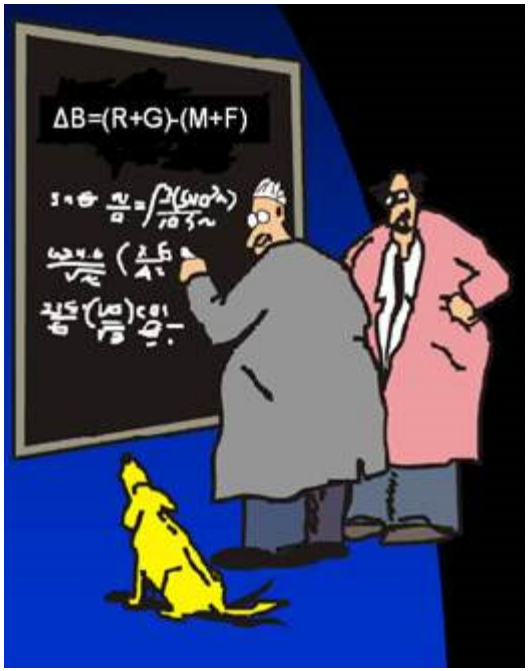
Marine Institute

FISH 6004: Overview of Statistical Stock Assessment



Noel Cadigan

CFER

Centre for Fisheries Ecosystems Research

MARINE INSTITUTE

MEMORIAL UNIVERSITY

Basic Course Description

- Introduction to concepts in fish stock assessment,
  - including survey sampling theory,
  - basic population dynamics,
  - optimal harvest strategies,
  - and stock assessment models.
- Learn how to fit several growth, reproduction, and stock assessment models using R software.
- Training in statistical estimation and inference methods involving maximum likelihood, profile likelihood, and bootstrap procedures. Also numerical methods.

Tentative Work Plan

- F6004 lectures: Tuesday afternoons, 1-4.
- 3 hour lectures with a 30 minute break about midway
- Labs Thursday 9:00-11:30 (Andrea Perreault), to support lectures.
- 11 lectures planned
- October 12: no class because of fall semester break
- No lab September 30 (to be confirmed) and November 11 (confirmed).
- Last Lecture: November 30, last lab December 2.
- Labs will involve R programming, statistical methods, assignment support, etc. as needs arise

Evaluation (registered students)

- Evaluation: 4 assignments worth 25% each.
- An optional 5th assignment – course mark based on best 4 of 5 assignments
- Assignments are like take home exams!! No collusion
- Final assignment due December 14

Office Hours (registered students)

- Very flexible via TEAMS
- Email for an appointment
- Don’t hesitate to ask!

My Requirements!

Instructor Information

Provide students with your location, contact information, availability, and any expectations around interactions.

Required

Information about your availability for consultation (in-person and, where appropriate, by other means of communication) outside of class.

Recommended

Office hours as prescribed by MUNFA and LUMUN collective agreements (i.e., 2 hours per course per week, to a maximum of 5 hours per week).

A statement regarding response times for inquiries. *e.g., Every effort will be made to respond to emails within 24h, with the exceptions of evenings, weekends and holidays.*

My Requirements!

Course Information

Along with the standard course information (course name and number), you may highlight the focus of your course, its purpose or relevance, questions that are addressed by your course, and/or indicate where your course fits within the context of the program.

Required

Any required prerequisites or co-requisites.

Recommended

Course description. Note that descriptions are available from the University Calendar, Faculty of Science, Section 11.

Course format. *e.g., team taught, lecture based, laboratories, tutorials, field work.*

Course expectations such as classroom etiquette, importance of attendance, use of formative/ungraded evaluations during class, and/or professional conduct statement.

My Requirements!

Learning Goals

Clearly outline what you want students to be able to do or demonstrate at the end of your course. These overall course goals do not necessarily result in measurable behaviour, but they will provide students with a clear purpose to focus studies on, and they provide direction for the specific learning outcomes and assessment strategies within the course.

Recommended

Essential understandings, theories or approaches students will learn.

Equations, strategies and core knowledge students will apply.

Key skills students will develop (*e.g., specific laboratory skills, critical thinking*).

Threshold concepts or attitudes students will develop (*e.g., evolutionary thinking, uncertainty in measurements, the Nature of Science*).

Required Text and Resources

List any textbooks, articles, books, media or other resources that students should consult. Be clear about which resources are required in the course and why, which are optional, and where these resources may be accessed. You may also wish to include a statement regarding how the text and resources will be used and how students should approach them.

My Requirements!

Method of Evaluation

Clearly outline how students will be evaluated in your course. This includes how assignments are counted, participation expectations, how overall grades are calculated, and submission policies (*e.g., how late submissions or missed assessments will be handled*).

Required

The allocation of marks for all parts of the evaluation including assignments, laboratory projects, presentations, tests, mid-term examinations, and/or final examinations.

Wherever possible, an explanation of the alternate evaluation which will be offered to students who are unable to complete a part of the evaluation due to acceptable cause, as described under Exemptions from Parts of the Evaluation (University Regulation 6.7.5).

With the exception of final examinations, and in accordance with Scheduling of Parts of the Evaluation (University Regulation 6.7.3), the probable dates of all in-class parts of the evaluation, and the probable dates on which all take-home parts of the evaluation are due.

As per University Regulations, evaluations must abide the following:

- Students must receive 20% of course grade by final drop date (6.7.6.1)
- Exemptions due to illness must be in keeping with University Regulations, Exemptions from Parts of the Evaluation (6.7.5)
- No evaluation is permitted in last two weeks of lectures (6.7.3.4)
- Attendance regulations may not be included without Senate approval (6.6.1)
- The return of graded work and notification of grades must be in keeping with the Access to Information and Protection of Privacy Act (6.7.2.5)

My Requirements!

Required

A statement of Memorial University of Newfoundland's commitment to accommodation of students with disabilities.

e.g., Memorial University of Newfoundland is committed to supporting inclusive education based on the principles of equity, accessibility and collaboration. Accommodations are provided within the scope of the University Policies for the Accommodations for Students with Disabilities (www.mun.ca/policy/site/policy.php?id=239). Students who may need an academic accommodation are asked to initiate the request with the Glenn Roy Blundon Centre at the earliest opportunity (www.mun.ca/blundon).

A statement regarding academic integrity, including a reference to the entry on Academic Misconduct (University Regulation 6.12).

e.g., Students are expected to adhere to those principles which constitute proper academic conduct. A student has the responsibility to know which actions, as described under Academic Offences in the University Regulations, could be construed as dishonest or improper. Students found guilty of an academic offence may be subject to a number of penalties commensurate with the offence including reprimand, reduction of grade, probation, suspension or expulsion from the University. For more information regarding this policy, students should refer to the University Regulations for Academic Misconduct (Section 6.12) in the University Calendar.

My Requirements!

Recommended

A statement regarding any restrictions around the use of visual and/or audio recording in the classroom, excluding any provisions made for students with special needs.

A statement regarding any restrictions or classroom etiquette around the use of personal electronic devices (*e.g.*, phones, laptops, tablets), excluding any provisions made for students with special needs.

A statement regarding student equity and the provision of a safe learning environment regardless of religious, linguistic and economic backgrounds, lifestyle choices, gender, nationality, physical ability or learning differences.

Memorial University's Land Acknowledgement (May be obtained from the Office of Aboriginal Affairs, https://www.mun.ca/aboriginal_affairs/). If used in syllabus, it is also recommended to deliver the acknowledgement verbally during the first class.

My Requirements!

Additional Supports

Memorial University offers a broad range of supports that may not be known to your students. Instructors are encouraged to direct students to academic supports as well as those listed at www.mun.ca/currentstudents/student/ and http://munsu.ca/studentlife/centres/

Recommended

A list, statement, or link outlining available academic supports including, but not limited to: *Memorial University Libraries, The Commons (QEII library), The Glenn Roy Blundon Centre, The Writing Centre, CITL Support Centre, Information Technology Services, Academic Advising, and specific departmental help centres.*

A list, statement, or link outlining available student life supports including, but not limited to: *Student Wellness and Counselling Centre, Student Support and Crisis Management, MUN Chaplaincy, Sexual Harassment Office, Student Parent Resource Centre, Aboriginal Resource Centre, Disability Information Support Centre, International Students Resource Centre, Sexuality And Gender Advocacy, Student Parent Assistance & Resource Centre, Students Older Than Average, Intersections – A Resource Centre for Marginalized Genders, and specific departmental societies.*

My Requirements!

Instructor Feedback

Instructors may wish to include a statement regarding the use of any feedback mechanisms used in the course, such as instructor developed feedback forms, prior-learning assessments, learning outcomes questionnaires, or the Course Evaluation Questionnaire.

Recommended

A brief statement regarding the timing of feedback, how feedback is used, and the value of feedback in improving the course for current and/or future students.

Tentative Course Schedule

A tentative schedule helps to ensure course expectations are clear, and aids students in time management during their studies.

Recommended

A tentative timeline (*e.g.,* a table) of topics broken down by week, including any tutorials, online meetings, assignments, tests, or assigned readings.

An indication of alignment with any required resources (*e.g., what sections of the text correspond with scheduled topics or lectures*)

A statement regarding the procedure for lecture or laboratory cancellations.

An intellectual property statement regarding lecture and course material (*e.g.,* permissions required for the reproduction of material).

F6004 Lecture 1 Outline

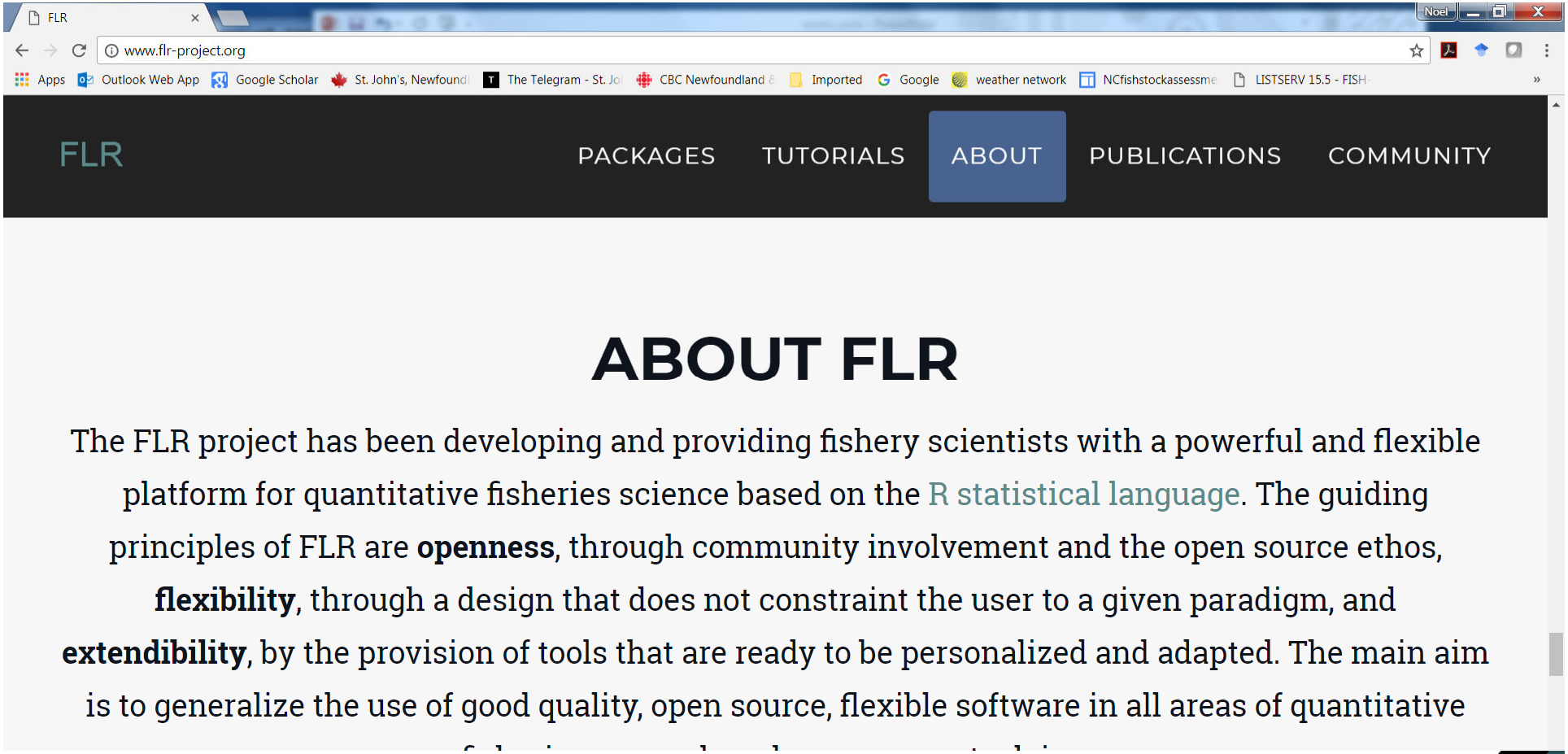
- What is stock assessment (SA).
- SA vs. Management.
- Different types of SA.
- Fish population dynamics: recruitment, growth, mortality, intrinsic growth, carrying capacity.
- The progression of fishing a new stock, changes in the fish and changes in the fishery.
- Fishery yield versus effort
- SA data

Course Readings: 1) Ch1-4, 7, 9-10 in "Marine Fisheries Ecology" by Jennings, Kaiser and Reynolds. 2) "A Guide to Fisheries Stock Assessment. From Data to Recommendations" by Andy Cooper.

