the same or to present both approaches to help convince the reader.

The authors then presented speed-time regressions for the sturgeon group followed by the pike group. They recognized that the dataset does not contain much data on burst rate for short distances and times. Thus, it could be argued that if the burst end of the spectrum is underrepresented then swim speed performance may be underestimated. It may not be possible to extrapolate beyond the available data. Data available for pike is especially limited to the prolonged swim time range so extrapolation outside the cluster of data points should be undertaken with extreme caution.

Comparison of speed-time regressions for progressively smaller sub-groups within the trout group was made on the basis of swimming mode using dimensionless analysis. Available data for carangiform swimmers was mostly limited to the burst swim range and for sub-carangiform/labriform swimmers to the prolonged swim range. Thus, relying on the swim performance data from only one group would limit the usefulness of the results. By combining them, the weaknesses of the individual datasets were balanced out. When only the sub-carangiform swimmers were examined, the scatter diagram showed a tighter data cluster with improved statistics. Data for just carangiform swimmers is more limited, comes mainly from a single data source and has less variability.

Participants talked about differentiation between burst and prolonged swim times. Brett (1964) established the 20-second threshold to describe juvenile Sockeye Salmon (*Oncorhynchus nerka*). It has been applied across species but may not be applicable for all species. It is likely more appropriate to think of a kinematic shift where fish use a burst-and-coast mode. Caution should be used when making assertions that something specific happens at 20 seconds because this has not been found in subsequent studies. The authors reported that they did not use 20 seconds as a threshold for distinguishing between the burst and prolonged modes.

The authors presented tables showing fatigue curve regressions for the various groups of species they had examined. It was noted by participants that these results are based on a log-log analysis in contrast to the log-linear analysis (i.e., the log of time is a linear function of swim speed) typically used by others in the past. This point should be highlighted in the Research Document. The log-linear approach is more consistent with geological theory and failure time theory in terms of the expected distribution. The log-log analysis could have some implications for how the model fits and may explain why they were able to fit the burst and prolonged data on a straight line. Possible effects of the log-log analysis on the results should be outlined in the document.

Scatter diagrams were shown for several species as examples of how well the data fit the fatigue curve regressions. In some cases, the data clustered relatively tightly along the regression line (e.g., White Sucker and Sea Lamprey) while in other cases the data were much more widely scattered (e.g., Rainbow and Steelhead trout). In some cases, there was large variability in individual swimming performance, which was not unexpected. Participants noted again that the exploratory and explanatory approach taken in the PowerPoint presentation is more helpful for the reader and should also be used in the Research Document.

Only a limited amount of swimming distance data was available in the literature, thus, the authors used the speed-time data to derive swimming distance. The fatigue curve for a fish is typically represented by a declining curve. Swimming distance can be calculated using a standard equation that incorporates the specific swimming speed of the fish, the water velocity opposing the fish's travel and endurance time. So fatigue data (speed-time) can be converted into swim distance versus water velocity; this has been done by other researchers. The authors compared their derived swim distance data (using prediction limits at 5%, 25%, 50%, 75% and 95% percentiles) against field-measured data (presented as box and whisker plots) for a number of species to see how well the predicted curves match actual swim distance data. They concluded that the derived swim distance data were reasonably close to direct measurements so this provides further evidence that the method can be used as a tool to estimate the swim capabilities of different species.

Estimates of fatigue time or distance may be useful when considering physiological aspects in practical applications such as fish screens and fishways. Participants noticed the field-measured data covered roughly the range between the 25% and 75% percentiles of the predicted data, suggesting there is considerable error in the projections. The 25% quartile at higher velocities matches up with the 75% quartile at higher swim distance, which signals there are some important limitations of the model. The authors reported that the prediction limits were based on all species not just one species so accuracy may be an issue. Given the high amount of variance associated with the plots showing all species grouped together, participants recommended the authors investigate how well the actual versus estimated information match for smaller groups before lumping groups of fishes together. That way, the variance can be better explained in the document.

The authors ended their presentation by summarizing their conclusions. They observed that many fish passage structures often generate non-uniform flows so that is an added complication in trying to apply the data generated in this study to real-life situations.

Participants felt that readers of the Research Document will likely first look for information about a particular species. If it is not available, or only very limited information is available, then the user will have to look at grouped data. The Research Document needs to clearly explain the criteria used to group the data for various analyses as well as what grouping each species was assigned to for various analyses. They also recommended the addition of a table that defines each of the coefficients and the parameters in the models and explains where they came from and what they mean.

