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Central and Arctic Region

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ASSESSMENT OF FISH SWIMMING PERFORMANCE CURVES

Figure 1. An example of a volitional flume. This temporary experimental open channel was constructed at the Noel Paul's Brook Research Facility in central Newfoundland, Canada (photo by M. Colavecchia). Published swim data obtained from this and various others types of experimental set-ups were included in the database compiled and used in this study to develop fish swim performance curves.

Context:

Fisheries and Oceans Canada (DFO) Habitat Management (HM) staff are required to review and/or provide advice on fish passage design criteria. Central and Arctic HM staff wanted to address information gaps related to swimming ability of fish as part of the assessment and mitigation works performed in the region. To assist them with this work, fish swimming performance curves were developed that estimate fish speed as a function of swim time and swimming distance as a function of water velocity for various groupings of fish species using an extensive database generated from the literature. DFO Science was asked to assess whether the analyses and results of the study are credible and conclusions drawn are scientifically sound, and to identify any problems and limitations with the analyses. This Science Advisory Report is from the February 9, 2011 meeting about Advice on Fish Swimming Performance Curves. Additional publications from this meeting will be posted on the DFO Science Advisory Schedule as they become available.

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SUMMARY

- An extensive database on fish swimming performance representing 132 freshwater and diadromous species was generated from the literature, based on a variety of fish swimming performance tests, which produced a mix of mean and individual swimming data.
- Combining high speed (sprint or burst) data collected in volitional swim tests in open channel flumes with the moderate (prolonged) speed data collected from tunnels (swim chambers), made it possible to define fatigue curves over a larger time range and helped to eliminate some bias.
- Fatigue curves were derived using three methods: swim time (or endurance) versus speed as a function of body length, swim time versus speed as a function of the square root of body length and dimensionless analysis using a dimensionless speed formulated by including the gravitational acceleration constant in the square root of body length.
- Fatigue curves generated using dimensionless variables produced more accurate estimates of performance for a range of fish sizes, swim times and swimming speeds compared to traditional methods.
- Although large variability in swimming performance exists between species and individuals, the data analyses indicated broad similarities in relative performance for groups of species. Significant speed-time regressions were developed for both weak and strong swim performers.
- Data were of sufficient quality for some species to permit the development of individual fatigue curves. Where insufficient data are available, dimensionless fatigue curves for groups of species with similar swimming characteristics may provide reasonable estimates for such species in cases where the quality of the available data is good.
- Speed-time regressions were used to provide estimates of swim distance-water velocity relationships for different confidence levels. Swim distance estimates from fatigue curves compared well with available direct measurements.
- The results of these analyses may represent the best information currently available to address fish passage questions given limitations of the database and analyses. They should not be used to assess situations where fish need to be excluded (e.g., invasive species).

INTRODUCTION

Freshwater and diadromous fish typically make localized movements and/or migrate between habitat types in order to complete their life cycle. In places where obstructions occur, fish may require passage in the form of fishways or bypasses to assist their movement upstream or downstream. Estimates of swim fatigue time or distance would be useful when considering physiological aspects in practical applications such as fish screens and fishways.

DFO Central and Arctic HM staff are required to review and/or provide advice on fish passage design criteria. To assist them with this work, fish swimming performance curves were developed that estimate fish speeds versus swim times, and curves of swim distance versus water velocity, which are useful for fishways and fish screens. Such fish swimming performance curves were developed for various groupings of fish species using an extensive database generated from the literature. This document provides advice on the completeness of the database, the scientific validity and limitations of the analyses and the results and conclusions associated with the fish swimming performance curves. Full details of the methods, analyses, and results of the study are available in Katopodis and Gervais (2016).

ASSESSMENT

Database

Most data included in the extensive fish swimming performance database were obtained from North and South American, Asian, European, and Australian studies reported in English language publications in peer-reviewed journals and some grey literature. The focus was on publications that contained swim time or swim distance measurements for freshwater species and species that included fresh water in their life cycle (e.g., diadromous[1] species). Most data extracted from the literature were in the form of processed data where performance results are reported as mean values with standard deviations or errors. Results published in literature are usually a summary of the measurements that were obtained from a particular experiment or trial where a number of individual fish were tested. The overall performance of the group is summarized and reported using statistical values. Variation in swimming ability between individual fish can be quite variable and testing of multiple fish is required to obtain realistic estimates of performance for a group of fish. Data grouping for a particular experiment or test is usually based on individual fish that are very similar (same species, similar in size and usually from the same population) and subjected to identical rearing and testing. Some performance data for individual fish were collected from the literature or obtained via data requests, however much of the raw data were not available. The lack of raw data is one of the limitations of this analysis.