Quantitative Methods in SA

- Survey sampling
- state-space models and other time series methods
- regression methods (GLM, GLIM, GLMM, GAM)
- Spatial methods (Gaussian Markov Random Field (GMRF), etc)
- ANOVA and multivariate methods
- Fitting customized models (**much of this**)
- using MLE and Bayesian methods
- We focus on overview of common methods and estimation+inference using R

R packages for SA models



FLR

PACKAGES

The FLR toolset is composed of a series of packages offering different classes, methods and models.

FLCore

Core classes and methods for FLR.

FLa4a

The a4a population model for stock assessment and MSE.

ggplotFL

Apply ggplot2 to the FLR classes.

FLBRP

Reference Points and Fisheries Advice.

FLFleet

Modelling of fishing fleet dynamics.

FLBEIA

Bio-Economic Impact Assessment of Management strategies.

FLSAM

SAM stock assessment model in FLR.

FLXSA

Data sets and methods to simulate data.

FLAssess

Support for FLR Stock Assessment methods.

FLash

Package for fisheries forecasting.

FLRDynState

2-Species Dynamic State Variable Model in FLR.

kobe

Methods for summarising results from SAs and MSEs in the Kobe format.

FLife

Methods for incorporating life history traits and processes.

diags

Diagnostics for stock assessment methods.

mpb

Biomass dynamics population and management procedures that can be simulation tested.

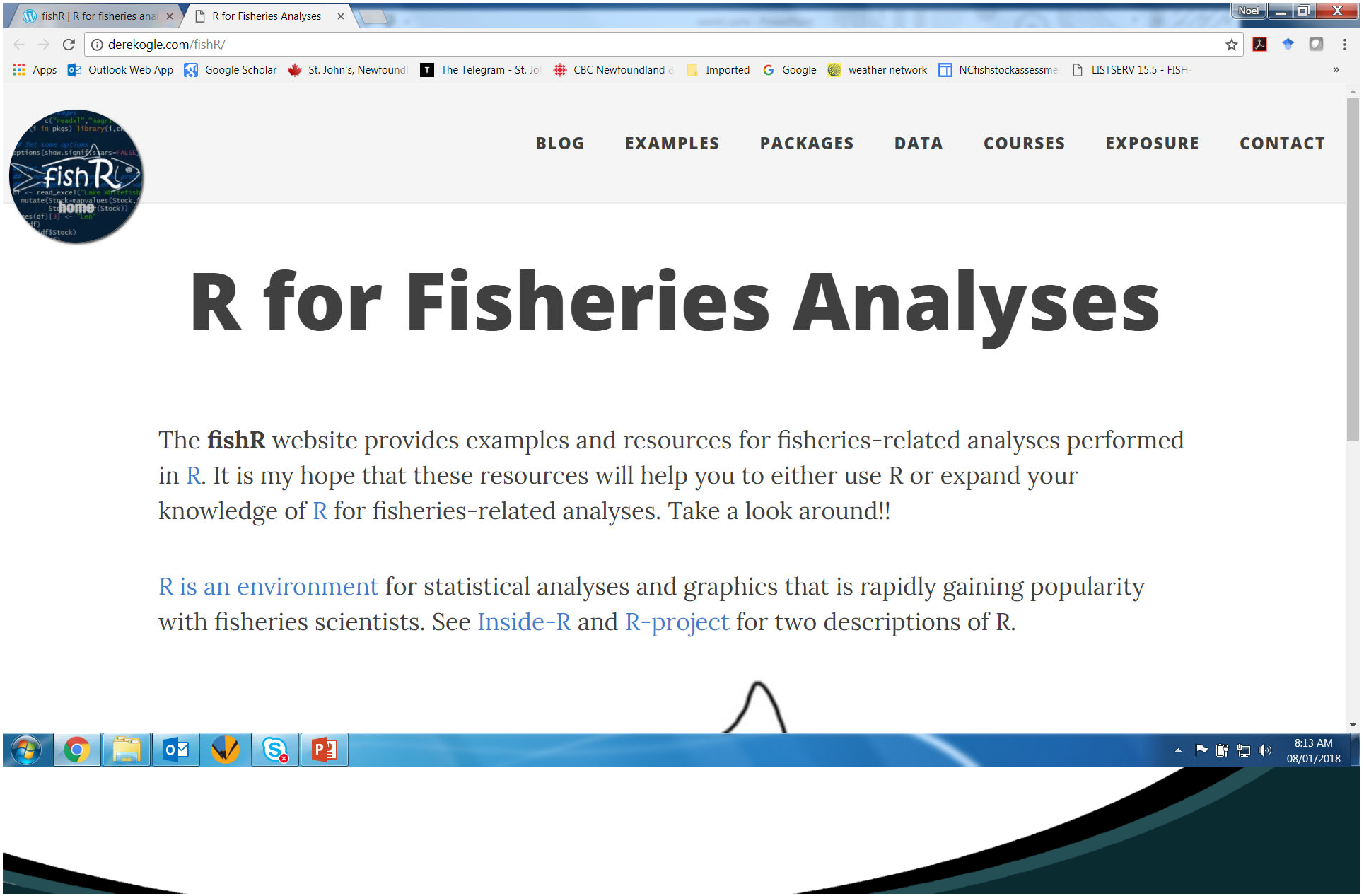
mse

Tools for implementing and evaluating management procedures using MSE.

FLasher

Next generation package for fisheries forecasting using Rcpp and cppAD.

R packages for SA models



FishR

Fishy Packages

- General Packages
- More Focused Packages
- Packages for Capture-Recapture Analyses
- Packages to Access Online Databases
- Packages for Limnological Data
- Collections of Code
- Packages Not Actively Maintained

How to Install Packages

The following are instructions to install packages from within various ways to interact with R – within RStudio, the R GUI for Windows, or the R GUI for Macintosh OS.

General Packages

- FSA: Fisheries Stock Assessment
  - FSAdata: Data for FSA
- DLMtool: Data-Limited Methods Toolkit – *Implementation of management procedures for data-limited fisheries*
- fishmethods: Fisheries Methods and Models in R
- fishdynr: Fisheries Science Related Population Dynamics Models
- FLR: Fisheries Library in R
- TropFishR: Tropical Fisheries Analysis with R – *collection of fisheries models based on the the FAO Manual "Introduction to tropical fish stock assessment" by P. Sparre and S.C. Venema. Focus is the analysis of length-frequency data and data poor fisheries.*

More Focused Packages

- ALKr – *age-length keys*
- Bioenergetics 4.0 – *a shiny app for bioenergetics modeling*
- Bioenergetics at ISEMP – *bioenergetics modeling as part of the Integrated Status and Monitoring Program*
- CatDyn – *population parameters from catch dynamics data*

- F6004+5 is about training modellers
- We will develop our own code
- Often in practise packages don't do exactly what you want
- But you may find they do sometimes in which case it may be more efficient to use them

Fish stock assessment (SA)

- What is the current "state" of the stock relative to its past or to reference values?
- What were the magnitudes of human impacts (e.g. fishing – harvest rate)?
- What should the stock state and harvest rate be?
  - Bcurrent/Bref; Fcurrent/Fref
  - numerator + denominator problems
  - Numerator: accounting/actuarial problem
  - Denominator: Essentially an ecology problem
- What will be the short- and long-term consequences of proposed management options?

Fish Management Options

- Quota's, effort
- allocations among fleets
- locations and time of fishing
- closed areas
- by-catch restrictions
- gear restrictions
- small fish protocols
- etc.

What is a fish stock?

- Cushing (1981, p70): those fish that return year after year to the same geographical region to spawn (i.e. reproduce).
- Some people refer to this as a population, and a stock may consist of multiple populations.
- We usually hope there is little immigration or emigration
- My definition: a stock is a subpopulation that is reproductively isolated, and in which immigration/emigration only play a minor role in stock productivity.

Recent examples of SA

- Lets look at the Terms of Reference for some recent stock assessment meetings.
- Canadian example, plus one from US and one from ICES (International Council for the Exploration of the Seas.

WHO WE ARE

- Member countries
- Council
- Advisory Committee
- Science Committee
- Expert Groups
- Secretariat
- Staff list
- Our history

Who we are

Print it Send to Share it

The International Council for the Exploration of the Sea (ICES) is a global organization that develops science and advice to support the sustainable use of the oceans.

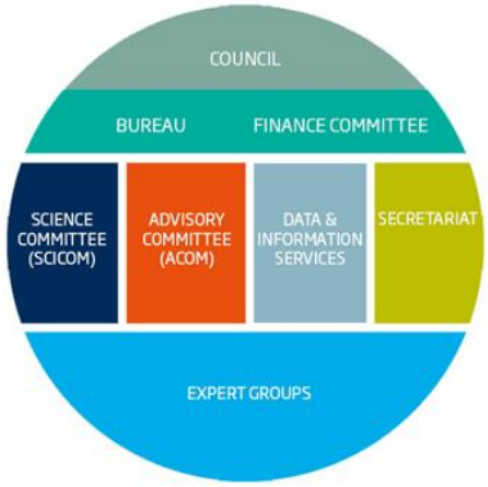
ICES is a network of more than 5,000 scientists from over 690 marine institutes in 20 member countries and beyond. 1,500 scientists participate in our activities annually.

Through strategic partnerships our work also extends into the Arctic, the Mediterranean Sea, the Black Sea, and the North Pacific Ocean.

ICES is committed to building a foundation of science around one key challenge: integrated ecosystem understanding of marine ecosystems.

ICES advances this through the coordination of oceanic and coastal monitoring and research, and advises international commissions and governments on marine policy and management issues.

Our goal is to provide the best available science for decision-makers to make informed choices on the sustainable use of the marine environment and ecosystems.



ICES structure

Canada

DFO - Canadian Science

www.dfo-mpo.gc.ca/csas-sccs/index-eng.htm

Apps | Outlook Web App | Google Scholar | St. John's, Newfound | The Telegram - St. Jo | CBC Newfoundland & | Imported | Google | weather network | NCfishsto

Government of Canada / Gouvernement du Canada

Canada.ca | Servi

Fisheries and Oceans Canada

On the water | Fisheries | Science and research | Ecosystems | Species | Aquaculture | Regions

Home → Science and Research → CSAS

Canadian Science Advisory Secretariat (CSAS)

Science advisory schedule, policies and directives, national and regional contact information.