Four summary statements were offered by a participant for the others to consider:

1. The diverse and variable database developed by the authors needs to be translated in such a way that the data are accessible.
2. The PowerPoint presentation helped to clarify the rationale, logic and assumptions, and to some degree the goals, of the data manipulations. These should be explicitly stated in the Research Document. Incorporating much of the presentation into the document would accomplish this.
3. There are limits to the study that the authors acknowledge. Those limitations need to be explicitly quantified or qualified in the Research Document (e.g., “for these data, we have *xx* quality/confidence in using them”). It would be useful to break the data down into four groups: good, adequate, weak, and non-existent. That would indicate to users whether they should have confidence, less confidence or no confidence in using the data.
4. The Research Document should indicate that data for individual fish species should be used when available. Recognizing that data are not always available for a specific species and that broad similarities exist among species, it is possible to use data from a pooled set of fish species if necessary. The other option is to collect data in order to fill the knowledge gap.

Participants agreed with the statements and recommended the authors revise the Research Document accordingly. They also recommended the authors re-order (or re-label) the appendices in the Research Document so they appear in the order in which they are referred to in the text.

In addition to the comments and recommendations previously raised about the database, the participants noted that the database seems to be fairly complete for North America. A participant noticed that Paul Webb’s dissertation on the swimming energetics of Rainbow Trout, published in the Journal of Experimental Biology in 1971, was not included. The authors could not remember the specifics but did recall that a number Webb’s publications were considered for inclusion in the database. Other swim performance data are available for Europe that could be considered but their omission was not thought to be critical as the purpose of the study is to provide useful information for Canada[6]. In response to a question about whether some data should be left out of the database, one participant identified the respirometry data for exclusion. About 13% of the database came from volitional channel experiments. Size of swimming tunnel is included in the database for more recent publications. The database also includes some flags

[6] Following the meeting, the authors confirmed that although the database focussed on Canadian species, data available for species from other geographic locations and areas, including Europe, were included.

indicating data that were incomplete so only partial information was included in the analyses or all of it was excluded. Some marine species were also added in the database but never used. The authors felt the database could use some cleaning up.

It is now known that fish can optimize their swim performance in volitional channel tests in ways not previously recorded during forced swimming tests. Given that, a participant questioned whether it is scientifically justifiable to combine data from both types of swim tests knowing that the forced swim data is negatively biased. The authors said that it is not known what biases exist in the volitional data which may also affect swimming performance. For example, turbulence, waves, non-uniform distribution of velocities and depths may provide easier hydraulic paths for fish to use in passing. The authors would like to remove various components from the database (e.g., respirometer data) to determine if, and how, that changes the results. A participant noted that the advice coming out of this study will be mean water velocities. It is unlikely those data can be “over interpreted” as there are many other components to swim capacity or performance that likely need to be considered in developing recommendations on how to pass fish. So the analyses can be kept as is, without removal of certain components, while recognizing the limits on the advice it can provide. The authors agreed that interpreting the results of this study for flow patterns in a more complicated fishway could be difficult. Data users might need more guidance on how to use the information from this study.

Another participant thought that the culvert data is inherently inferior to all other test apparatus. In one case, the data were collected by simply counting fish at the upstream end of a culvert at the end of study. Culverts have a rough bottom and the quality of the data is suspect. If any data are to be excluded from the fish performance database, it should be the culvert dataset. The authors agreed that culvert data are problematic especially those with substrate which produces variable velocities and turbulence within and along the culvert. Fish are able to take advantage of more favourable hydraulics. For that reason, the authors did not use the data from culvert passage studies to derive fatigue curves. They only used swimming distance data from culvert studies (where relevant) as a check of the distance data estimate derived from speed versus time data. Participants agreed with the approach taken and cautiously agreed with keeping the culvert data in the database.

In summary, the participants concluded that the data used in the study was appropriate but what, why and how the data were used, and its limitations, need to be more clearly explained in the Research Document.

One participant raised two other points about the scientific validity of the data analyses. Firstly, as a matter of convention, swim speed should be placed on the horizontal axis and time on the vertical axis, not the reverse. Likewise, the equations presented showed speed as a function of time when, in fact, it should be the other way around because we want to know is how long it takes for a fish to fatigue as a function of how fast it swims. The way the equations were presented in the PowerPoint presentation is not intuitive and potentially could lead to some other misinterpretations. Switching the units around to reverse the equations should be a relatively simple transformation. A bigger concern is the use of a log-log approach, instead of a log-linear approach, which probably makes it easier for eliminating dimensions.

