Incorporating time-varying fishery catchability in assessment models for Atlantic herring (*Clupea harengus*)

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*Clupea harengus*, Atlantic Herring
Catchability, $q$

- the proportion of a fish stock captured by a unit of fishing effort

\[ I_t = q N_t \quad \text{and} \quad F_t = q f_t \]

- Fishery-independent indices: $q$ often time-invariant

- Fishery-dependent indices (e.g., fishery CPUE): $q$ often time-varying due to
  - Spatial and seasonal variation in $q$
  - Variation in fishing power (changes in gear, vessels, other technology)
  - Effects of management actions on fishing efficiency
  - Effects of changes in fishing behaviour on fishing efficiency
  - Effects of changes in fish behaviour on fishing efficiency – e.g., density-dependent $q$
Assessment models for Atlantic herring in the southern Gulf of St. Lawrence

**Spring Spawners**
- Single Population
- VPA model
  - Fishery CPUE
  - Acoustic survey indices
  - At low abundance

**Fall Spawners**
- Three Populations, assumed unmixed after recruitment
- VPA model
  - Main index is Fishery CPUE
  - At relatively high abundance
Spring Spawner VPA model

Traditional model
– time invariant $M$ and $q$

Severe lack of fit:
- Strong retrospective pattern
- Very poor fit to the Fishery CPUE index (but reasonable fit to the acoustic index)

Non-stationarity in $M$ or $q$?
Spring Spawner VPA model

Time-varying fishery $q$

\[ q_{1990} = q_{\text{Init}}, \quad q_t = q_{t-1} e^{q_{\text{Dev}_t}} \]

$q_{\text{Dev}_t} \sim N(0, sd), \quad sd=0.1$
Spring Spawner SCA model
Time-varying fishery $q$
Spring Spawner Models

- time-varying q – more pessimistic view of stock status, especially with VPA
- VPA - more pessimistic results than SCA
Causes of changes in fishery $q$ of Spring Spawners?

Density-dependent: $q$ increases as SSB declines below 60,000 t.

Decrease following management measures to reduce fishing efficiency.
Interesting if true – simulation tests of time-varying $q$ models
Fall Spawner VPA model

Modelled as 3 populations (which may mix at recruitment)
Fall Spawner VPA model – fit to the fishery cpue index

**Constant $q$**

**Time-varying $q$**
Fall Spawner VPA model – time-varying fishery $q$

Variation in $q$ is mostly density-independent

May be related to changes in the behaviour of fish or fish harvesters:

- Harvesters in the South (but not in the North) indicate important changes in their fishing behaviour in recent years
- Grey seal abundance has been increasing exponentially and harvesters report changes in herring behaviour in response to the presence of seals
Fall Spawners – effect of time-varying $q$ on estimates

- Recent estimates of SSB are higher in the North and lower in the South when time-varying $q$ is taken into account.
- This difference may be important given the status of the South population.
Conclusions

• Evidence of time-varying $q$ for fishery cpue indices of both spring- and fall-spawning stocks of herring

• Apparent causes differed between stocks

• Strong evidence for density-dependent $q$ for the depleted spring spawning stock

• Failure to account for time-varying $q$ can lead to incorrect conclusions on stock status (e.g., spring VPA)

• Based on simulation tests, both SCA and VPA models were able to identify time trends in $q$ in most instances

• VPA and SCA estimated similar trends in population biomass, though the SCA estimates were more optimistic in recent years.