Follow:

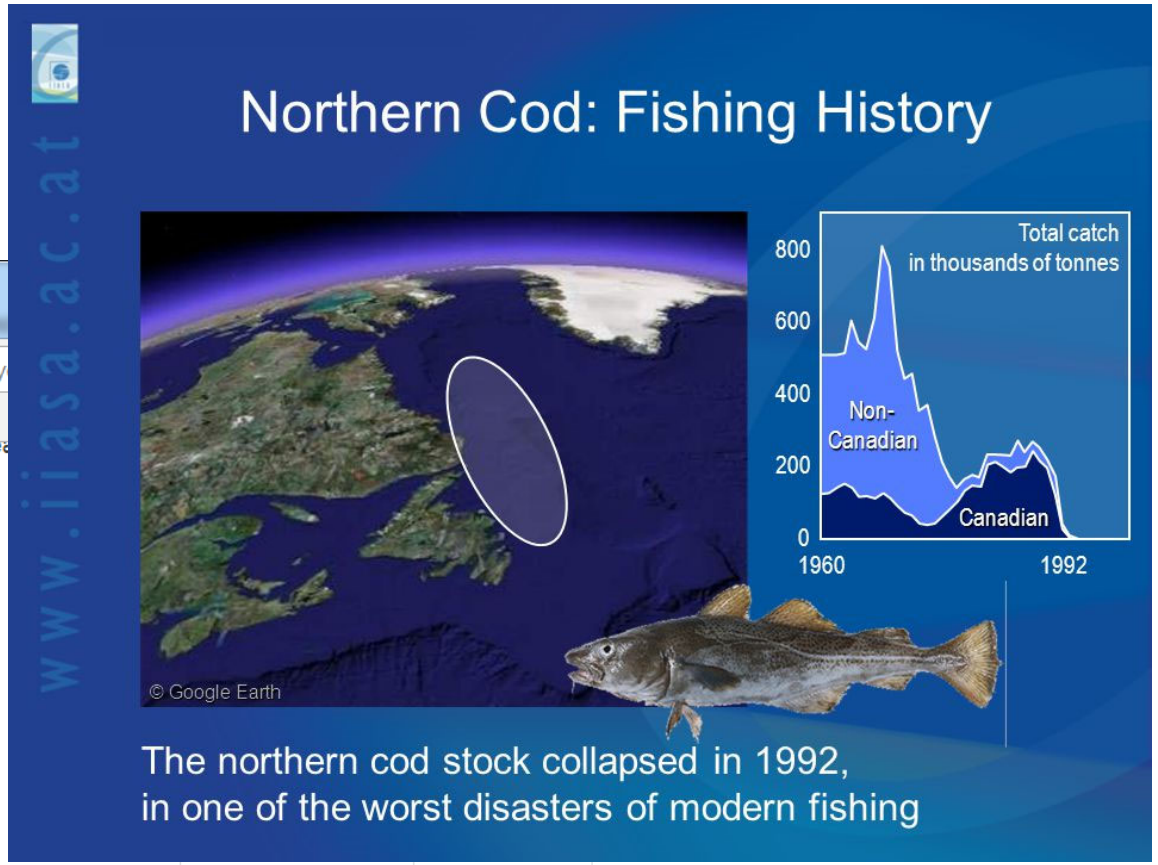
Services and information

Most reque

Science advisory schedule

Policies and guidelines

Northern cod



lsi.gc.ca/csas-sccs/applications/events-evenements/result-eng.asp?y

Google Scholar | St. John's, Newfound | The Telegram - St. Jo

Regional Framework Discussion on Marine Safety and Area

Data Products

Dartmouth, NS

March 21–24 and March 30-31, 2016 Stock Assessment of Northern Cod (Divisions 2J3KL) St. John's, NL	Regional Peer Review NEWFOUNDLAND & LABRADOR	Davis, Ben Chair 709-772-0560 Meade, James CSA Coordinator 709-772-3332	Expected publications: Research Document and Proceedings Terms of Reference Science Advisory Report 2016/026

Northern Cod

Context

The status of Northwest Atlantic Fisheries Organization (NAFO) Divisions 2J3KL Atlantic Cod (i.e., Northern cod) was last fully assessed in March 2013 (DFO 2013). An update was completed in 2014 (DFO 2014) and 2015 (DFO 2015). In November 2010 a limit reference point, as described in the decision-making framework developed by Fisheries and Oceans Canada (DFO) for the application of precaution in the fishery, was determined (DFO 2011). A Regional Peer Review Process was held November 30 - December 4, 2015 to review multiple models of population dynamics, and to discuss the utility of various data sets available for assessing this stock (DFO 2016, *in prep.)*. A stock assessment, in accordance with the Sustainable Fisheries Framework, is requested by Fisheries Management to provide the Minister with advice on the status of the stock covering the period 1 April 2016 - 31 March 2019.

Northern Cod

Objectives

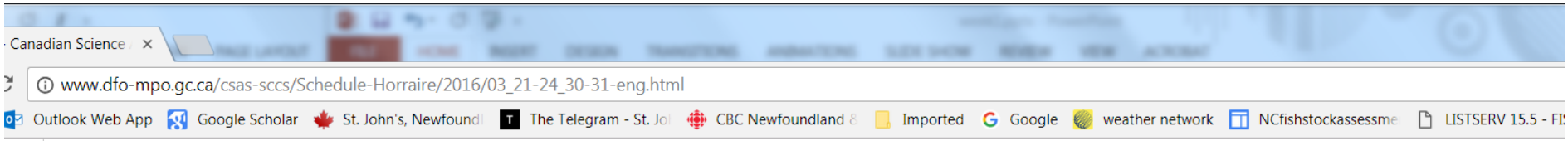
- Provide an ecosystem overview (e.g., physical and biological oceanography, predators, prey) for the stock. If possible, this information should be integrated into the advice.
- Provide an assessment of the current status of cod in Divs. 2J3KL using information updated to 2016.
- Assess the current spawning stock biomass (SSB) relative to the Limit Reference Point (Blim), total biomass, strength of year-classes entering the exploitable population in the next 1 to 3 years, exploitation rate, fishing and natural mortality, distribution, and other relevant biological characteristics.
- Identify the major sources of uncertainty, where applicable.

Northern Cod

Objectives (continued)

- Identify the maximum level of annual removals that will enable a 50% growth in SSB over 2016-2020 years with a high probability of success (>75%).
- DFO's Precautionary Approach (PA) framework indicates there is zero tolerance for preventable decline. Identify the level of removals that provide a very high probability (>95%) of continued stock growth over 2016-2018.
- Identify indicators to follow the stock status during the years without a full stock assessment, and identify events that would trigger an earlier-than-scheduled full assessment.
- 3 year management advice is requested covering the period 1 April 2016 - 31 March 2019.

Northern cod



Expected Publications

- Science Advisory Report
- Proceedings
- Research Document

Participation

- Fisheries and Oceans Canada (DFO) Science and Fisheries Management
- Province of Newfoundland and Labrador Department of Fisheries and Aquaculture
- Non-Governmental Organizations
- Industry Representatives
- Academia
- Aboriginal Groups
- Other invited experts

References

DFO. 2011. Proceedings of the Newfoundland and Labrador Regional Atlantic Cod Framework Meeting: Reference Points and Projection Methods for Newfoundland cod stocks; November 22-26, 2010. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2010/053.

DFO. 2013. Stock Assessment of Northern (2J3KL) Cod in 2013. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2013/014.

DFO. 2014. Northern (2J3KL) Cod Stock Update. DFO Can. Sci. Advis. Sec. Sci. Resp. 2014/030.

DFO. 2015. Northern (NAFO Divs. 2J3KL) Cod Stock Update. DFO Can. Sci. Advis. Sec. Sci. Resp. 2015/018.

Notice:

Participation to CSAS peer review meetings is by invitation only.

US

1 INTRODUCTION

1.1 WORKSHOP TIME AND PLACE

The SEDAR 54 Assessment Process was held via a series of webinars between May 2017 and August 2017.

1.2 TERMS OF REFERNCE

1. Conduct a stock assessment of Sandbar Shark using Stock Synthesis (SS) with data through 2015 using the same data inputs used in the SEDAR 21 benchmark assessment model to the fullest extent appropriate. Document any differences between SS and the previous model.
2. Evaluate the input data listed below compared to the SEDAR 21 assessment model data and document any changes or deviations with respect to those data:
    - Updated life history information (age and growth and reproductive parameters)
    - The relative abundance indices vetted in SEDAR 21 and used in the baseline scenario
    - Updated commercial and recreational discard information
    - Updated length composition information
    - Any new data sources that may have become available since SEDAR 21 was conducted and that may be used with Stock Synthesis.

US

Provide updated input data tables, as appropriate, including any catch (e.g., commercial, recreational, discards) in both weight and number.

3. Provide model parameter estimates and their variances, model uncertainties, diagnostics to determine model performance, including fit to data and convergence, and estimates of stock status and management benchmarks. Provide criteria used to identify the base model run and conduct model sensitivity analysis to address uncertainty in data inputs and model configuration, including model runs that represent plausible alternate states of nature previously identified and vetted in SEDAR 21, as well as other model uncertainties identified during the assessment.
4. Project future stock conditions regardless of the status of the stock. Develop new rebuilding schedules, only if there is new and unexpected information about the status of the stock. Stock projections shall be developed in accordance with the following:

   A) If the stock is overfished and no new rebuilding schedule is warranted, then utilize projections to evaluate current rebuilding plan (started in 2008, projected to end in 2070):

   - F resulting in 50% and 70% probability of rebuilding by 2070
   - Fixed level or removals (TAC) allowing rebuilding of stock by 2070 with 50% and 70% probability

US

B) If the stock is overfished and a new rebuilding schedule is warranted, then utilize projections to determine:

- Provide the estimated generation time for the stock.
- Year in which F=0 results in a 70% probability of rebuilding (Year $F=0_{p70}$)
- Target rebuilding year (Year $F=0_{p70}$ + 1 generation time) ($Year_{rebuild}$)
- F resulting in 50% and 70% probability of rebuilding by $Year_{rebuild}$
- Fixed level or removals (TAC) allowing rebuilding of stock with 50% and 70% probability