Secondly, the manner in which the distance curves were derived needs to be explained more thoroughly to clarify what measures from the fatigues curves were used to derive the corresponding distance curves. (See Katopodis and Gervais 2016 for an explanation of the methods used.)

The authors had used a log-log scale because it spreads out the data points making them easier to see. One participant preferred the use of log-linear because the log of time is a linear function of covariates, thus, it is the standard way to present this kind of data. The log-linear approach also has implications for the underlying biology. It is a question of whether things are strictly multiplicative or there is an additive component and how they factor out. Also, that affects the coefficients of the exponents and how they will build into the rest of the model including the derivations of those distance curves. It was noted that taking the derivative of log-log is different from log-linear. The participant didn't have a fundamental problem with the use of log-log so long as the methods used to derive the fatigue curves, and reasons for using them, are clearly described in the Research Document. The units will make more sense if the starting point is the adjusted equations discussed earlier (i.e., time as a function of speed). The authors will consider the issue of switching the units around to reverse the *x* and *y* axes on the graphs and the equations. They will leave the data representations in the log-log format but provide a better explanation for how and why they took that approach. (See Katopodis and Gervais 2016 for additional statistical analysis addressing this issue.)

The database contains both fixed and increasing velocities. During the fixed velocity test, final swimming time is measured while velocity is fixed whereas during the increasing velocity test, final velocity is measured while time is fixed. Participants thought that using time increments for the fixed velocity test puts an artificial construct on it that introduces error into the analysis. The estimate of error that is introduced is stacked and appears in the R^2 term but if the data had been reported differently, or the experiments performed slightly differently, then some of that variance would have been lost. It was also thought that using fixed time for increasing velocity is not appropriate. A more accurate time period that should be used is the proportion of time to fatigue during the final step.

The authors countered that a fish starts to fatigue during earlier steps although ultimately reaches complete fatigue in the final step. They examined species for which there was both fixed and increasing velocity data and found that for the most part the time step corresponded to where it would fall on the endurance curve so that is why they chose that time step. Participants noted that the time increment could be thought of in terms of someone climbing a set of steps one at a time or ten at a time. The individual climbing ten steps at a time may not get past the first interval. The chosen time interval must have biological relevance as well as the ability to accurately resolve the question of interest. The plots in the PowerPoint presentation show clusters of points with more error than necessary, as a result of including the time interval rather than something more accurate like the proportion of time to fatigue during the final time interval. Unfortunately, the latter information was usually not reported in the literature. It was recommended the authors identify this limitation in the Research Document.

It was noted that the experimental design appears to drive fatigue time. For example, if a fish fatigues at a relatively high velocity and the time step is very long, then one would incorrectly conclude the fish has a long endurance at the high velocity. The report should indicate there is variability in the dataset. The co-chairs asked if there is a better way of describing the limitations of the data. Participants said that unless the data are reanalyzed, the authors should state there are errors intrinsic to the dataset. The authors said it would be possible to calculate what the final time step would be if the starting time and velocity steps and number of iterations are known. Perhaps at lower velocities, fish may not fatigue as much as at higher velocities but each subsequent time step adds to overall fatigue in a fish. Just looking at the final duration of swim time is not valid because fish use both aerobic and anaerobic swimming as they move through the steps. Beamish (1978) had reviewed the relationship between time increment and the final fatigue time. The authors wondered how valid short time steps in the range of 5 minutes would be compared to data generated using longer time steps like 20, 30 and 60 minutes. Participants felt that unless the authors can reanalyze the data or generate new data to supplement the available data, it would be best to indicate there are errors intrinsic to the dataset.

Although the available data have limitations they do provide information about the direction and magnitude of fish swim performance. From the management perspective, any errors should be made on the side of caution to ensure that fish are able to pass. For that reason, the authors tried to provide curves that, if anything, underestimate fish performance. Participants recommended the authors add a statement to the report that fish are more stimulated to move upstream by a stronger current. This means that it is possible to be overly cautious. We have to make decisions in spite of having imperfect knowledge but we have to keep in mind that it is not always true that moving at a slower pace is the precautionary approach. The authors confirmed that for some of the data fewer attempts at passage were made for lower water velocities than higher velocities for some species. A participant reported that skeletal muscle in fish evolved for cruising. Steve Peake's data show that fish can move through higher-velocity channels very quickly and Ted Castro-Santos' data has shown some remarkable swimming speeds.