Several criteria were used to screen data for the database to ensure scientific rigour. Fish swimming performance data found in the literature reflects a diverse range of experimental objectives. Swimming performance has been used to assess the effects of contaminants, water temperature, diet, training, tagging, and a variety of other factors. Data used in the analysis was screened to exclude any results that were based on experiments where the performance was significantly affected by external factors such contaminants, extreme temperatures or other treatments that were outside what fish would normally experience. Only data for the control or untreated group was used in the analysis; however treated data were used if it was reported to be not statistically different from the untreated group. Individual data were then compared with other data in the database as a measure of its quality.

Outliers were investigated to determine if they should be removed or retained. Flags were added to the database to signal factors that may affect data quality such as incomplete data or if the test fish had been subject to anesthesia, surgery or tagging. The database can be searched and partitioned using the flag field. Flags were used to code and screen certain data that had been entered into the database and that were found to be incomplete, incorrect or not relevant as the analysis of the data proceeded. For example, marine species that had been initially entered into the database were flagged and excluded from further analysis at this stage. The decision to focus on freshwater and diadromous species was based on DFO staff needs, since these are the species which are involved in most projects with fish passage issues and to limit the extra time and effort that would be required to include marine species. Swim data obtained from the published literature were collected through a variety of fish swimming performance tests, which tended to cover different parts of fatigue curves. Most swim data in the literature are based on forced swimming tests which are conducted in the laboratory using a stamina tunnel or rotating swim chamber. Forced swimming tests are conducted by either using a fixed velocity (endurance test) or an increasing velocity protocol. The latter is typically used to determine what is referred to

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[1] Diadromous fishes migrate between saltwater (i.e., the sea) and freshwater.

as critical velocity. These swimming tests produce data mainly in the prolonged range. Fish in forced swimming tests may be unable to express their optimal swimming performance because of behavioral limitations (see below).

Forced swimming performance tests have been used longer and more extensively than volitional tests (which are more recent) and in general measure performance in the moderate to lower range of swimming speeds (speeds that can be maintained for many minutes to hours). As a result fewer data are available from volitional swimming tests and they represent a smaller proportion of the data included in the database. In those tests, swim distance or time is measured for fish swimming upstream against a controlled water velocity in an open channel or culvert with the attempt at passage at the discretion of the fish. Volitional tests using a channel or culvert tend to involve relatively short distances (i.e., < 100 m) and swimming times in the range of a few minutes or less. Compared to swim chambers or tunnels, open channel raceways provide more variable velocities and turbulence, hydraulic conditions which may enhance passage and produce positively-biased results. Recent work indicates that fish can optimize their swim performance in volitional channel tests. In the opinion of some researchers, fish behaviour associated with gait transition may be restricted in swim chambers, which may produce negatively biased results. Within limits, flume length in volitional tests does not seem to affect gait transition speed or limit performance, such as fatigue, but reflects constraints on swimming behaviour.

A 20-second threshold has been used in much of the literature to distinguish between burst and prolonged swim speeds in juvenile Sockeye Salmon (*Oncorhynchus nerka*). This threshold was not used in this study because it may not apply for all species. Extrapolating fatigue curves derived from only swim tunnel data would underestimate burst performance because these data are characterized by flatter slopes. Extrapolating fatigue curves derived from only volitional channel data would underestimate prolonged performance because these data are characterized by steep slopes. For these reasons, both types of data were used to define the entire fatigue curve for a species. Combining forced and volitional swim data helps to define the entire fatigue curve but the limitations of forced and volitional swimming tests should be recognized as they may influence the results.