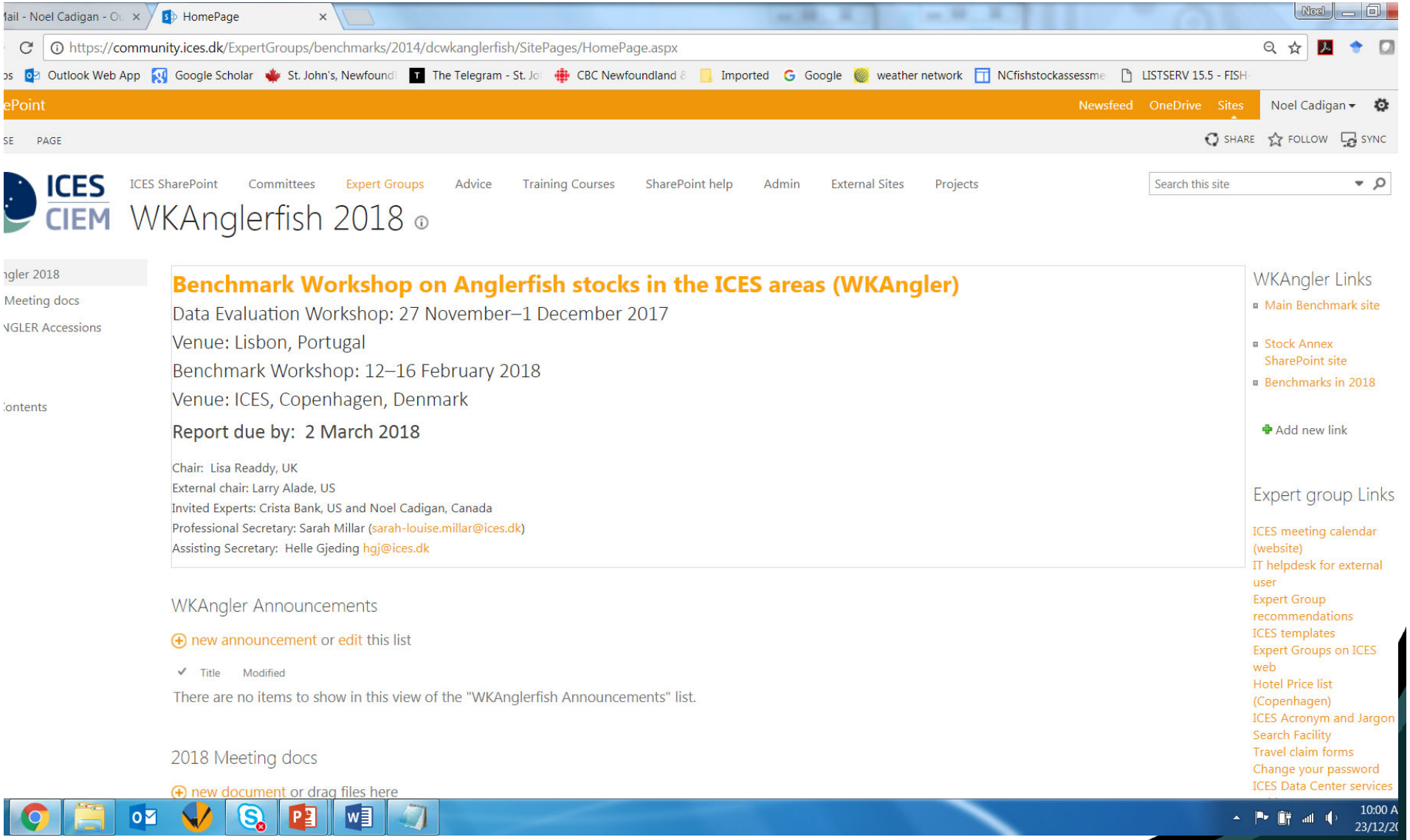
C) Otherwise, utilize a P* approach to determine:

- The F needed and corresponding removals associated with a 70% probability of overfishing not occurring ($P^* = 0.3$)

D) If data or other issues preclude classic projections (i.e. A, B or C above), explore alternate projection models to provide management advice.

5. Develop a stock assessment report to address these TORs and fully document the input data, methods, and results.

Europe - ICES


HomePage
https://community.ices.dk/ExpertGroups/benchmarks/2014/dcwkanglerfish/SitePages/HomePage.aspx
Outlook Web App
Google Scholar
The Telegram - St. Jo
CBC Newfoundland
Imported
Google
weather network
LISTSERV 15.5 - FISH
Newsfeed
OneDrive
Sites
Noel Cadigan
SHARE
FOLLOW
SYNC
ICES SharePoint
Committees
Expert Groups
Advice
Training Courses
SharePoint help
Admin
External Sites
Projects
Search this site
ICES CIEM
WKAnglerfish 2018
Meeting docs
Benchmark Workshop on Anglerfish stocks in the ICES areas (WKAngler)
Data Evaluation Workshop: 27 November–1 December 2017
Venue: Lisbon, Portugal
Benchmark Workshop: 12–16 February 2018
Venue: ICES, Copenhagen, Denmark
Report due by: 2 March 2018
Chair: Lisa Readdy, UK
External chair: Larry Alade, US
Invited Experts: Crista Bank, US and Noel Cadigan, Canada
Professional Secretary: Sarah Millar (sarah-louise.millar@ices.dk)
Assisting Secretary: Helle Gjeding hgj@ices.dk
WKAngler Announcements
new announcement or edit this list
Title
Modified
There are no items to show in this view of the "WKAnglerfish Announcements" list.
2018 Meeting docs
new document or drag files here
WKAngler Links
Main Benchmark site
Stock Annex SharePoint site
Benchmarks in 2018
Add new link
Expert group Links
ICES meeting calendar (website)
IT helpdesk for external user
Expert Group recommendations
ICES templates
Expert Groups on ICES web
Hotel Price list (Copenhagen)
ICES Acronym and Jargon Search Facility
Travel claim forms
Change your password
ICES Data Center services

WKAnglerfish – Benchmark Workshop on Anglerfish

ToRs

a) Evaluate the appropriateness of data and methods to determine stock status and investigate methods for short term outlook taking agreed or proposed management plans into account for the stocks listed in the text table below. The evaluation shall include consideration of:

   i. Stock identity and migration issues;

   ii. Life-history data;

   iii. Fishery-dependent and fishery-independent data;

   iv. Further inclusion of environmental drivers, multi-species information, and ecosystem impacts for stock dynamics in the assessments and outlook

WKAnglerfish – Benchmark Workshop on Anglerfish

ToRs

b) Agree and document the preferred method for evaluating stock status and (where applicable) short term forecast and update the stock annex as appropriate. Knowledge about environmental drivers, including multispecies interactions, and ecosystem impacts should be integrated in the WGmethodology

   If no analytical assessment method can be agreed, then an alternative method (the former method, or following the ICES data-limited stock approach) should be put forward;

c) Re-examine and update if appropriate necessary) MSY and PA reference points according to ICES guidelines (see Technical document on reference points);

d) Develop recommendations for future work to improve the assessment and data collection and processing;

WKAnglerfish – Benchmark Workshop on Anglerfish

ToRs

e) As part of the evaluation:

i. Conduct a 5 day data evaluation workshop (DEWK). Stakeholders are invited to contribute data (including data from non-traditional sources) and to contribute to data preparation and evaluation of data quality. As part of the data compilation workshop consider the quality of data including discard and estimates of misreporting of landings;

ii. Following the DEWK, produce working documents to be reviewed during the Benchmark meeting at least 7 days prior to the meeting

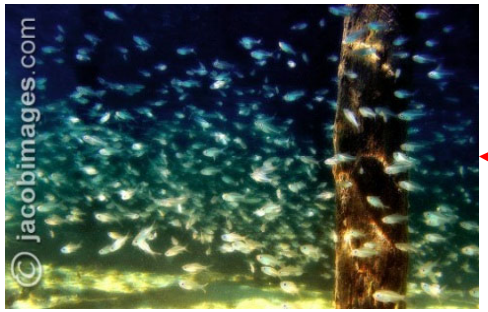
Stocks	Stock leader
Black-bellied anglerfish (*Lophius budegassa*) in Divisions 7b-k and 8a,b,d (West and Southwest of Ireland, Bay of Biscay)	Joana Silva
Black-bellied anglerfish (*Lophius budegassa*) in Divisions 8c and 9a (West and Cantabrian Sea, Atlantic Iberian Waters)	Ricardo Alpoim
White anglerfish (*Lophius piscatorius*) in Divisions 7b-k and 8a,b,d (West and Southwest of Ireland, Bay of Biscay)	Agurtzane Urtizberea
White anglerfish (*Lophius piscatorius*) in Divisions 8c and 9a (West and Cantabrian Sea, Atlantic Iberian Waters)	Paz Sampredo
Anglerfish (*Lophius budegassa, Lophius piscatorius*) in subareas 1 and 2 (Northeast Arctic)	Kjell Nedreaas
Anglerfish (*Lophius Budegassa, Lophius piscatorius*) in subareas 4 and 6, and in Division 3.a (North Sea, Rockall and West of Scotland, Skagerrak and Kattegat)	Helen Holah

SA

- Most RFMO (regional fisheries management organizations) and countries have some type of full and update assessment.
- Canada: framework+updates
- ICES: benchmarks+assessments
- US: full+update

Population Dynamics

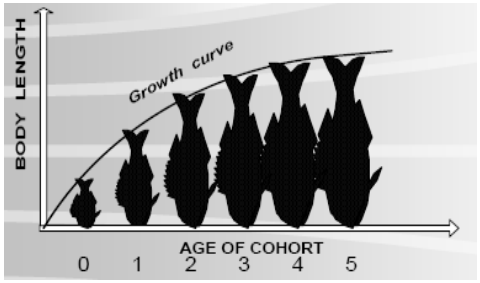
Recruitment



Natural death

Fish stock

Individual growth



Fishing removal

Basic Population Dynamics Theory

- Let *N(t)* denote stock size at time *t*
- The logistic model of population growth:

$$\frac{dN(t)}{dt} = N'(t) = rN(t)\left\{1 - \frac{N(t)}{K}\right\}$$

- When *N(t) = K* then *N′(t) = 0* and the population is stable (i.e. is not increasing or decreasing)

$$\lim_{N(t)\to 0} \frac{N'(t)}{N(t)} = \lim_{N(t)\to 0} r\left(1 - \frac{N(t)}{K}\right) = r$$

- r is called the intrinsic rate of increase

Basic Population Dynamics Theory

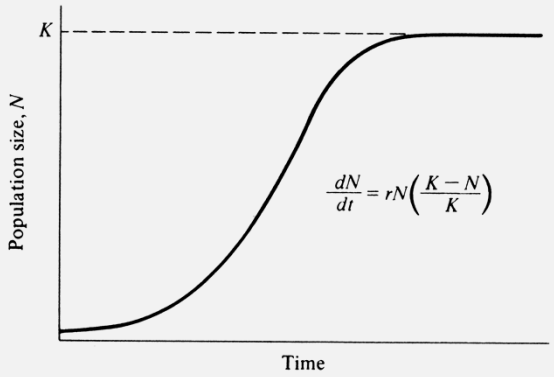
- The differential equation has the solution

$$N(t) = \frac{KN_o \exp(rt)}{K - N_o + N_o \exp(rt)}$$

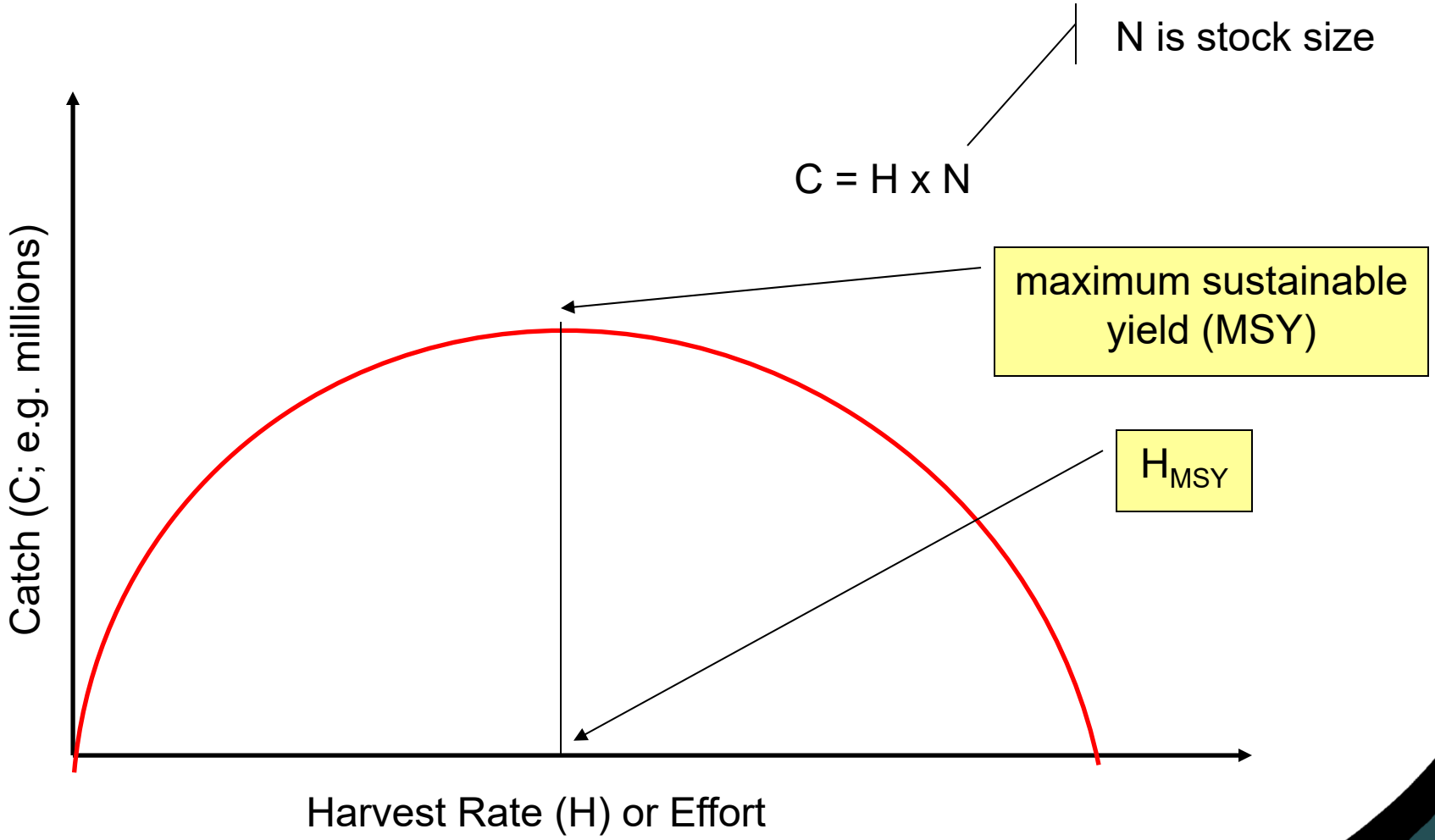
- Easy to show that

$$\lim_{t \to \infty} N(t) = K$$

- *K* is the carrying capacity



Basic Theory of Fishing (in the long run)