The participants resumed an earlier discussion about the 30-minutes swim time limit driven by culvert length. One participant said that if the purpose of this time constraint is related to culvert passage, then the topic has been thoroughly discussed already. However, in cases where it may take days for a fish to traverse a large-scale fishway, one needs to be circumspect about using the data. A caveat needs to be added to the Research Document that if longer endurance is required then this model may not be appropriate. The authors responded the database was truncated to 30 minutes for these analyses because of a point made earlier about lower sustained speeds. Also resting areas are usually available to fish in most fishways, with low enough velocities that fish could use non-fatigue sustained speeds for long times, while reserving prolonged and burst speeds to navigate the limited higher water velocity areas. However, the database contains data that could be truncated at a longer time period (e.g., 200 minutes) for other applications (e.g. analysis of sustained fish speeds). Participants agreed that boundaries need to be put around the 30-minutes data in the document to describe their purpose and limitations, and what the analysis is attempting to do.

Identifying features in the dataset that have a bearing on quality of the data (e.g., anesthesia, surgery, tagging, and pollution effects) was raised again. While participants thought it was generally a good idea because it would eliminate the need to consult source papers, it could involve considerable effort by the authors to flag all possible factors that may affect data quality. In older papers, details of this sort often were not provided. The authors agreed that it would be difficult to identify all quality control issues for each and every study included in the database but they could highlight, in a more general sense, the factors that may impact the quality of the data that was included in the database. During their analyses, the authors compared individual data with other data in the database as a measure of its quality. Outliers were investigated more carefully to determine if they should be removed from the database or retained but flagged. The database can be searched and partitioned using the "flag" field, though the field codes are not overly sophisticated. Testing under extreme temperatures is one of the flagged factors.

A final comment was made by a participant about an earlier discussion regarding scaling. Some improvement in the R^2 value gained by trying to get at the dimensionless number is really an artifact of approaching something that is biologically meaningful. The Research Document should explain this ancillary benefit resulting from taking the dimensionless approach. The model used by the authors is one approach and it produced a solution to a problem (normalizing to BL when it was not appropriate) that has been plaguing the field for some time. The model can probably be refined further, using regression that is not dimensionless, to provide more reliable data.

Returning to the topic of dimensionless analysis, a participant reiterated concerns about the physical implications of using gravity as a constant. The participant thought that normalizing swim speed to the square root of BL gives a good correlation but the argument that the Froude number is important is a completely different issue. Another participant said that gravity isn't important to fish and that dimensionless analysis needs biological meaning to justify its use. The authors countered that gravity plays a role in the case of a surface wave, though not if the fish is fully submerged. If there was a surface wave in an open channel, it would have a wave length equivalent to the length of the fish and period equivalent to time. Conceptually it makes sense to compare the speed of the wave to the speed of the fish but it may not biologically.

Another participant had trouble with the physical meaning of celerity scaled with the length of fish. It was not clear how the speed of a wave in deep water is related to something physically meaningful for non-dimensional fish speed. In contrast, the Froude number makes sense. It's a classic non-dimensional parameter used in fluid mechanics to describe sub-critical, critical, and super-critical flow. Participants felt that the example used by the authors caused more confusion than clarity. Fish data were normalized for all studies including those where there was no wave (e.g. respirometer tests), not just studies where waves were dominant. The authors took the approach that whenever a fish swims, regardless of the type of channel, it is compared with a wave in an open channel.

Participants understood what the authors were trying to do, but not all agreed with their approach. From a fluid mechanics perspective it makes sense to use gravity but not from a biological perspective. Thus, some participants wanted the authors to remove gravity. It was suggested that in place of gravity an acceleration term could be added for the sole purpose of getting rid of dimensions. The authors did not try to imply that gravity affects fish but using it as a dimensionless parameter meant that it was *de facto* implied, otherwise it is unclear why it would have been used. The authors tried various parameters including Reynolds number. Gravity yielded the best results. Participants recommended again that the Research Document needs a better description of dimensionless analysis and, in particular, the use of gravity to justify their use, as well as a description of other parameters that were tried and what did and did not work.