The pre-processed database, representing 131 fish species[2], contained swim times of less than 150 minutes. As fish can swim at low sustained velocities for an indefinite period of time, at least theoretically, a swim time limit of 30 minutes was applied to the data analyses presented. The 30-minute limit was based on a practical consideration that it is unlikely a fish will require more than 30 minutes to swim in front of a typical fish screen or through a section of a fishway or a culvert. However, a fish may take much longer (e.g., days) to traverse a large-scale fishway. Data collected from the literature for 131 fish species included burst, prolonged and sustained swimming speeds that correspond to swim times that ranged from seconds to hours. The analysis was restricted to swimming data that was 30 minutes or less in duration. The 30 minute time limit for endurance was based on design considerations for fish passage and protection facilities, where the design of such structures to handle swimming speeds that exceed 30 minutes (continuous swimming) are both challenging and expensive to produce. Although unlikely, for applications where longer endurance is required, especially for small fishes that typically swim more slowly, applicability of the data may be limited.

Although the database has limitations, it provides information about the range and magnitude of fish swim performance for a large number of fish species.

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[2] Original working paper identified 82 species. Revisions following the meeting increased the number of species to 131.

Analyses and results

The data obtained from the literature contains a mix of mean and individual swimming data. In an effort to improve the consistency of the data used in the analysis, certain datasets that held individual fish measurement data were reformatted by grouping the data in a manner that was similar to other grouped datasets collected from the literature. Grouping was performed at the dataset level (i.e., from a specific paper or publication) where individual measurements from a group of fish subjected to the same tests and where differences in fish length, water temperature, swim speed or time were 10% or less.

Mean values were used for these grouped data. Median values were used for some fixed-velocity tests where time to fatigue was measured and some fish in the test group swam beyond the time limit of the test. Data obtained from culvert passage studies were not directly used to derive fatigue curves because they are subject to variable velocities and turbulence within the culvert and allow fish to take advantage of more favourable hydraulics. Measurements from culvert passage studies were used to check prediction-derived distance equations.

Traditional fatigue curves, with endurance time plotted as a function of swim speed (commonly calculated in body lengths per second) have been reported in the literature. However complete fatigue curves are available for very few species and most commonly are limited in the range of fish lengths and endurance times. In an effort to improve the accuracy of performance estimates derived from traditional fatigue curves, a series of new relationships based on dimensionless parameters were tested. Different dimensionless parameters were developed and tested by comparing the predicted results over the range of fish sizes, fatigue times and swimming speeds. The correlation coefficient was not the only factor that was used to pick the best relationships.

Insufficient data were available in the published literature for many species from which individual fatigue curves could be derived. The relationship between swim speed, normalized as a function of body length and swim time were calculated for all fish species combined and resulted in relatively low R^2 values. Next, swim speed was normalized as a function of the square root of body length which led to relatively high R^2 values. Furthermore, swim speed was made dimensionless by including gravity in the square root of length, which led to similarly high R^2 values, as the gravitational acceleration is constant. This dimensionless analysis of fatigue curves was undertaken because it permitted the use of the maximum amount of data available, therefore allowing a more global analysis for groups of fish species of similar performance and hydrodynamic similarity, as well as better scaling for different fish lengths. Additionally, dimensionless analysis also provided the ability to use limited datasets and extrapolate to cases where good quality data are not available. This made it possible to combine all available swim performance data to build more general swimming speed-versus fatigue time curves.

The relationship between the circumference of a circle and its diameter was used as a simple analogy to explain dimensionless analysis. More complex and more closely connected analogies include the relationship between drag coefficient and Reynolds number[3] given its relevance to hydrodynamics and fish movement.

It is worthwhile to note that swimming performance measures such as fatigue time are dependent on fish physiology as well as hydrodynamic characteristics. An ecohydraulic[4] approach was used

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[3] In fluid mechanics and hydrodynamics, the Reynolds number is a dimensionless number that gives a measure of the ratio of inertial forces to viscous forces and consequently quantifies the relative importance of these two types of forces for given flow conditions.

[4] 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.

in combining hydrodynamic and physiological variables to formulate the dimensionless analysis. Several dimensionless parameters, including Reynolds number, were tried. A fish speed which includes the gravitational acceleration was chosen because it is a relatively universal constant and important in terms of wave motion. Additionally, it yielded the best results of the parameters tested. The speed of a wave (i.e., celerity) is proportional to the square root of gravity multiplied by wave length. The analysis draws an analogy between a swimming fish and a wave moving in an open channel. While this analogy may be more apparent in volitional open channels and more ambiguous in the case of enclosed swim chambers, gravity is included in dimensionless friction factors for pipe flow as well (e.g., Moody diagram). It is not clear what the biological value of gravity is and the relationship of Froude number[5] to swimming performance may warrant further investigation. An acceleration term related to drag might also be useful for future investigations given that drag scales with length.

