Outputs and Milestones for SFO274

(An administrative final report)

SF0274 was the modelling and analysis aspect of a linked pair of projects, with SF0272 supplying field data for model parameterisation and testing.

Year 1: 2006/07

1. **Prepare an FRS internal report detailing developments under scientific objective 1. (" devise, document and test against existing data from the Girnock Burn, a model structure capable of describing growth of salmon parr in a stochastic environment.")**

   An internal report was prepared and submitted as required (Appendix 1), and a separate refereed publication has been prepared, submitted and published: Gurney W.S.C. and Veitch A.R. (2007) *The dynamics of size at age variability*. Bulletin of Mathematical Biology 69(3) 861-885 (Appendix 2).

   Using data on salmonid growth and maturation in a number of UK and Scottish waters, this report demonstrated the necessity of developing a consistent modelling structure for describing individual to individual variability in growth performance in order to model within-cohort variability in age at smolting. The accompanying paper describes a preliminary attempt to define such a formalism.

2. **Submit for publication to a refereed journal a paper describing the modelling developments under scientific objective 1.**

   A paper has been prepared and submitted as required. It is now published: Gurney W., Tyldesley G., Wood S., Bacon P., Heath M., Youngson A. and Ibbotson A (2007*). Modelling length at age variability under irreversible growth*. Canadian Journal of Fisheries and Aquatic Science (2007) 64, 638-653, (Appendix 3)

   The formalism reported in Gurney and Veitch (2007), while mathematically elegant, is unable to describe irreversible growth exactly, and does not lend itself to efficient computation. The discrete-time extension described by Gurney et al. (2007) incorporates an exact description of irreversible growth and naturally implies a highly efficient computational implementation, suitable to data-fitting applications.

3. **Prepare an FRS internal report detailing developments under Scientific Objective 2 ("to devise and document an extension of this model to describe the growth of a set of quasi-closed sub-populations of parr existing in geographically distinct locations within a single river catchment")**

   A preliminary report was submitted as required, but is not reproduced here since it was superseded by the more complete account given in the paper prepared, submitted and published under 4 below.

Year 2: 2007/8

1. **Prepare for publication in a refereed journal a paper describing the modelling of smolt development** .

   A paper has been prepared as required, submitted and published as Gurney W.S.C., Bacon, P.J., Tyldesley G and Youngson A. *Process-based modelling of decadal trends in growth, survival and smelting of wild salmon (Salmon salar) parr in a Scottish upland stream.* Canadian Journal of Fisheries and Aquatic Science 65,2606-2622. (Appendix 4.)

   This paper describes the application of the modelling framework developed in Gurney and Veitch (2007) and Gurney et al. (2007) to describe the growth of cohorts of salmon parr in localised sub-catchments such as the Girnock Burn. It successfully predicts the size at age of observed cohorts as well as the distribution of ages at smolting. The paper applies this extended model to examine the decadal changes in age at smolting which have been observed in the Girnock and consider the extent to which climate change may have been the major driver behind such changes.

2. **Prepare an FRS internal report describing the marine-phase dataset compiled under research objective 3**

   Under this heading a model-facing working document was prepared (Appendix 5), followed by a data-facing report (Appendix 6) which was submitted in fulfilment of this milestone. A related paper has been prepared and submitted: Bacon P.J., Palmer S.C.F., MacLean J.C., Smith B.D.M., Gurney W.S.C and Youngson A.F (2009) *Empirical analyses of the length, weight and condition of adult Atlantic salmon on return to the Scottish coast between 1963 and 2006.* ICES journal of Marine Science (in press)(Appendix 7)

   Key observations were first that salmon and grilse coexist in characteristically different proportions in different sub-catchments of Scottish rivers and second that all density dependent processes within the salmon life-cycle occur within the river. Hence we conclude that critical non-linearities in the life-cycle of Scottish salmon must be described at a sub-catchment scale.

3. **Prepare an FRS internal report describing the adaptation and wider management use of a fully modular version of the single sub-population river-phase model.**

   A report has been prepared and submitted (Appendix 8). In the light of the importance of intra-catchment variability in habitat and environment, consequent on conclusions of the data analysis exercise, this report gives extensive consideration to the data requirements inherent in sub-catchment scale modelling.

Year 3: 2008/9

1. **Prepare a brief internal FRS report which spells out the qualitative reasons why any realistic model of wild Scottish salmon populations that imposes catchment wide management (such as the single-catchment ICES/NASCO Conservation Limits) will inevitably lead to less appropriate and less fine-tuned management than a model incorporating the fundamental sub-structuring which pertains within catchments for many Scottish salmon populations**

   A report has been prepared and submitted (Appendix 9) and a elated paper has been prepared and submitted: GurneyW.S.C., Bacon P.J., McGinnity P., MacLean J., Smith G. and Youngson A. (2009) *Form and uncertainty in stock-recruitment relations: observations and implications for Atlantic salmon management*. Canadian Journal of Fisheries and Aquatic Science (in review) (Appendix 10).

   The key conclusions of the report and the accompanying paper are that the details of the shape of the stock-recruitment curve both at very high and very low stocks play a central role in determining stock persistence. These shapes are determined by competition which takes place on a sub-catchment scale (probably only a few km) and are likely differ significantly between sub-catchments. Simulation experiments have shown that failure to recognise such diversity will inevitable lead to misleading analyses of whole catchment stock recruitment data.

2. **Collaborate with FRS FL staff to prepare an internal FRS report reviewing the international literature on key, potentially dynamically-controlling, processes, of the marine and river-ascent phases of the salmon life-cycle.**

   See 3 below

3. **Collaborate with FRS staff in using the set of model components documented in Mar-08, combined with the findings of the literature review (2 above), to quantitatively investigate which of the potential control mechanisms are the priorities for investigation.**

   Milestones 3 and 4 were envisaged as stepping stones on the way to a workable multi-sub-catchment model. Work on stochastic stock-recruitment driven models has led to an understanding that very simple models appropriate for management use can be constructed using techniques developed as a simplification of those used in the earlier phases of this ROAME. A prototype model, single sub-catchment model has been constructed using these methods and a report has been submitted detailing these developments (Appendix 11)

4. **Prepare an internal FRS report describing the collaborative use with FRS FL staff of the models of (3 above) to assess the cost-effectiveness of various fieldwork options which FRS FL staff could undertake to most effectively distinguish between the key controlling mechanisms (marine and river-ascent phases), and including recommendations on a way forward**.

   See 6 below

5. **Prepare an internal FRS report describing a full set of data, including the status of juvenile populations, necessary to parameterise the proposed models in novel catchments and thereby extend the utility of the models more widely to salmon management in Scotland, as agreed during collaborative discussions with FRS FL staff.**

   See 6 below.

6. **Prepare an internal FRS report describing consensus recommendations, reached with FRS FL staff, on choosing and parameterising an interacting spatial population model, and including costed schedules (fieldwork and modelling) for achieving this.**

   The developments described in Appendix 11 led us to propose a follow-on project in which the proposed sparse modelling techniques would be deployed in a sustained effort to involve stakeholders in the modelling and analysis process. This proposal (Appendix 12) , which has been accepted for funding over the period 2009-12, goes well beyond the preparatory work envisaged under 4-6 above, but has been agreed by FRS management as constituting de facto fulfilment of the required milestones.