An acceleration term related to drag might be useful, in terms of how drag scales with length because area will increase as the square of length. Comparing gravity flow with pressure flow, the gravity term is equivalent to the pressure gradient term, thus, it may be possible to argue that gravity is still relevant. The pressure gradient is driving the flow and it could be equated to what the equivalent gravity term would be. The acceleration term could be used in terms of negative pressure gradient (i.e., pressure flow versus open channel flow). The authors pointed out that regardless of any hydraulic or biological role that gravity may have, the gravitational acceleration was used as a constant in the dimensionless swim speed and swim time and it does not affect the regression results. The statistical strength and variability are a result of the use of the square root of fish length, rather than gravity.

There may be some error associated with the dimensionless analysis that would be better dealt with using regression techniques. There are papers in the literature that talk about the effects of scale on swimming ability. Ultimately, the question of scale will likely get resolved using regression analysis not dimensional analysis. In the meantime, values in this study were assigned to parameters that may have biological relevance but which may get buried as dimensions are eliminated. For this reason, the Research Document should explain in detail how the analyses were conducted.

It was agreed that a summary bullet should be included to say that the Research Document contains baseline information.

A participant asked if the database allows the user to group the data electronically in a graduated step-wise fashion. The database permits this. For example, it contains information about genus and family. The database is currently formatted in Microsoft Access; it is not yet online. The authors extracted the data from Access and analyzed it using statistical software packages. Earlier in the meeting, participants discussed their concerns about data groupings at the highest levels, such as what species to include in the trout and eels groups. The authors said it was necessary to pool the data at those higher levels because finer groupings end-up with gaps in the fatigue curves. Using the trout and eel groups made it possible to see distinct differences between the points while being able to predict the overall fatigue curve. The Research Document contains information for a number of groups (e.g., sturgeons and salmonids).

The co-chairs asked if the participants were comfortable with the way in which the data were presented. Participants recommended not including regressions in the document for cases where only one or two data points are available because they are not informative.

Participants revisited an earlier discussion about the box and whisker plots. The authors confirmed that the predicted swim distance line shows the maximum theoretical distance a fish should be able to ascend over a range of water velocities. This line is based on regression, which is not very tight, so there is a standard error of estimate around the line. Participants asked how the percentage components (i.e., 5%, 25%, 75%, and 95%) were derived. The authors set prediction limits on the regression. They used prediction intervals from speed versus time regressions to derive the distance predictions intervals. They were not specifically trying to identify the percent passage. Essentially they plotted the variance from the mean where they expected passage to be possible. Participants raised the question of the percent passage as a management goal. The authors said that data users will need guidance on this. For example, what percent passage is adequate for a fish population? Participants noted that the method used to develop the box and whisker plot does not provide that information. They recommended the Research Document clearly explain that the prediction lines show the maximum distance, with confidence intervals, that should be passable not the proportion of the population passed. This has important implications for how the data can be used for management purposes.

The summary and conclusions bullets presented by the authors at the end of their PowerPoint presentation were reviewed. Participants reiterated the need to identify data quality and gaps in the Research Document. Earlier in the meeting, participants had discussed the value of starting the analysis at the species level and then grouping species together as necessary for subsequent analyses. Participants discussed the bullet that said “there is insufficient data available for many species to derive individual fatigue curves”. One participant felt that language was a bit loose. The PowerPoint presentation showed that fatigue curves for some species, based on data from various studies, are relatively tight and follow the same lines. Those data are of sufficient quality that managers can use them to answer questions about fish passage for those species and perhaps for other related species too. Participants recommended adding a table to the document showing the quality of data (e.g., no data or weak, satisfactory or good data) that would inform the reader about whether the data are sufficient for drawing conclusions. Participants also recommended adding text about whether there are similarities in the data that are likely to emerge. For example, could good data from Brown Trout be extrapolated for all trout?

Participants raised the point that using a broad-brush approach, as the authors have done, eliminated the influence of temperature. Different stocks of Sockeye Salmon have been shown to have different temperature profiles. When optimum swim performance curves that look quite different are lumped together and used to derive the fatigue curves, the resulting noise in the curves may lead to false conclusions. The authors used temperatures in the normal range encountered by respective fish species and excluded experimental data intended to demonstrate temperature effects outside this range, so the relationships developed should only be used for the normal temperature range of each species. Salmon show little acclimatization compared to other species. Swim performance appears to be less susceptible to temperature at sprinting speeds than at the slower speeds because the white muscle used during short-duration sprints operates with a very low Q_{10} effect. The problem is that a fish forced to sprint must recover aerobically and the Q_{10} effect on aerobic recovery is quite different. It is possible for a fish to successfully pass through a culvert but not recover afterwards. Thus, swim performance can be assessed at two levels:

(1) can a fish pass through a structure and

(2) does it survive afterwards.

