Fisheries Biology, Assessment & Management

Lecture 2 (part 1)

How Many Fish in the Sea? (The Science of Fish Stock Assessment)

Remembering ...

- Processes
  - “Birth”, Growth, Maturation, Reproduction, Death (due to fishing and natural causes)
- Stock abundance
  - as numbers, or as biomass
  - by age and by year (yearclasses/cohorts)
- Yield: catches and death rate due to fishing
  - the effect of fishing effort: $F = qE$
- Recruitment: dependence on spawning stock
Questions asked by “managers”

- The effects of current exploitation rates?
- Potential for improvement?
  - Increased yields and/or biomass
    - now (short-term) or future (long-term)
- Possibility of “Optimal” Exploitation?
- Sustainability?
- Desirable Conservation Measures?
  - direct (controls on catch or effort)
  - “technical” (mesh sizes, closed areas)

What we would like to know

- The present Level of Exploitation
  - Fishing Mortality (depends on age/size)
- The Size of the Stock(s)
  - Biomass & Age/Size Composition
  - Trends with time?
- The Risk of Collapse
  - Stock/Recruitment Relationships
- Catch Forecast (for TAC’s)
  - Recent & Future Recruitment : Fluctuations
Stock Assessment (1)

- Analysis of biological samples
  - length & age compositions
  - catch curve analysis
- Analysis of fishing survey data
  - Abundance indices & total mortality rates
- Use of total international catch-at-age data
  - Virtual Population Analysis (VPA)
    - Cohort Analysis (simplified technique)

Stock Assessment (2)

- “Tuning” of VPA (using CPUE & Survey indices)
  - Extended Survivors Analysis
- Yield-per-Recruit Calculations
- Stock-Recruitment Relationships
- Catch Forecasts (for TAC’s)
Data we can use

- **Biological samples**
  - length (and age ?) compositions
  - mortality rates (approximate, average)
- **Catch & Effort data**
  - mortality rates (reasonable)
  - stock sizes & trends
- **Research Surveys**
  - acoustic, plankton & fishing surveys
  - *** fishery independent ***

Biological Sampling

- Length Measurements
- Age determination (if possible)
  - count growth rings (otoliths or scales)
- Sample many landings
  - (areas, gears, seasons.....)
- Compare over several years
- Fair indication of mortality rates
  - ... over or under-exploited ??
### Length compositions

**Raja Clavata : Irish Sea**

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<tr>
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<td>16</td>
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<tr>
<td>45</td>
<td>47</td>
<td>31</td>
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<tr>
<td>51</td>
<td>28</td>
<td>27</td>
<td>29</td>
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</table>

### Length compositions

**Raja Clavata : Length Composition**

![Length Composition Graph](image-url)
Plaice Otolith

Age compositions

North Sea cod: Age composition of Catch (numbers)
“Catch Curve Analysis”
by log catch ratios

- \( C(y,a) = F(y,a) \ P_{\text{bar}}(y,a) \)
- \( C(y+1,a+1) = F(y+1,a+1) \ P_{\text{bar}}(y+1,a+1) \)
- If \( F \) is constant (w.r.t. both time and age)
  - \( \ln\left( \frac{C(y,a)}{C(y+1,a+1)} \right) = \ln\left( \frac{P_{\text{bar}}(y,a)}{P_{\text{bar}}(y+1,a+1)} \right) \)
  - \( = Z(y,a) \)
  - Fit (straight) lines to data points (on log scale)
  - Or construct tables of log catch ratios

Catch-at age data:

North Sea Cod: Catch-at-age data

<table>
<thead>
<tr>
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<tbody>
<tr>
<td><strong>Age</strong></td>
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<tr>
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<td>1032</td>
<td>479</td>
<td>430</td>
<td>513</td>
<td>283</td>
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</table>
“Catch Curve” : for a single year