Basic Theory of Fishing (in the long run)

- We can think of catch in weight (e.g. kilograms, tonnes, kilotonnes)
- $C = H \times B$, where B is stock biomass
- If we fish at the rate H_{MSY} for long enough then we expect the stock to stabilize at a level B_{MSY}.
- This is the stock size that produces maximum fishing yield.

Evolution of a fishery

- Conceptually, at the beginning of a fishery the stock should be around its carrying capacity, *K*
- As the fishery progresses, the stock will usually get smaller.
- If we fish at the rate H_{MSY} for long enough then we expect the stock to stabilize at a level B_{MSY} which is often about *K/2*.

Evolution of a fishery

- If we fish with size-selective gear then we can expect changes in the size and age distribution of the stock
- We usually target larger and older fish, so the effects of size selective fishing is a reduction in the average age of the stock.
- With individual variability, we can get phenotypic and genotypic changes in stock structure, often favouring slow growth and early maturation

Stock Assessment

- Many stock assessments focus on estimating what is B_{MSY}, and what is the current size of the stock in relation to B_{MSY}.
- Also, many assessments focus on what is F_{MSY}, the fishing mortality rate that results in MSY.
- Note that $F = -log(1-H)$, or something similar.

Fisheries Data

- Stock assessment involves data and analysis
- We usually try and assemble all, or at least the important, sources of data about the stock,
- and use this information to **objectively** draw conclusions about stock status and the impacts of fishing
- Stakeholders prefer objective information based on **peer reviewed** analysis

Stock assessment data: fishery

- Surveillance information on total catch (e.g. tonnes) and effort (no. vessels, hours fished, etc).
  i. Dealer reports and purchase slips (accuracy????)
  ii. Self-reported via logbooks (return rates??)
  iii. Dockside monitoring (random or subset of ports)
  iv. At sea observors (random or subset of fleets/vessels)
- There are economic incentives to not report catch in many fisheries.
- Problems: unreported catches, discarding, high-grading
- Science does not usually collect the catch data

Catch data

- Fishing vessels are usually required as a condition of licence to report their catch (landings and discards).
- In addition, they may be required to report catch composition, fishing region, days at sea, vessel information, gear type, etc.
- The accuracy of the reported landings may be checked at sea and at dockside
- Some fisheries require onboard observers so that catches are independently monitored.

Catch data

- This does not happen for all “fleets” however.
- It is usually too expensive to have observers or dock-side monitors for small boat fisheries that may land many small catches.
- Similar for recreational fisheries – and these can be extensive with removals greater than commercial fisheries

Catch data

- In these cases the total fleet removals may be estimated using a statistical survey approach;
- that is, some type of random sampling approach in which the catch is measured for a subset of fleets members, etc
- and then the total catch is estimated by scaling up the measured catch by the sampling fraction.
- In this sense, the monitoring of large boat fleets can be considered to be a census (fraction=1).

Catch data

- The survey sampling designs used to estimate catches can be quite complex,
- and involve cluster (e.g. port, vessel, day, …) sampling, or stratified (e.g. region, quarter, …) cluster sampling.
- A cluster is a group of “fishing events” whose responses are usually correlated
- A stratum is a division of all fishing events.

Catch data

- Clusters are randomly sampled, whereas all stratum are sampled.
- The estimation of total catch can also be complex, and involve auxiliary variables and results from previous surveys.
- Regulatory agencies often have groups of people who specialize in monitoring and estimating fishery catches.
- Objective is to provide unbiased estimates

Statistics

In order to monitor fisheries-related activities and identify trends over time, Fisheries and Oceans Canada (DFO) collects and compiles statistics related to aquaculture, commercial fisheries, recreational fishing and trade (imports/exports). Statistics play a key role in the Department's decision-making processes, helping to ensure sustainable management of Canada's aquatic resources.

National Statistics

Aquaculture

- Value Added
- Production Quantities and Values
- Other Statistics and Key Figures

Commercial Fisheries

- Landings
- Licences
- Quota Reports
- Publications
- Consumption

Recreational Fishing

- Canada
- Great Lakes
- Pacific

Trade

- Canadian
- World
- Publications

Maritime Sector in Canada

- Summary Tables
- Maritime Sector Methodology

Fisheries and the Canadian Economy

- Values and Outputs
- Employment
- Gross Domestic Product (GDP)

Highlights

- Fast Facts 2016 (PDF)
- Fast Facts 2015 (PDF)
- Fast Facts 2014 (PDF)
- Fast Facts 2013 (PDF)
- Fast Facts 2012 (PDF)
- Fast Facts 2011 (PDF)
- Fast Facts 2010 (PDF)
- Fast Facts 2009 (PDF)
- Fast Facts 2008 (PDF)

Economic Analysis

Methodology, Data Sources and Contacts

Reports and Publications

Catch data

- Biological sampling of fishery catches is often conducted by science groups.
- Again complicated survey designs may be employed to estimate
  - length and age compositions, and sex ratios,
  - by country, region, gear, quarter, vessel class, etc.

Basic Estimation of Catch at Age

- The age composition information is often used to estimate catch numbers at age (C_a)
- C_a are unknown population values that we estimate using total landed weight (TWT) and biological survey sampling estimates of proportion at age ($\hat{P}_a$; $P_a = C_a / \sum_a C_a$) and weight at age ($\hat{W}_a$)
- Notation: $\hat{P}_a$ is an *estimate* of the **unknown population value** of $P_a = C_a / \sum_a C_a$. $\hat{P}_a$ based on biological sampling data
- Same for $\hat{W}_a$.

Basic Estimation of Catch at Age

- Population value of $TWT = \sum_a C_a W_a = \sum_a C_{tot} P_a W_a = C_{tot} \sum_a P_a W_a$
- $\Longrightarrow C_{tot} = TWT / \sum_a P_a W_a$
- We estimate C_{tot} using
- $\hat{C}_{tot} = TWT / \sum_a \hat{P}_a \hat{W}_a = TWT / \hat{\bar{W}}$,
  - where $\hat{\bar{W}} = \sum_a \hat{P}_a \hat{W}_a$
- $\hat{C}_a = \hat{C}_{tot} \hat{P}_a$
- $CV^2(\hat{C}_a) \cong CV^2(\hat{P}_a) + CV^2(\hat{C}_{tot})$

Comes from enforcement monitoring

Quinn and Deriso (1999)

Catch data

- There is often considerable uncertainties about catches – both surveyed and surveillance (i.e. census) catches.
- Discards are often not reported, sometimes even when observers are onboard
- Landings may be misreported, when no one is looking
- high-grading (discarding of less profitable species and sizes) occurs

Catch data

- Recreational effort (i.e. number participants, number of trips) is difficult to estimate
- Recreational discards and their mortality rates are difficult to estimate.
- There is usually high-grading in recreational fisheries.
- Reporting/recall bias in telephone surveys

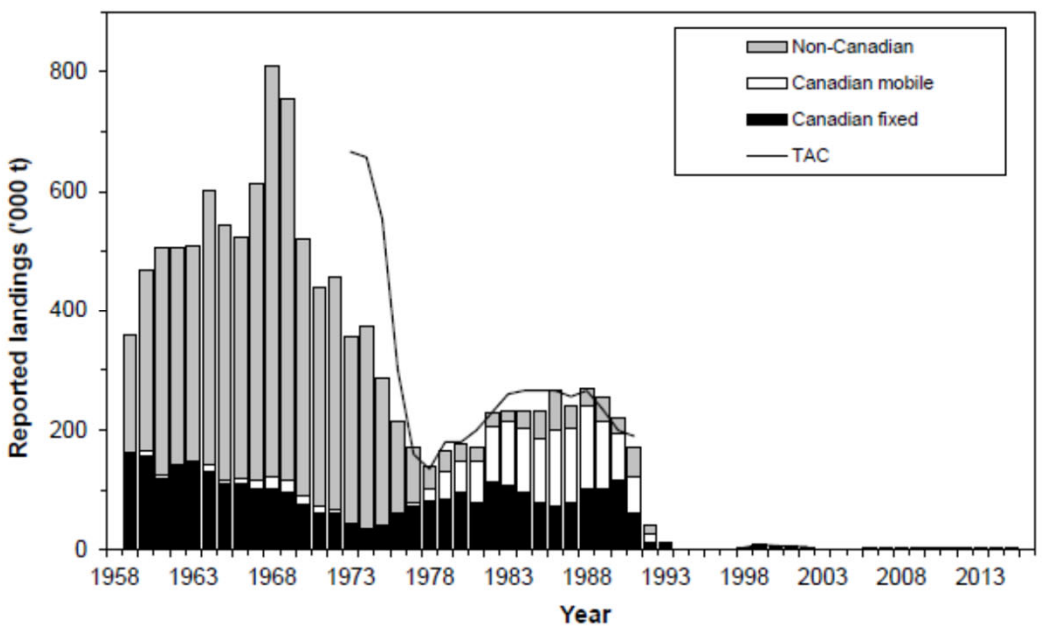
Catch data

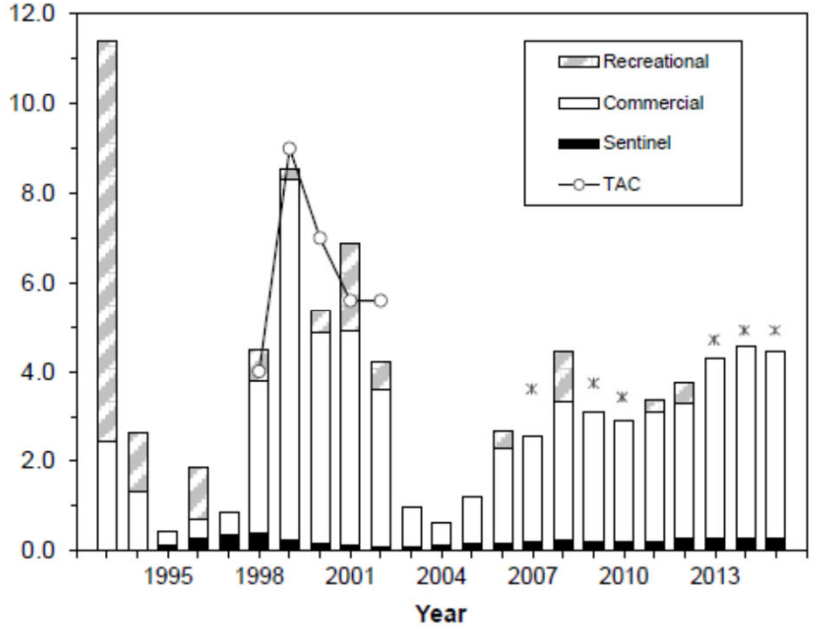
- Species/stock, location, and gear type may be mis-reported.
- MSC (Marine Stewardship Council) is improving the situation
- Certification requires that fish can be traced back through the entire supply chain back to the source fishery – from boat to plate.

