The development and application of a length-based method to estimate the spawning potential ratio in data-poor fish stocks

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Declaration

I declare that this thesis is my own account of my research and contains as its main content work which has not been submitted for a degree at any tertiary education institution.

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Abstract

Although they support many millions of people, the vast majority of the world's fisheries are small-scale and data-poor, and without the resources or data systems needed for comprehensive stock assessments. There is strong evidence that unmanaged fisheries are a recipe for disaster, with over-exploitation of the stock almost inevitable. Additionally, it is increasingly recognised that the spatial scale of the stocks of many marine species is much smaller than previously thought, which adds another layer of cost to the stock assessment process, as the cost of collecting and analysing such fine-scale data is prohibitive. The overall aim of this thesis was to develop and test novel methods of stock assessment for data-poor and small-scale fisheries, based on the basic biological characteristics of the exploited species.

Knowledge of the basic biological parameters of fish stocks, such as the natural mortality rate (M), the growth parameters (commonly described by the von Bertalanffy equation, L_∞ and k), and the length at maturity (L_m), is important for many stock assessment methodologies. However, collecting such information is costly, and usually requires sophisticated ageing studies. I conducted a meta-analysis of over 120 marine species, from a range of taxa including teleosts, chondrichthyans, mammals and invertebrates, and examined the variation and patterns in the life-history ratios, and the relationships between size and spawning potential (Chapter 2). These patterns were examined by standardising the age and size of each species so that the relationship between size and spawning-per-recruit for a large range of diverse species could be compared on the same scale. This meta-analysis demonstrated that species that are often considered to be quite different, essentially have the same life-history strategy when viewed on the same relative scale. For example, tuna can be considered as 'larger, slower', anchovies, while prawns are 'smaller, faster' versions of fish. Additionally, and somewhat surprisingly, a number of teleosts with low $\frac{M}{k}$ values of ≤ 0.5 appear to have life-histories similar to marine mammals, and quite different from those expected of fish. The results of this study suggest that there is potential to establish a theoretical framework for 'borrowing' knowledge from well-studied species to apply to unstudied species and populations as an initial starting point for management.

The ratios of these parameters $\left(\frac{M}{k} \text{ and } \frac{L_m}{L_\infty}\right)$ are less variable between individual stocks of the same species than the individual parameters, and certain values of these ratios $\left(\frac{M}{k} = 1.5 \text{ and } \frac{L_m}{L_\infty} = 0.66\right)$, known as the Beverton and Holt Life History Invariants (BH–LHI) have been used commonly to provide preliminary estimates of unknown parameters. However, many species have life-history ratios that vary considerably from the BH–LHI, and in this study I demonstrate the link between variation in the ratios $\left(\frac{M}{k} \text{ and } \frac{L_m}{L_\infty}\right)$ and the life-history strategy of a species. For example, species with low $\frac{M}{k}$ $\left(\text{e.g., } \frac{M}{k} \leq 0.5\right)$

mature, and reach maximum size, early in life; i.e., have determinate growth and unfished populations dominated by large, mature, individuals. Conversely, species with higher $\frac{M}{k}$ $\left(\text{e.g., } \frac{M}{k} = 3.0\right)$ mature at a smaller relative size, and have indeterminate growth. I developed analytical models to examine the relationship between these ratios and length structure, growth pattern, spawning-per-recruit, and the spawning potential ratio (SPR) for exploited stocks (Chapter 3). These analytical models were extended to include more realistic assumptions about maturity and selectivity-at-length, and a model that uses knowledge of the life-history ratios, and data on the length structure of the catch, was developed to calculate the SPR, an internationally recognised measure of stock status; the length-based SPR model (LB–SPR).