North Sea cod : "Catch Curve" for 1990

- Age
- Total International Catch Number

Problem : variable recruitment

- variable yearclass strength
  - causes “wiggles” in the catch curve in any single year
  - looks like (i.e. confounded with) variation of mortality with age
- solution : use data for separate cohorts
  - (not separate years)
- Calculate log catch ratios
### Log Catch Ratio Spreadsheet

**North Sea Cod: Catch-at-age and Log Catch Ratios**

<table>
<thead>
<tr>
<th>Catch Numbers</th>
<th>Year</th>
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<tbody>
<tr>
<td>1</td>
<td>11841</td>
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<tr>
<td>2</td>
<td>54692</td>
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<tr>
<td>3</td>
<td>11994</td>
</tr>
<tr>
<td>4</td>
<td>4360</td>
</tr>
<tr>
<td>5</td>
<td>2462</td>
</tr>
<tr>
<td>6</td>
<td>304</td>
</tr>
</tbody>
</table>

**Log Catch Ratios ( ~ Z )**

<table>
<thead>
<tr>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-0.69</td>
<td>-0.86</td>
<td>-0.69</td>
<td>-1.66</td>
<td>-1.37</td>
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<tr>
<td>2</td>
<td>1.18</td>
<td>1.00</td>
<td>1.04</td>
<td>0.97</td>
<td>0.67</td>
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<tr>
<td>3</td>
<td>1.28</td>
<td>1.22</td>
<td>1.00</td>
<td>1.31</td>
<td>1.38</td>
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<tr>
<td>4</td>
<td>1.14</td>
<td>1.14</td>
<td>1.15</td>
<td>1.32</td>
<td>1.35</td>
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<tr>
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<td>0.87</td>
<td>1.07</td>
<td>0.90</td>
<td>1.12</td>
<td>1.11</td>
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</table>

*not fully exploited*

### “Catch Curve” : for a single cohort

**North Sea Cod: Catch Curve : 1989 Cohort**

![Catch Curve Graph](image-url)
Problem: variable effort

- If effort varies from year to year, so does fishing mortality
  - i.e. $F(y,a)$ is not constant, causing errors
- but CPUE = $q \bar{P}$ [not dependent on $F$]
- Better to use log CPUE ratios
  - still requires $q(y,a+1) = q(y,a)$
  - i.e. catchability independent of age & time
- a weaker assumption, but still not guaranteed
- needs catch & effort data (for individual fleets)

Catch & Effort Data

- From log-books, landings declarations
- Catch-per-unit-effort indices
  - are a valid indicator of stock size ...
  - if catchability is constant (w.r.t. age & time)
- Combine with age composition data (from biological samples) to get estimates of $Z$, and therefore also of $F$
- ??? are the basic data reliable ???
- ?? is catchability constant ??
Problem: partial selection

- younger (smaller) fish are not fully vulnerable
- so fishing mortality is not constant
- the “catch curve“ is not a straight line
- catches are not proportional to population size for these age groups

Virtual Population Analysis

- An alternative way (J. Gulland) to estimate:
  - population numbers (by age & year)
  - fishing mortality rates (by age & year)
- Uses total international catch data (not effort)
  - (N.B.: need other countries’ data)
- Requires catch numbers-at-age
  - does not assume F or q to be constant
- Based on the catch equation
- Need several years data (about 5, or more)
Cohort Analysis

- simplified approximate method (J. Pope)
- work with data for each cohort separately
- divide fish at beginning of year into
  - survivors (natural mortality only, full year)
  - victims (assume all caught at mid-year)
    - i.e. subject to M for half the year only
- \( P(y,a) = \exp(M) \, P(y+1,a+1) \) (survivors)
- \( + \, \exp(M/2) \, C(y,a) \) (victims)

Cohort Analysis (cont’d)