Catch data

- So commercial catch monitoring is improving
- But recreational fisheries remain a challenge
- Stock assessment usually requires a long time series of catches
- So even if recent catches are better, problems in historic data can still be a major problem for reliable stock assessments

Northern cod fishery background





Some fleets are more difficult to monitor than others

Catch data

- Lets look at some of the catch data that has been measured over time for cod in NAFO (North Atlantic Fisheries Organization) Subdivision 3Ps, for cod (*Gadus morhua*)
- This data is presented in the 2017 research document for this stock:

Fisheries and Oceans Canada | Pêches et Océans Canada

Ecosystems and Oceans Science | Sciences des écosystèmes et des océans

Canadian Science Advisory Secretariat (CSAS)

Research Document 2017/063

Newfoundland and Labrador Region

Catch data

Assessing the status of the cod (*Gadus morhua*) stock in NAFO Subdivision 3Ps in 2016

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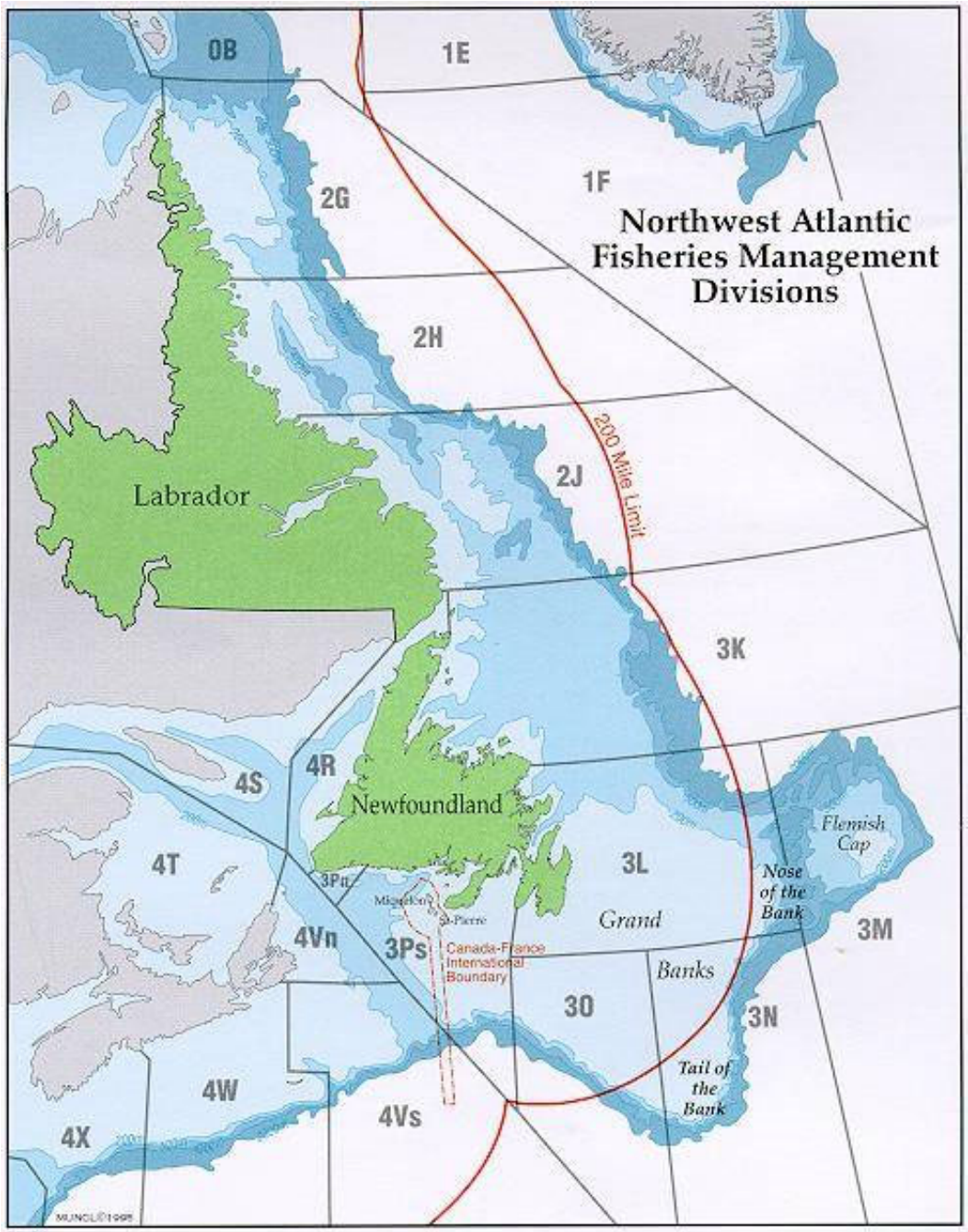

Northwest Atlantic
Fisheries Management
Divisions
0B
1E
1F
2G
2H
2J
3K
3L
3M
3N
3O
3Ps
3Pn
4R
4S
4T
4Vn
4Vs
4W
4X
Labrador
Newfoundland
200 Mile Limit
Canada-France
International
Boundary
Grand
Banks
Flemish
Cap
Nose
of the
Bank
Tail of
the
Bank
St-Pierre

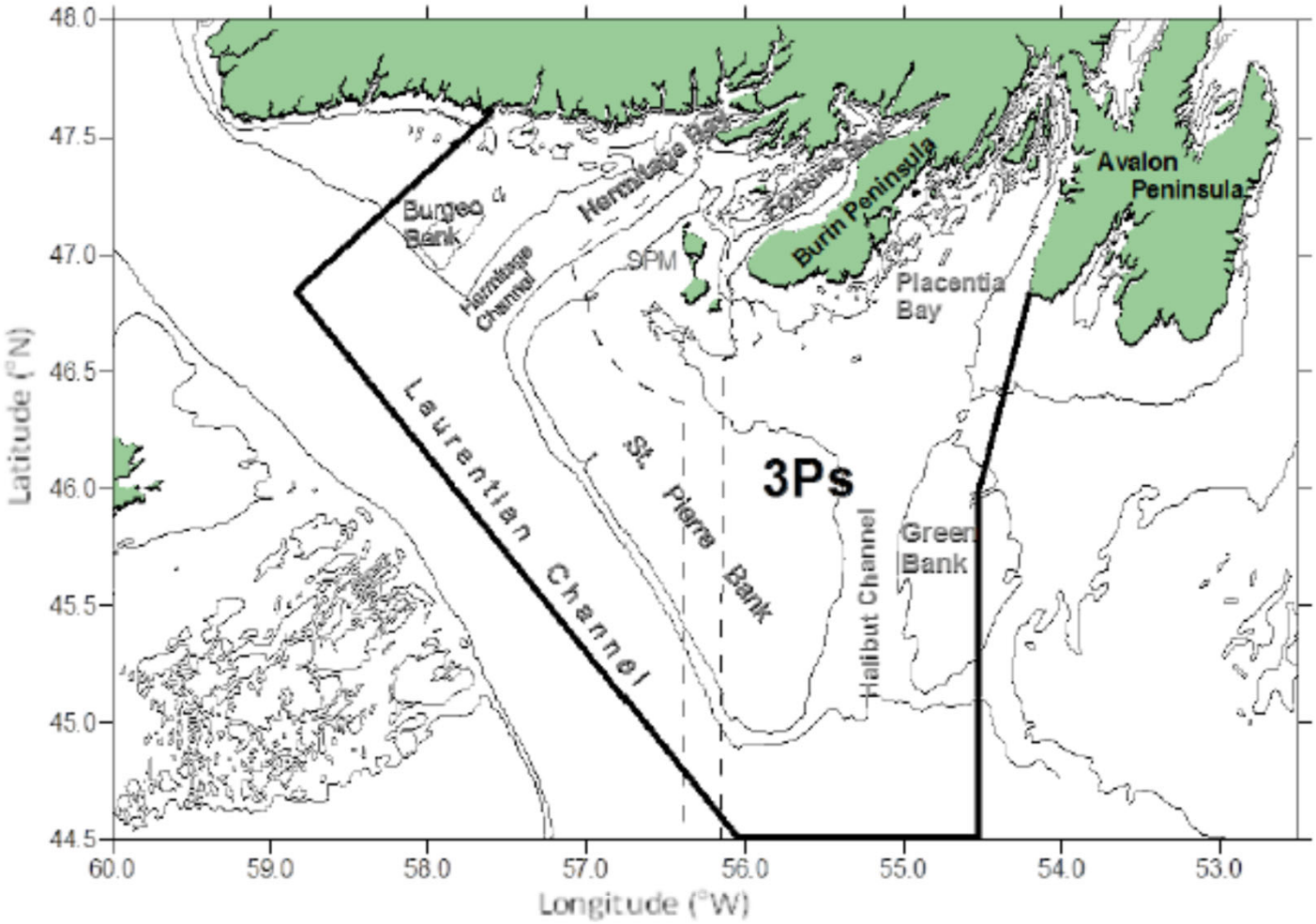


Figure 2. NAFO Subdiv. 3Ps management zone showing the economic zone around the French islands of St. Pierre and Miquelon (SPM, dashed line), the 100 m and 250 m depth contours (grey lines) and the main fishing areas.