The data grouping process was complicated by data limitations, as groups were further refined by drilling down to smaller subgroups. The lack of data tended to cause an imbalance in the overall fatigue curve. The original presentation and working paper were based on only two broad groups of species classified as Trout and Eel groups, to reflect the dominant category of species in each group. It was recommended these groups be renamed high and low swim performance groups to avoid confusion given the mixture of species pooled together, especially in the so-called Trout group. Following recommendations made at the review some additional work on data grouping with extra data obtained from the literature resulted in the creation of six groups: Catfish and Sunfish Group; Clupeidae (Herring) Group; Eel Group; Pike Group; Salmon and Walleye Group and Sturgeon Group (Katopodis and Gervais 2016). The database was subsequently divided into increasingly smaller groups of fishes based on characteristics that suggested similar modes of locomotion.

The objective of dividing the database from one large group into smaller ones was to improve the R^2 value and standard error of estimate for the swimming speed versus fatigue time regressions until the point was reached at which limitations of the dataset exceeded any additional gains. The first division of the database presented problems because both groups contained a wide range of species, some of which used different modes of swimming. Grouping on the basis of kinematics (i.e., number of waves per body length) may be more appropriate if kinematic information is available.

The length of time it takes for a fish to fatigue was examined in relation to how fast it swims. The relationship between swim speed, as a function of body length, and swim time, at the species level, for 122 fish species combined was relatively weak for both the unweighted and weighted (by sample size) data. The R^2 value for the weighted points was 0.244. Analysis of the same data using dimensionless variables yielded a significantly higher R^2 value of 0.617 for the weighted points. Similarly, the “Trout Group” consisting of 65 of the 76 species had R^2 values of 0.354 when swim speed was expressed in body lengths per second compared to 0.730 when swim speed was expressed as a function of the square root of body length or as the dimensionless speed (including gravity in square root of length).

Knowledge of scaling has improved immeasurably since the traditional approach was developed to express swim speed as a function of body length. Dimensionless analysis normalizes swim speed to the square root of body length which better reflects the effects of scaling on locomotion according to current knowledge of fish physiology. The dimensionless analysis brought the data

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[5] The Froude number is a dimensionless number defined as the ratio of a characteristic velocity to a gravitational wave velocity. In fluid mechanics, the Froude number is relevant where the weight of the fluid is an important force, and is used to determine the resistance of an object moving through water, and permits the comparison of objects of different sizes.

for juvenile and adult fish in line with each other because scaling accounted for differences in body length. Improvement in the R^2 value gained from dimensionless analysis was likely a result of applying a more biologically meaningful approach than the traditional body lengths per second method. The net effect of using dimensionless analysis was establishing overall trends and producing relatively good correlations and reductions in variability. While dimensionless analysis can be used as a tool for analyzing fish swim performance data, it has limitations. There are likely better ways of deriving relationships to account for more variability in the model. For example, the information-theoretic approach could be used to build regression models that would potentially offer better parameters for estimating scale effect and may produce even more accurate results.

Significant speed-time regressions were developed for the weak and strong swim performer groups. Broad similarities in relative performance within the two groups of species were detected despite variability in swimming performance between species and individuals within species. Both the body length and dimensionless analysis showed the weaker swim performer group had lower swim speeds than the stronger group, suggesting there is value in developing separate fatigue curves for both groups. Further subdivision of the dataset into smaller groups produced some improvement in the R^2 value though obvious differences in regression slope were detected within some groupings (e.g., sturgeon versus eel species). The results of the reanalysis following the meeting using different grouping of species are presented in Katopodis and Gervais 2016.

A more rigorous approach to analyzing the data was recommended, starting at the species level. R^2 values for speed-time regressions calculated for individual species should be compared to determine if they are significantly different. Similar species can be grouped together as appropriate for subsequent analyses (see Katopodis and Gervais 2016).