- \( P(y,a) = \exp(M) \, P(y+1,a+1) \)
- \( + \, \exp(M/2) \, C(y,a) \)
- apply sequentially, backwards
  - i.e. start with the oldest
  - need a starting value for the survivors
    - e.g. assume (guess) equal to last catch number
- also \( Z(y,a) = \ln\{ P(y,a) / P(y+1,a+1) \} \)
- \( F(y,a) = Z(y,a) - M \)
- complete set of values for \( P(y,a) \) and \( F(y,a) \)
Cohort Analysis: single cohort

North Sea Cod: Cohort Analysis: Single Cohort: 1989 Yearclass

\[ M = 0.2 \quad \exp(M/2) = 1.105 \]

<table>
<thead>
<tr>
<th>Age</th>
<th>Population</th>
<th>Catch</th>
<th>Z</th>
<th>F</th>
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<td>283</td>
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<tr>
<td>7</td>
<td>283</td>
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</tr>
</tbody>
</table>

N.B. Start here

assumed = final catch number

work backwards from oldest age

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Cohort Analysis: single cohort

Population number at age

North Sea Cod: 1989 Cohort

![Graph showing population number at age](image-url)
Cohort Analysis: single cohort
Fishing mortality at age

North Sea Cod: Fishing Mortality from Cohort Analysis: 1989
Cohort

Cohort Analysis: multiple cohorts

<table>
<thead>
<tr>
<th>Population Numbers</th>
<th>Year</th>
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</thead>
<tbody>
<tr>
<td>Age</td>
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</tr>
<tr>
<td>1</td>
<td>69619</td>
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<td>2</td>
<td>97245</td>
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<td>707</td>
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<tr>
<td>7</td>
<td>304</td>
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### Cohort Analysis: multiple cohorts

#### Fishing Mortality

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<td>0.188</td>
<td>0.210</td>
<td>0.065</td>
<td>0.094</td>
<td>0.644</td>
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### Cohort Analysis: multiple cohorts

#### Population at age

#### North Sea Cod: Cohort Analysis: Population Number

- **1990**
- **1991**
- **1992**
- **1993**
- **1994**
- **1995**
- **1996**

![Graph showing population number over age for different years]
Cohort Analysis: multiple cohorts
Fishing Mortality at age

North Sea Cod: Cohort Analysis: Fishing Mortality

Practical Session
Cohort Analysis
VPA & Cohort Analysis

- work with each cohort separately
  - hence the name of the method
- examples of Sequential Population Analysis
- need **total international** catch data
- need a sensible assumed value for the survivors ...
- i.e. one has to **assume** what one would most like to determine!
- good for retrospective analysis

VPA & Cohort Analysis
the “tuning” problem

North Sea Cod: Cohort Analysis: 1989 Cohort: Varying Terminal F
VPA & Cohort Analysis
the “tuning” problem

North Sea Cod: Cohort Analysis: 1989 Cohort: Varying
Terminal F

![Graph showing fishing mortality for different terminal F levels across age]

- High
- Med
- Low
VPA & Cohort Analysis: the “tuning” problem

- Need independent estimates of abundance
  - but these can be relative, e.g.
- CPUE from effort data
  - ideally for several fleets
- CPUE from fishing surveys
  - preferably by research vessels
- Need to combine with VPA
  - many and various methods, including
    - ad hoc, ADAPT, Extended Survivors Analysis

North Sea Cod: the "Tuning" Problem

![Graph showing population numbers and survey index for North Sea Cod]
Research Survey Data

- Fishing Surveys (demersal fish)
  - data by species, size, age, maturity, etc
- Acoustic Surveys (pelagic fish)
  - species ???, sizes ??, calibration ?
- Plankton Surveys (of eggs & larvae)
  - spawning stock biomass only
- Cost (> £500 000 per survey)

Overview

- To assess the relative state of a stock (trends and fishing mortality) one needs:
  - catch & effort data for at least one fleet (or research survey)
  - plus biological samples (length & age compositions)
- To get absolute stock size one needs
  - total international catch (numbers-at-age)
  - more CPUE or survey data (for “tuning”)