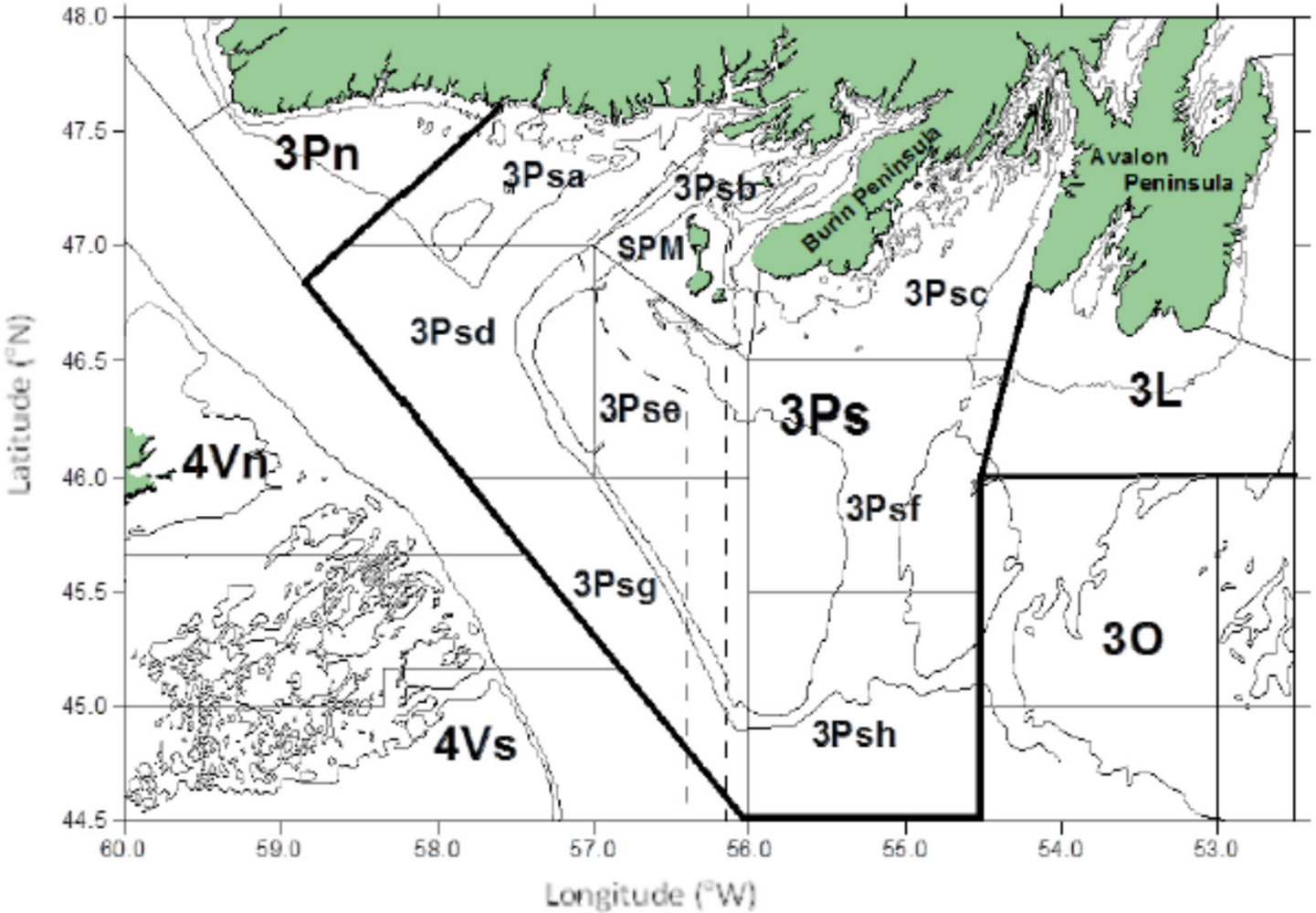


Figure 1. NAFO Subdiv. 3Ps management zone showing the economic zone around the French islands of St. Pierre and Miquelon (SPM, dashed line), the 100 m and 250 m depth contours (grey lines) and the boundaries of the statistical unit areas (solid lines).

Table 1. Reported landings of cod (t) from NAFO Subdiv. 3Ps by country and for fixed and mobile gear sectors. Landings are presented by calendar year but note that since 2000 the TAC has been established for April 1-March 31. Catch estimates for 2016 are incomplete since the fishing year was in progress at the time of the assessment. See Healey et al. (2014) for pre-1980 data.

Year	Canada NL (Mobile)	Canada NL (Fixed)[2]	Canada Mainland (All gears)	France SPM (Inshore)	France SPM (Offshore)	France Metro (All gears)	Others (All gears)	Total	TAC
1980	2,809	29,427	715	214	1,722	2,681	-	37,568	28,000
1981	2,696	26,068	2,321	333	3,768	3,706	-	38,892	30,000
1982	2,639	21,351	2,948	1,009	3,771	2,184	-	33,902	33,000
1983	2,100	23,915	2,580	843	4,775	4,238	-	38,451	33,000
1984	895	22,865	1,969	777	6,773	3,671	-	36,950	33,000
1985	4,529	24,854	3,476	642	9,422	8,444	-	51,367	41,000
1986	5,218	24,821	1,963	389	13,653	11,939	7	57,990	41,000
1987	4,133	26,735	2,517	551	15,303	9,965	-	59,204	41,000
1988	3,662	19,742	2,308	282	10,011	7,373	4	43,382	41,000
1989	3,098	23,208	2,361	339	9,642	892	-	39,540	35,400
1990	3,266	20,128	3,082	158	14,771	-	-	41,405	35,400
1991	3,916	21,778	2,106	204	15,585	-	-	43,589	35,400
1992	4,468	19,025	2,238	2	10,162	-	-	35,895	35,400
1993	1,987	11,878	1,351	-	-	-	-	15,216	20,000
1994	82	493	86	-	-	-	-	661	0
1995	26	676	60	59	-	-	-	821	0
1996	60	836	118	43	-	-	-	1,057	0
1997	108	7,594	79	448	1,191	-	-	9,420	10,000
1998	2,543	13,609	885	609	2,511	-	-	20,156	20,000
1999	3,059	21,156	614	621	2,548	-	-	27,997	30,000
2000	3,436	16,247	740	870	3,807	-	-	25,100	20,000
2001	2,152	11,187	856	675	1,675	-	-	16,546	15,000
2002	1,326	11,292	499	579	1,623	-	-	15,319	15,000
2003	1,869	10,600	412	734	1,645	-	-	15,260	15,000
2004	1,595	9,450	790	465	2,113	-	-	14,414	15,000
2005	1,863	9,537	818	617	1,941	-	-	14,776	15,000
2006	1,011	9,590	675	555	1,326	-	-	13,157	13,000
2007	1,339	9,303	294	520	1,503	-	-	12,959	13,000
2008	982	8,654	377	467	1,293	-	-	11,773	13,000
2009	1,733	5,870	193	282	1,684	-	-	9,762	11,500
2010	1,419	5,244	196	76	1,364	-	-	8,299	11,500
2011	1,392	4,046	300	456	682	-	-	6,876	11,500
2012	658	3,596	277	265	291	-	-	5,087	11,500
2013	378	2,680	174	366	768	-	-	4,366	11,500
2014	472	4,199	637	279	1,158	-	-	6,745	13,225
2015[1]	962	3,706	175	440	724	-	-	6,008	13,490
2016[1]	1,602	2,037	222	273	616	-	-	4,751	13,043

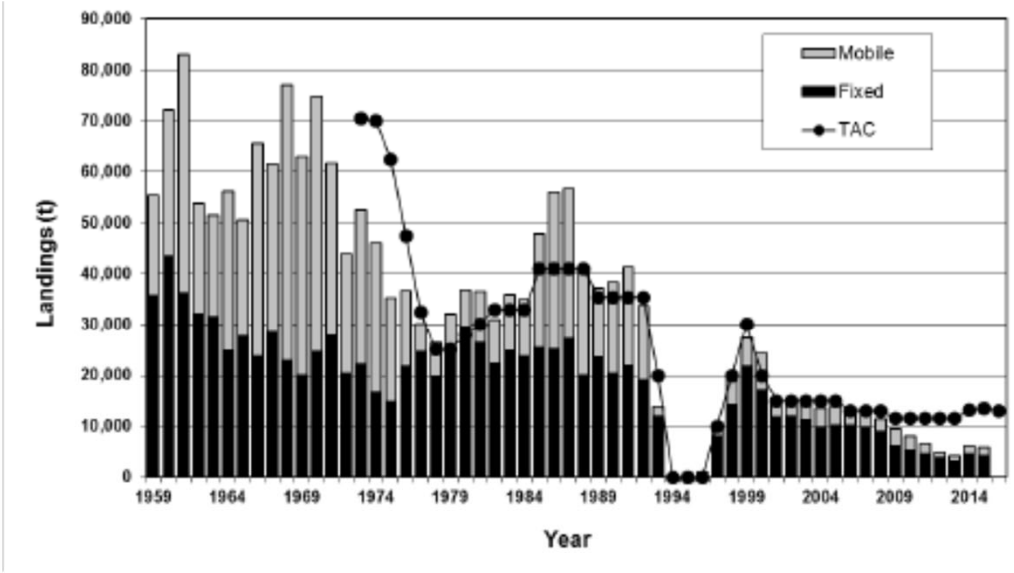


Figure 3b. Reported landings of cod by fixed and mobile gears in NAFO Subdiv. 3Ps. Note that the 2016 fishery was still in progress at the time of the current assessment.

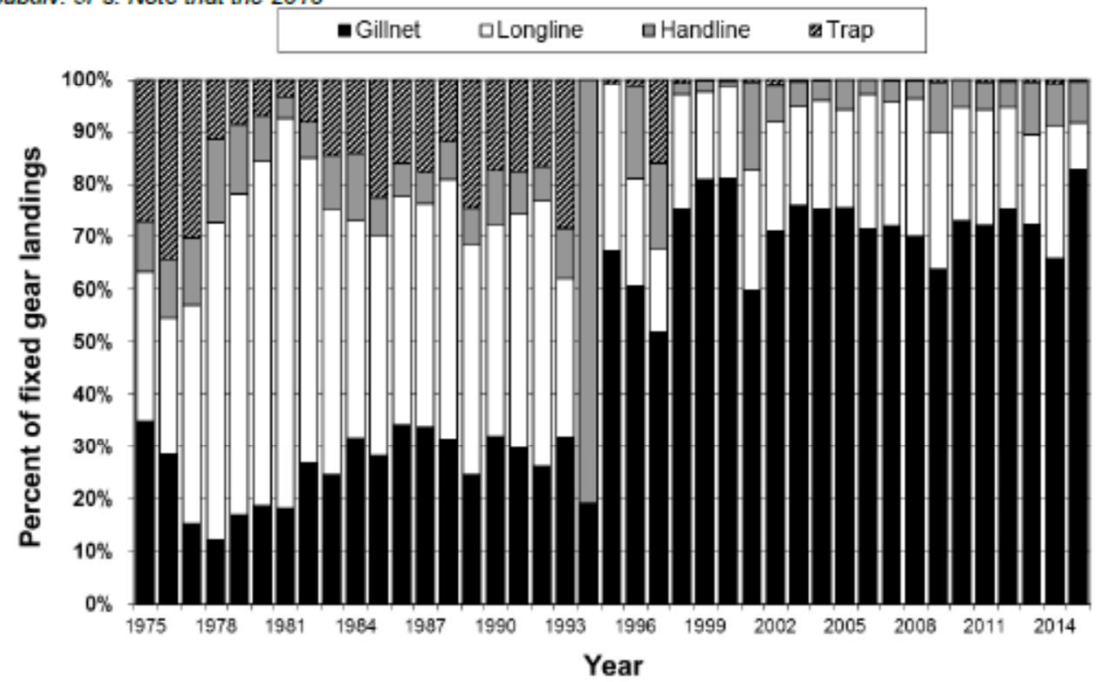


Figure 4. Percent of total fixed gear landings by the four main fixed gears used in the cod fishery in NAFO Subdiv. 3Ps. The fishery was under a moratorium during 1994-96 and values for those years are based on sentinel and by-catch landings of < 800 t.

