The influence of the freshwater environment and the biological characteristics of Atlantic salmon smolts on their subsequent marine survival

Ian Russell, Miran Aprahamian, Jon Barry, Ian Davidson, Anton Ibbotson, Richard Kennedy, Julian Maclean, Andy Moore, Jaime Otero, Ted Potter & Chris Todd
Freshwater and marine environments intimately linked - freshwater history of juvenile salmon can influence survival in marine environment.
Climate change a particular concern for freshwater environment:
- temperature rises greater over land than at sea
- increased climate variability – more floods & droughts
- changes in flow patterns (e.g. early snow melt)
- knock-on effects on water quality

Range of potential impacts for Atlantic salmon, including northward shift in thermal niche, with lower production & population extinction in more southerly areas

Various anthropogenic impacts:
- contaminants
- abstraction
- barriers & obstructions
- sedimentation
Examine freshwater influences on biological characteristics and behaviour of smolts and resulting impact on marine survival

Three specific issues:
- smolt size / age
- smolt run-timing
- smolt quality

Part review / part examination of data from international collaborations

Consider potential implications for management
Smolt size / age
Critical size (or size-related development stage) needed for smolting to occur

Significant negative correlation between smolt age and index of growth potential (degree-days and photoperiod) – i.e. smolts typically older and slower growing at more northerly latitudes

Smolt size variable – broad geographic factors, but also river/tributary, and year to year differences

Within populations, smolt size and age depend on growth rates – size typically increases with age
Data available for 31 (wild) stocks around N. Atlantic
- data derived from scales of returning adults
- sig. decline (1989 on) in mean smolt age in 17 stocks (55%)
- sig. increase in only 3 stocks (10%)

Broad regional differences apparent
Several authors report increases in parr sizes & freshwater growth and declines in smolt age concurrent with temperature increases.

Not a universal picture – in other studies parr size negatively correlated with spring temperatures.

Relationship between size-at-age and temperature more complex than laboratory experiments indicate.

While temperature may be main driver, this is not exclusive of other environmental influences, e.g.

- density-dependent effects
- prey availability
- increased freshwater production
- hydrological regime
Faster growth expected to result in higher proportion of younger smolts and these typically smaller.

**Potential effects of smolt size:**

- **On marine survival** - mortality at sea growth mediated - smaller smolts experience higher losses (e.g. predation). Clear supporting evidence for this for hatchery smolts; evidence for wild smolts more equivocal.

- **On marine growth** - conflicting evidence (-ve relationships / +ve relationships / independent of freshwater growth history)

- **On Marine residency (sea-age)** - conflicting evidence (-ve / +ve / no causal link / strength of relationship influenced by sex of fish)

- **Damping the impact of higher marine mortality** – assuming higher survival to smolt not outweighed by greater vulnerability at sea
Run-timing

River Bush smolt monitoring facility
- Day length ultimate trigger
- Run-timing varies with latitude
- Also occurs later in the NW than in the NE Atlantic
- River conditions (e.g. temp, discharge, turbidity) act as proximate triggers
- Migration timing also affected by body size (larger/older smolts migrate earlier)
Importance of run-timing

- Timing of sea water entry has evolved so that smolts enter sea in synchrony with optimal biotic/abiotic conditions.

- Correlations reported between both sea temperature & food availability at time of sea entry and subsequent adult returns.

- Interactions with predators.