A comparison of the swimming performance data for sub-carangiform/labriform (SCL) and carangiform swimmers showed there are more published data available for SCL swimmers. However, some labriform swimmers are mostly limited to the prolonged swim range thus the burst end of the spectrum is underrepresented and swim performance may be underestimated. Less swimming data are available for carangiform swimmers and they are mostly limited to the burst swim range but have less variability than the SCL data. In these cases, relying on swim performance data from only one group would limit usefulness of the results. By combining groups the weaknesses within individual datasets are balanced out. The updated database (Katopodis and Gervais 2016) groups all subcarangiform swimmers together and names them “Salmon and Walleye Group”. They include sufficient burst and prolonged data to derive balanced fatigue curves with an R^2 value of 0.70 when swim speed is expressed as a function of the square root of body length (and 0.31 when swim speed is expressed in body lengths per second).

In this study, the fatigue curve regressions were calculated for various groupings of species using a log-log scale analysis because it allowed the data points to spread out thereby making them easier to see. This approach may account for why the burst and prolonged data could be fit to a straight line. Fatigue curve regressions are typically analyzed using a log-linear scale (i.e., the log of time is a linear function of swim speed expressed in body lengths per second), which is more consistent with failure time theory in terms of the expected distribution. Since the log-log approach may affect the results obtained a discussion and more detailed explanations of, and justification for, this approach is included in Katopodis and Gervais (2016).

Swim performance can be affected by temperature. This study excluded data collected under very high and very low temperatures or when investigating the effects of temperature. Swim performance appears to be less susceptible to changes in temperature at sprinting speeds than at slower speeds because the white muscle used during short-duration sprints operates with a very low Q_{10} effect. Thus, there may be little effect on a fish while sprinting, however, there may be more significant effects during the recovery period if the fish has been pushed to its limit. It was recommended the Research Document discusses how temperature would affect the derived fatigue curves given current knowledge of fish biochemistry.

Swim performance data for some species (e.g., White Sucker, *Catostomus commersonii*, and Sea Lamprey, *Petromyzon marinus*) clustered relatively tightly along the fatigue curve regression line, suggesting those data are of sufficient quality to answer questions about fish passage for those species and perhaps other related species. In other species (e.g., Rainbow Trout and Steelhead Trout, *Oncorhynchus mykiss*), there was large variability in individual swimming performance. Species for which there were insufficient data to derive individual fatigue curves should be pooled to make it possible to predict the overall fatigue curve. A table should be added to the Research Document showing the quality of data (e.g., none, weak, satisfactory or good) for each species to inform the reader about whether it is sufficient for drawing conclusions. It should also be noted when similarities between species may permit extrapolations from one to another. For example, can the good quality data from Brown Trout (*Salmo trutta*) be extrapolated for all trout? It was recommended that regressions not be included for cases in which only one or two data points are available because they are not informative.

Estimates of fatigue time and swim distance have practical applications when considering the physiological aspects of fish passage. For that reason, the fatigue (speed-time) curve regressions were converted into swim distance-water velocity curves. The prediction limits were based on all species. The derived swim distance data was relatively comparable to direct measurements of swim distance data, although some discrepancies were evident. For example, the field-measured data only cover the 25% to 75% percentiles of the predicted data suggesting there is considerable error in the projections. However, maximum theoretical distance should exceed what fish actually do because they typically fail to optimize their swim performance. Another noticeable irregularity in the derived swim distance-water velocity curves was the 25% percentile at higher velocities matches the 75% percentile at higher swim distances suggesting there are important limitations of the model.

Overall, the swim distance results presented in the study are of sufficient quality to be used for management purposes once the following recommendations have been met. Comparison of actual versus estimated swim data should be performed for smaller groupings of fishes so that variance in the predicted data can be better understood. The method used to derive the distance curves needs to be explained more thoroughly. It was also recommended the Research Document clearly explains that the prediction lines in the box-and-whisker plot show the maximum distance, with confidence intervals, that should be passable for fish not the proportion of the population that passed. This has important implications for how the data can be used be management purposes.

Several additional recommendations were made for general improvements to the Research Document. The diverse and variable swim performance database needs to be translated in such a way that the data are more accessible. The goals, rationale and assumptions of the data analyses need to be better explained. Limitations of the analyses need to be explicitly quantified or qualified.

The results of this study represent the best information currently available on the range and magnitude of swimming performance for many fish species, although the database and analyses have limitations. Data for individual fish species should be used when available. Recognizing that data are not always available for a species and broad similarities exist among species, it may be possible to use data from a pooled set of fish species if necessary. Otherwise, data must be collected to fill the knowledge gap.