Participants recommended the authors discuss in the Research Document how temperature would affect the fatigue curves based on what is known about biochemistry. That is, there may be little effect on a fish while sprinting but more significant effects during the recovery period if the fish has been pushed to its limit.

The remaining conclusion bullets were reviewed starting with the one about significant speed-time regressions. Participants previously agreed that the eel and trout group names should be changed to low and high performance groups, respectively. They also recommended the authors separate or group species for the speed-time regressions according to what makes the most sense. The conclusion about variability in swimming performance was also reviewed. No revisions were suggested.

The conclusions about deriving fatigue curves from dimensionless quantities were then discussed. The net effect of using a dimensionless approach results in good correlations and reduction in variability (from roughly two orders of magnitude to one order or less depending on the species). Participants re-iterated the need for thorough descriptions of what analyses was done and why in the document. A participant recommended including some additional analysis for one or two data-rich groups, using the square root of length instead of gravity, for illustrative purposes. The square root of length is probably more appropriate for scaling. This additional analysis would provide an intermediate step between log-log and wave theory that would increase the reader's confidence in extrapolating to the theoretical analysis. The authors agreed to produce these additional graphs in the revised Research Document. The results were expected to be very similar. A participant asked if the authors had any juvenile data to compare with the adult data. The authors said the dimensionless analysis brought juveniles and adults in line with each other because scaling took body length into account.

Participants discussed the conclusion about speed-time regressions providing estimates of swim distance. As noted earlier in the meeting, the method used to measure swim speed affects the results. For example, volitional data show that fish have higher swim performance capabilities than is usually reported in the forced swimming data. Swim tunnels tend to underestimate swimming ability. Additionally, most fish deviate from the optimal swim curve. So when predictions line up with observations, it may be coincidental. Maximum theoretical distance should far exceed what fish actually do because fish typically fail to optimize their swim performance. The results presented here are good enough to be used for management purposes but there should be a caveat in the document that indicates that some the data included in the analysis are from swim chamber studies in which fish do not swim their optimum distance. Explicit statements about the limitations of the data are needed in the document. Most of the dataset probably pre-dates the recent research that demonstrated the importance of gait transition. Participants recommended the authors also include citations or personal communications related to the gait transition research. Researchers who conducted early work in Scotland using a swimming wheel, trained fish to use a visual cue (flashing light) to stimulate swimming. One such study reported a swim speed of 30 BL/s per second.

Participants recommended the authors separate the conclusions of their work from the limitations. The limitations should be put in a separate section of the report.

The Research Document said the results of this study could be used as a guideline to exclude fish from an area. If fish have a higher swimming performance than indicated by the study results, as thought, then these data should not be used as the basis for making decisions about exclusion. The authors said the upper limits of the curves should be used for exclusions, not the lower limits. Participants recommended extreme caution in using the curves to address velocity barrier questions, otherwise fish will pass rather than being blocked as intended. The negative consequences of unintended passage could be significant. The study was designed to answer questions related to fish passage not exclusion of exotic or invasive species (e.g., Asian Carp). The data are based on studies designed to have fish swim fast but we cannot be certain that fish are incapable to swimming faster. Assessing fish exclusion depends on a very different null hypothesis than what was used here to assess fish passage. Thus, the results of this study can be used to assess fish passage, though with some caution, but should not be used at all for fish exclusion because it would depend on extrapolation. That having been said, using velocity as a barrier or filter for fish exclusion has potential. Participants recommended including this information in the Research Document.

The meeting Proceedings and Science Advisory Report will be drafted and distributed to participants for their comments. The authors will update their document into a CSAS Research Document based on the meeting discussion. The meeting documents are not intended for practical applications by habitat practitioners. Participants recommended including that a note to habitat managers in the Research Document so they are made aware of limitations of the study and do not use the results in unintended ways. The value of the study results should also be highlighted in the Research Document.