- Optimum window - highest returns when physiological and environmental ‘windows’ coincide.
Run-timing getting earlier (~3 days per decade)

Likely linked to warming temperatures

Temperature increases greater over land (& fresh water) than over the sea

Potential for mismatch with optimum environmental conditions
Implications of change

- Direct temperature effects:
  - effect on physiological processes and growth
  - reduced survival in seawater challenge tests with gradient >4-6°C
  - osmotic stress more severe at SSTs <6-7°C
  - risk of elevated energetic costs if behaviour changed in search of optimal SSTs

- Indirect temperature effects through ecosystem changes:
  - reduced food availability (energy expenditure increases when smolts enter saltwater and adequate prey critical)
  - impacts on rearing environment

- Potential for increased vulnerability to predators
River Bush

Smolts running earlier

Increasing temperature differential

Correlation between run-timing and marine survival

Kennedy & Crozier, 2010
Smolt quality
Smolt quality

- Smolt life-history traits genetically determined & population specific, with implications for quality of smolts & marine survival
- Environmental conditions in freshwater also affect smolt physiology & energy reserves
- Some evidence that plumper (higher CF) and better quality smolts have higher survival (data limited)
- Wide range of environmental factors known to impact on smolt physiology and ability to adapt to saline conditions, e.g. -
  - pesticides / herbicides
  - acid water / aluminium
  - oestrogenic compounds
  - brominated flame retardants
  - suspended sediments
Exposure to the pesticide atrazine

Atlantic salmon smolt migratory behaviour

Freshwater migratory behaviour reduced

Moore et al., 2007
Reduced gill ATPase activity and smolt survival on entering sea water

Waring & Moore, 2004
Atrazine in the River Avon and catch of 1SW salmon the year after freshwater exposure

Moore et al. *unpublished*
Other effects and implications

- Contaminants may also:
  - modify smolt olfactory sensitivity and imprinting
  - reduce growth & size at sea entry
  - affect post-smolt behaviour & vulnerability to predators

- Potential for effects of contaminants to be exacerbated by climate change / anthropogenic impacts:
  - higher temperatures reduce purification capacity
  - increased run-off and mobilisation of pollutants
  - higher levels of abstraction
  - dams, hydropower, etc.

- Potential for direct effects on metabolism (physiological window) and delays to migration (mis-match with environmental window)

- Obvious implications for survival ("smolts take it with them when they go" – McCormick et al. 2009)
Summary & Implications for Management
Implications for management

- Freshwater environment critical to performance of salmon at sea
- Substantial & increasing pressures – challenge for fish & managers
- Freshwater more amenable to management:
  - abstraction, river regulation, riparian shading, buffer strips, catchment management, obstructions, managed retreat? ..........
- Good evidence base vital
- Evidence gaps:
  - further explore links between smolt size & adult recruitment (develop predictive capacity)
  - extent and significance of run-timing mis-match
  - effect of contaminants (e.g. timing, extrapolating to pop’ns)
- Monitoring programmes provide essential indicators of change and for assessing biological responses to environmental variables
- Information sharing
Acknowledgements

SGBICEPS Investigations
Johan Dannewitz
Stephen Dye
Adrian Fewings
Peder Fiske
Erik Petersson
Stig Pederson
Ger Rogan
Peter Amiro
Jaimie Gibson
Gerald Chaput
Dave Reddin
Brian Dempson
Jaakko Erkinaro
Gilles Euzenat
Peder Fiske
Gudni Gudbergsson
Ross Jones
Gordon Smith
Tim Sheehan
Joan Trial
Alexander Zubchenko
Melanie Dionne
Atso Romakkaniemi

Otero Investigation
Thorulfur Antonsson
John Armstrong
Fridthjof Arnason
Jo Vegar Arnekleiv
Jean-Luc Baglinière
Pablo Caballero
Ted Castro-Santos
Brian Dempson
Jaakko Erkinaro
Sigurdur Gudjonsson
Gregg Horton
Nils Hvidsten
Arne Jensen
Erkki Jokikokko
Bror Jonsson
Ingi Runar Jonsson
Nina Jonsson
John Kocik
Jan Henning L'Abée-Lund
Anders Lamberg
Benjamin Letcher
Simon McKelvey
Paul Music

Eero Niemelä
Atso Romakkaniemi
Nils Stenseth
Geir Storvik
Alexey Veselov
Leif Asbjørn Vøllestad