This study was designed to answer questions related to fish passage not the exclusion of exotic or invasive species. The database was comprised of studies designed to have fish swim quickly but we cannot be certain they are incapable of swimming faster. For that reason, it is recommended the results of this study may be useful for fish screens and low risk fish exclusion but should not be used to answer questions about high risk fish exclusion of exotic or invasive species. The negative consequences of unintended passage of exotic or invasive species could be significant. That having been said, using velocity as a barrier or filter for fish exclusion may have potential, so information about this should be included in the Research Document.

Sources of Uncertainty

Some of the experimental methods used in the swimming performance literature produced intrinsic errors, and increased variability in the database and uncertainty in the study results. Reanalysis of the data, or generation of new data to supplement the available data, would be required to overcome these types of intrinsic errors in the database.

Sources of uncertainty include the interpretation of data from critical swimming speed tests in terms of endurance and where these data would fit on the fatigue curve. Limitations in the existing data from volitional channels and the lack of additional data are also sources of uncertainty in terms of the performance estimates. Another potential source of uncertainty is the limited actual swimming distance data to more adequately verify swim distance estimates using swim speed and endurance time.

Swimming performance depends on factors which cannot be measured conclusively. Actual fish passage structures often generate non-uniform flows (i.e., hydraulic conditions which defer from those tested in any swimming performance device). The data used to derive performance estimates were based on testing where flow conditions were fairly uniform and the application of these results to flows that are highly turbulent may result in inaccurate estimates.

CONCLUSIONS

An extensive database on fish swimming performance was generated from the literature for 131 freshwater and diadromous species. Data were collected through a variety of fish swimming performance tests, which tended to cover different parts of fatigue curves. Criteria were used to screen and assess the quality of the data. After updating the database following the meeting, 122 species (processed data) were included in Katopodis and Gervais (2016). Since the database contains a mix of mean, median and individual swimming data, the latter were converted to mean or median values for consistency.

Combining burst speed data with prolonged speed data, made it possible to define fatigue curves over a larger time range and eliminate biases associated with using only one type of data. However, questions of fish behaviour associated with gait transition remain for forced speed tests. Similarly, effects of variation in water velocity and turbulence may influence accuracy of fish performance measurements in open channels. Both swim chambers and open channels present hydraulic conditions which are more uniform than those through fishways. Such limitations, in addition to other biological and hydraulic factors, contribute to variance in fish swim speeds and fatigue times. Therefore swimming performance estimates are not exact but vary intrinsically as well as with the hydraulic conditions fish navigate through.

A swim time limit of 30 minutes was applied to the database for practical considerations. For applications where longer endurance is required, especially for small fishes that typically swim more slowly, applicability of the data may be limited.

Fatigue curves were derived using three methods: swim time versus speed as a function of body length, swim time versus speed as a function of the square root of body length, and dimensionless analysis using a dimensionless speed formulated by including the gravitational acceleration constant in the square root of body length. There are insufficient data available for many species to derive individual fatigue curves. An ecohydraulic approach using the dimensionless speed allowed more global data analyses for groups of fish species and the ability to use limited data sets.

Although variability in swimming performance exists between species and individuals within a species, data analyses indicated broad similarities in relative performance for groups of species. Significant speed-time regressions were developed for both weak and strong swim performers. Smaller groupings may produce slight improvements in regressions.

Data were of sufficient quality for some species to permit the development of individual fatigue curves. Where insufficient data are available for smaller groups or individual species, dimensionless fatigue curves for groups of species with similar swimming characteristics may provide reasonable estimates in cases where the quality of the available data is good.

Speed-time regressions provided estimates of swim distance-water velocity relationships for different confidence levels. Swim distance estimates from fatigue curves compared reasonably well with available direct measurements.

Although there are limits and uncertainties associated with the database and analyses, the results of this study provide information about the range and magnitude of fish swim performance. Specific endurance and/or distance curves are available for some species that can be applied in a practical way. The results of this study should not be used as a guideline for exclusion of exotic or invasive fish species.

SOURCES OF INFORMATION

This Science Advisory Report is from the February 9, 2011 Advice on Fish Swimming Performance Curves. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

Katopodis, C., and Gervais, R. 2016. Fish swimming performance data base and analyses. DFO Can. Sci. Advis. Sec. Res Doc 2016/002. vi + 550 p.

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