The key parameters of the LB–SPR model are: $\frac{M}{k}$, L_∞, and the variation in length-at-age (CV_{L_∞}), as well as information on the size of maturity (L_m). The utility of the LB–SPR model, and its sensitivity to violations of the main assumptions, was examined using Monte Carlo simulations (Chapter 4). Length data were generated for four different species, reflecting different life-history strategies, and the variation of the estimated SPR was examined in a number of scenarios, including: misspecification in the input parameters, the number of fish measured, presence of dome-shaped selectivity, and recruitment variability. The results demonstrate that the model returns unbiased estimates of SPR, and performs well when the biological parameters are well known and the stock is at, or near, equilibrium. However, the model is sensitive to misspecification in the input parameters, particularly to L_∞, where SPR can be significantly under- or over-estimated if L_∞ is not close to the true value. With high recruitment variability, the variation in estimates of SPR from the equilibrium-based LB–SPR model becomes greater, particularly when recruitment trends are auto-correlated. The results of the sensitivity tests indicate that the LB–SPR model has potential to provide a tool for rapid and cost-effective estimation of SPR for data-poor fisheries, which could be used for guiding management decisions and prioritising the direction of future research. Nevertheless, the results also showed that care must be taken to evaluate the validity of the assumptions of the LB–SPR model, and the precision of the biological parameters for the relevant stock, when interpreting the results of the model.

Fisheries managers usually make their decisions in response to estimates of the stock status. For example, if the stock is estimated to be below some target reference point, managers may choose to reduce catches or fishing effort to allow the stock to rebuild. The linking of the status of the stocks and the management decisions are often done by means of a harvest control rule (HCR), which defines a pre-determined agreed response to the estimated status of the stock. I developed a simulation model to perform a management strategy evaluation (MSE) to test a HCR that links the estimates of the SPR from the LB–SPR model to an appropriate management decision (Chapter 5). Three species, representing different life-history types, were investigated and the performance of the model was examined under a number of different scenarios, including: increased recruitment variability, dome-shaped selectivity, and time-varying natural mortality. The results indicate that

the LB–SPR HCR is capable of recovering an over-exploited stock within an acceptable time-frame. The results also demonstrate that care must be taken when setting SPR target reference points, especially when the biology of the species is not well known, and when recruitment is highly variable.

The developments of this thesis highlight the potential of applying a simple methodology to assessing and managing data-poor stocks, requiring only basic information on life-history and length composition of the catch. A framework was established for using knowledge from well-studied species to inform data-poor stocks, which allows initial estimates of the stock status to be made with only minimal data requirements. The methodology developed in this thesis thus provides a cost-effective, easily understood, and transparent method for estimating the SPR for data-poor and small-scale fisheries with only minimal data requirements, and thus allows managers and other stakeholders to begin making informed decisions without having to wait for the collection of additional data. In this respect, the LB–SPR model developed and demonstrated in this study provides a starting point for the assessment of data-poor and small-scale stocks, and assists in identifying important data gaps, prioritising research and collecting information to validate the unknown biological parameters, and beginning the process of gathering additional data to allow alternative assessment methods to be applied in the future (e.g., a time-series of total catches). Finally, this study has also identified areas for additional research, particularly further empirical testing of the LB–SPR model and the development of an integrated harvest strategy framework based on SPR reference points (Chapter 6).

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Dedication

In loving memory of my mother, Arly Hordyk (1953–2013)
for believing in me, and teaching me to believe

Publications resulting from this study

The following chapters of this thesis have been peer reviewed and accepted for publication:

Chapter 2 Prince, J. D., Hordyk, A. R., Valencia, S., Loneragan, N. R. & Sainsbury, K. 2014. Revisiting the concept of Beverton–Holt Life History Invariants with the aim of informing data-poor fisheries assessment. *ICES Journal of Marine Science.* fsu011.

Chapter 3 Hordyk, A. R., Ono, K., Sainsbury, K., Loneragan, N. R. & Prince, J. D. 2014. Some explorations of the life history ratios to describe length composition, spawning-per-recruit, and the spawning potential ratio. *ICES Journal of Marine Science*. fst235.

Chapter 4 Hordyk, A. R., Ono, K., Valencia, S., Loneragan, N. R. & Prince, J. D. 2014. A novel length-based empirical estimation method of spawning potential ratio (SPR), and tests of its performance, for small-scale, data-poor fisheries. *ICES Journal of Marine Science*. fsu004.

Chapter 5 has been accepted for publication in the journal *Fisheries Research*. Hordyk, A.R., Loneragan, N. R., & Prince, J.D. An evaluation of a harvest strategy for data-poor fisheries using the length-based SPR assessment method. Submitted February 2014 to *Fisheries Research*.