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APPENDIX 1. TERMS OF REFERENCE

Terms of Reference

Advice on Fish Swimming Performance Curves

Central and Arctic Regional Advisory Meeting

Teleconference and WebEx

9:30 a.m. to 4:30 p.m. (Central Standard Time) on 9 February 2011

Co-chairs: Kathleen Martin and Roger Wysocki

Background

Fisheries and Oceans Canada (DFO) Central and Arctic (C&A) Habitat Management (HM) staff are required to review and/or provide advice on fish passage design criteria. To assist them with this work, two C&A HM staff developed fish swimming performance curves that estimate swimming distance, as a function of water velocity, for various groupings of fish species using data collected from the literature. The curves are intended to serve as guidelines in terms of water velocity criteria for fish passage, exclusion, and guidance systems such as fishways (including culverts), fish screens, fish barriers (including sea lamprey velocity barriers), and fish louvers.

C&A HM has requested advice from Science sector on whether the fish swimming performance analysis and results are credible and conclusions drawn are scientifically sound. Advice resulting from the science advisory meeting will be used to identify any problems and limitations with the analysis. The fish swimming performance curves will become the basis for guidelines developed by DFO C&A HM for reviewing or providing advice on fish passage design criteria.

Objectives

The objective of the meeting is to provide advice on the following aspects of the working paper drafted by Katopodis and Gervais:

- completeness of the database used to develop the fish swimming performance curves,
- scientific validity of the analysis, results and conclusions reached, and
- limitations of the study.

Expected publications

The Regional Advisory meeting will generate a proceedings report that summarizes the discussions of the participants. It will be published in the Canadian Science Advisory Secretariat (CSAS) Proceedings Series on the CSAS website. Advice resulting from the meeting will be published as a Science Advisory Report and the working paper reviewed at the meeting, which provides the support for the advice, will be published as a CSAS Research Document.

Participation

DFO Science and Habitat sectors, U.S. Geological Survey and academia are invited to this advisory meeting.

Working paper

Katopodis, C. and R. Gervais. Fish swimming performance data base and analyses. Draft report.

APPENDIX 2. MEETING PARTICIPANTS

Name	Affiliation
Glenn Cada	U.S. Department of Energy, Oak Ridge National Laboratory, Oak Ridge, TN
Theodore Castro-Santos	S.O. Conte Anadromous Fish Research Center, U.S. Geological Survey, Turners Falls, MA
Holly Cleator	Fisheries and Oceans Canada, Winnipeg, MB
Marie Clement	Fisheries and Oceans Canada, Moncton, NB
Aline Cotel	University of Michigan, Ann Arbor, MI
Eva Enders	Fisheries and Oceans Canada, Winnipeg
Tony Farrell	University of British Columbia, Vancouver, BC
Richard Gervais	Fisheries and Oceans Canada, Winnipeg
Wolfgang Jansen	North/South Consultants Inc., Winnipeg, MB
Chris Katopodis	Katopodis Ecohydraulics Ltd, Winnipeg, MB
Kathleen Martin (co-chair)	Fisheries and Oceans Canada, Winnipeg, MB
Vincent Neary	U.S. Department of Energy, Oak Ridge National Laboratory, Oak Ridge, TN
Peter Schweizer	U.S. Department of Energy, Oak Ridge National Laboratory, Oak Ridge, TN
Karen Smokorowski	Fisheries and Oceans Canada, Sault Ste. Marie, ON
Evan Timusk	Fisheries and Oceans Canada, Sault Ste. Marie, ON
Christian Turdorache	Leiden University, Holland
Roger Wysocki (co-chair)	Fisheries and Oceans Canada, Ottawa, ON

APPENDIX 3. AGENDA

Advice resulting from a peer review of fish swimming performance curves

9 February 2011

Teleconference and WebEx

9:30 a.m.	Introductions and opening remarks (co-chairs)
9:50	Presentation (Katopodis and Gervais)
10:35	Questions about presentation
10:50	Completeness and appropriateness of data included in the database used to develop the swim perform curves
11:10	Scientific validity of the data analyses used to process data • individual species data • dimensionless variables
11:45	Lunch
12:45 p.m.	Data analyses (continued)
1:15	Scientific validity of conclusions reached
2:15	Latest methodologies used to evaluate fish swimming performance
2:45	Coffee break
3:00	Limitations of the study
3:30	Conclusions
4:00	Closing remarks (co-chairs)
4:15	Meeting concludes