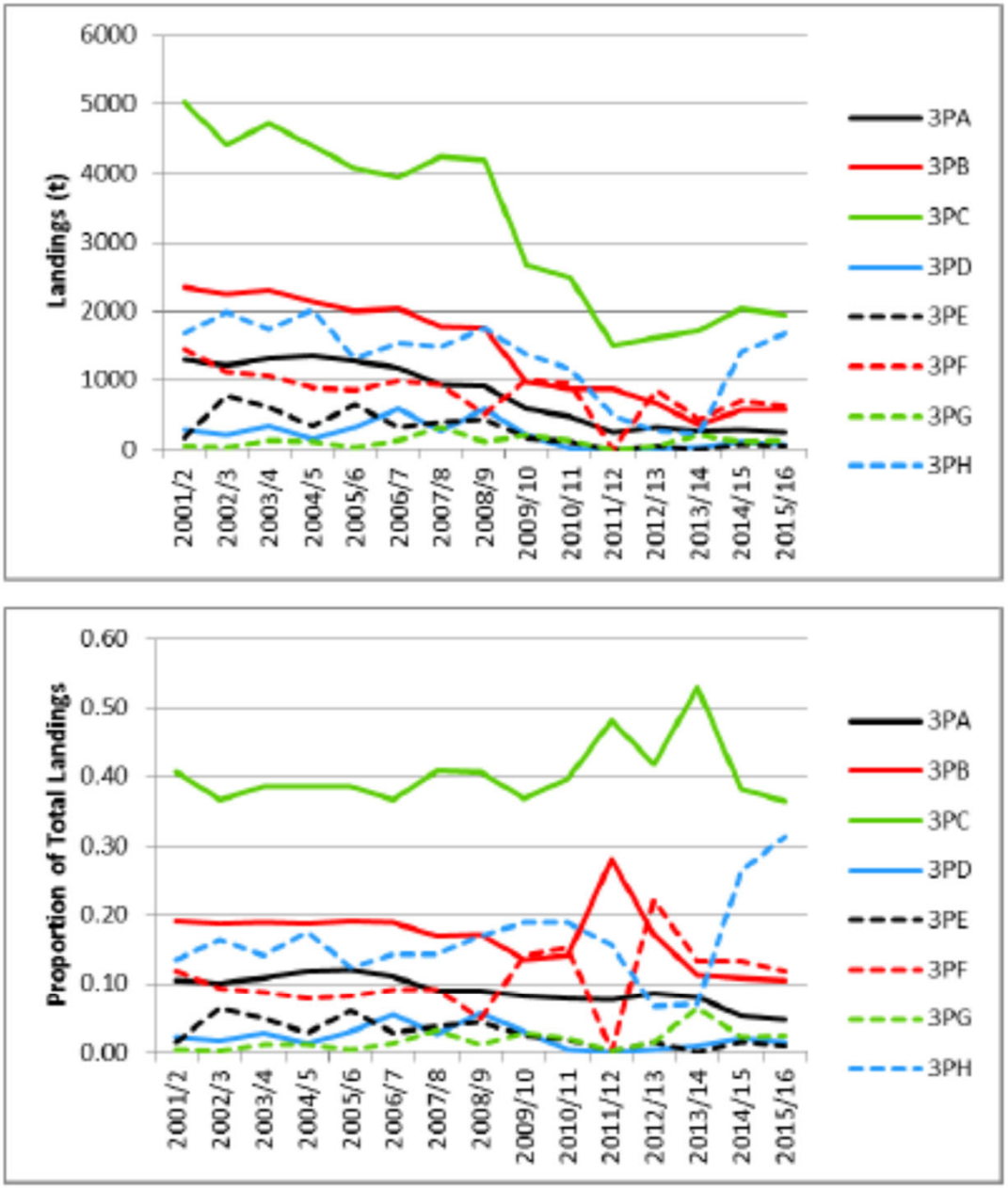
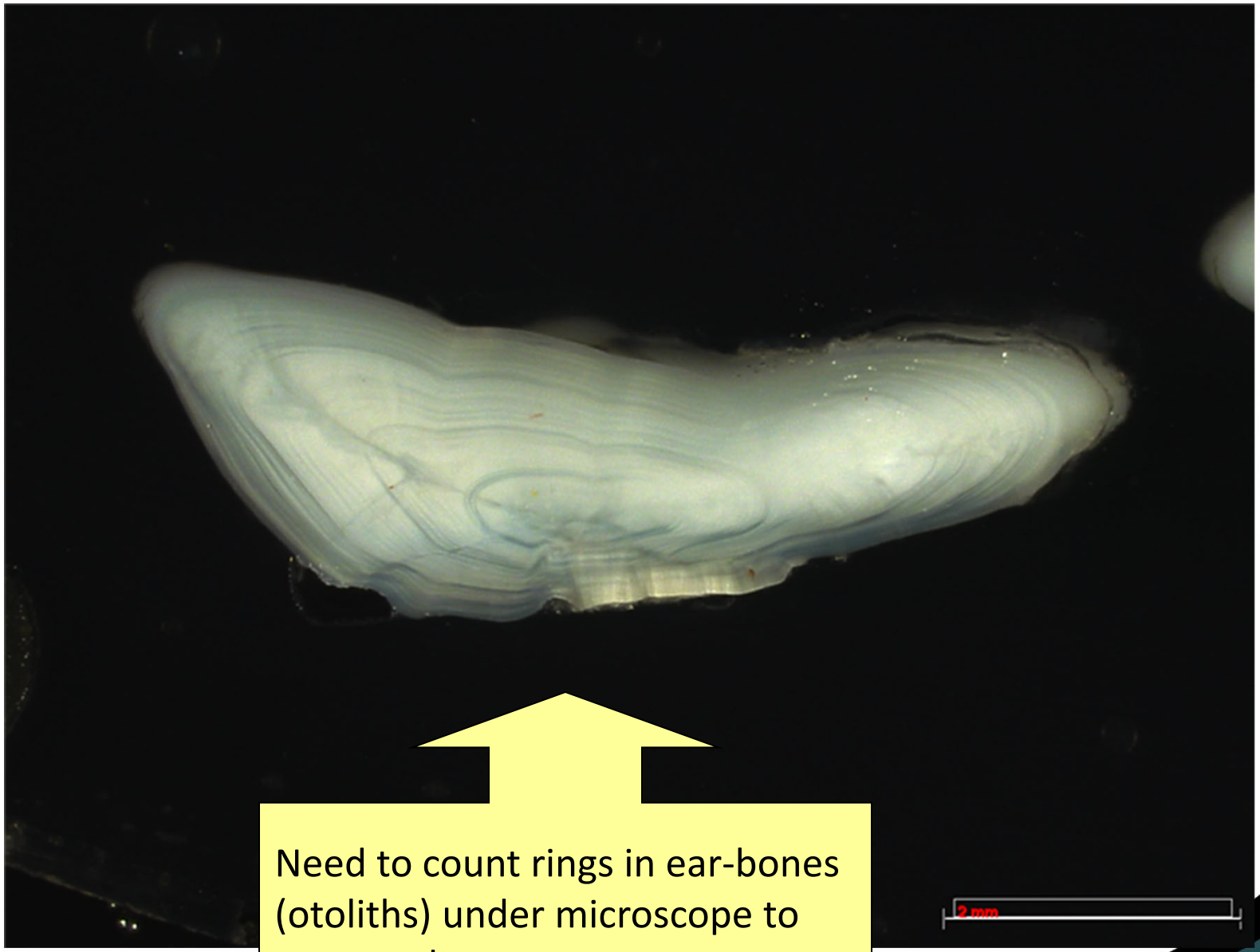


Figure 5. Breakdown of recent Canadian annual landings of 3Ps cod by statistical unit areas. Both landings (upper panel) and percent of total landings (lower panel) are presented. Unit area is not available for SPM landings. Refer to Figure 1 for locations of unit areas.

Catch at age data

- This is very important for stock assessment
- First estimate catch at length, which is cheap to do because lengths are easy to measure
- Then estimate an age-length key (age-distribution at length)
- This is more expensive to do because aging cod is more expensive
- DFO uses quarterly age-length keys, by gear?



Need to count rings in ear-bones (otoliths) under microscope to age a cod

Table 4. Number of cod sampled for length and age and available to estimate the commercial catch at age for 2009

	Number Measured (Canada)							
	Offshore			Inshore				
Month	Ottertrawl	Gillnet	Linetrawl	Gillnet	Linetrawl	Handline	Other	Total
Jan	1,826			3,200	1,343		63	6,432
Feb	1,357		409	2,261	635	76		4,738
Mar	1,052				96			1,148
Apr								0
May				542		154		696
Jun				7,419	2,058	314	81	9,872
Jul				4,868	2,324		503	7,695
Aug				542	2,342		111	2,995
Sep		474		199	2,032		49	2,754
Oct		717		466	2,837		0	4,020
Nov		251	561	653	6,456	154	143	8,218
Dec				732	2,327	5	20	3,084
Total	4,235	1,442	970	20,882	22,450	703	970	51,652

	Number Aged (Canada)							
	Offshore			Inshore				
Quarter	Ottertrawl	Gillnet	Linetrawl	Gillnet	Linetrawl	Handline	Ottertrawl	Total
1	612		178	597	197	25		1,609
2				578	251	77		906
3		114		349	696			1,159
4		244	117	207	1,076	33		1,677
Total	612	358	295	1,731	2,220	135	0	5,351

Sampling by France (SPM)

	Measured		Aged	
Quarter	Ottertrawl	Gillnet	Ottertrawl	Gillnet
1				
3				
4	730		32	
Total	730	0	32	0

Catch Sampling - 2016

30,782 fish measured

Commercial sampling:

- Gillnet 53%
- Hand line 7%
- Line trawl 12% **(no offshore)**
- Otter trawl 31%

- 61% of LFs from observers, 39% from port sampling

Sentinel Sampling:

- Gillnet 32%
- Line trawl 68%

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
COMMERCIAL													**23511**
GILL NET													
3PA		994											994
3PB	74	1139					31						1244
3PC	417	1359				1983	1511				2101	374	7745
3PD										282			282
3PF									1704	399			2103
HAND LINE													
3PC		16				744	809				61		1630
LINE TRAWL													
3PA		308											308
3PB	974	395											1369
3PC	897	61							224				1182
OTTER TRAWL													
3PD			29										29
3PH	620	3008	1368									1629	6625
3PH (FR)		627											627
SENTINEL													**6644**
GILL NET													
3PB					91	97	20						208
3PC	127				14	244	375	200	303	154	242	259	1918
LINE TRAWL													
3PB	321						637	67	645	363	1817	565	4415
3PC								17	25	61			103
TOTAL	3430	7907	1397	0	105	3068	3383	284	2901	1259	4221	2827	30782

Age Sampling - 2016

1,209 fish aged

- 80% from commercial
- 20% from sentinel

	Quarter				
	1	2	3	4	Total
COMMERCIAL					**968**
GILL NET					
3PC				55	55
3PF				8	8
HAND LINE					
3PC			147		147
LINE TRAWL					
3PA	57				57
3PC	109			28	137
3PG	52				52
OTTER TRAWL					
3PH	431			81	512
3PH (FR)	75				75
SENTINEL					**241**
GILL NET					
3PB			42		42
3PC				39	39
LINE TRAWL					
3PB				160	160
Total	724	0	189	371	**1209**

Catch at age data

- The same age-length key can be used for different gear types
- Whereas the length distribution (and age distribution) will vary for different gear types.

Age-length key

	ages																													
len group	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	tot
10	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
11	0	2	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9
12	0	1	13	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16
13	0	0	11	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19
14	0	0	15	9	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25
15	0	0	7	16	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	28
16	0	0	1	10	16	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30
17	0	0	0	3	25	6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	35
18	0	0	0	0	11	11	10	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	34
19	0	0	0	2	12	14	6	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	38
20	0	0	0	0	3	10	7	9	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32
21	0	0	0	0	5	10	5	6	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30
22	0	0	0	0	2	3	7	9	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24
23	0	0	0	0	1	6	3	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16
24	0	0	0	0	1	1	1	6	3	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13
25	0	0	0	0	0	2	0	1	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
26	0	0	0	0	0	0	0	3	2	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8
27	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
28	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
29	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
30	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

Catch at age data

- The steps to estimate the age distribution from catch-at-length and age-length key are:
- Compute proportion at age for each length group
- Multiply catch-at-length by corresponding proportion at age in each length group
- Sum catch-at-age-by-length over lengths to produce the catch-at-age

Proportion-at-age-by-length

	ages																													
len group	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
10	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	0.00	0.22	0.78	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	0.00	0.06	0.81	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	0.00	0.00	0.58	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	0.00	0.00	0.60	0.36	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	0.00	0.00	0.25	0.57	0.11	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	0.00	0.00	0.03	0.33	0.53	0.07	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	0.00	0.00	0.00	0.09	0.71	0.17	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	0.00	0.00	0.00	0.00	0.32	0.32	0.29	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	0.00	0.00	0.00	0.05	0.32	0.37	0.16	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.09	0.31	0.22	0.28	0.06	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21	0.00	0.00	0.00	0.00	0.17	0.33	0.17	0.20	0.07	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22	0.00	0.00	0.00	0.00	0.08	0.13	0.29	0.38	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23	0.00	0.00	0.00	0.00	0.06	0.38	0.19	0.31	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24	0.00	0.00	0.00	0.00	0.08	0.08	0.08	0.46	0.23	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.17	0.17	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.38	0.25	0.25	0.00	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.00	0.00	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Catch-at-length

len group	catch
10	100
11	150
12	200
13	250
14	300
15	300
16	300
17	400
18	400
19	300
20	300
21	300
22	250
23	250
24	250
25	200
26	200
27	150
28	100
29	50
30	10

4760 in total

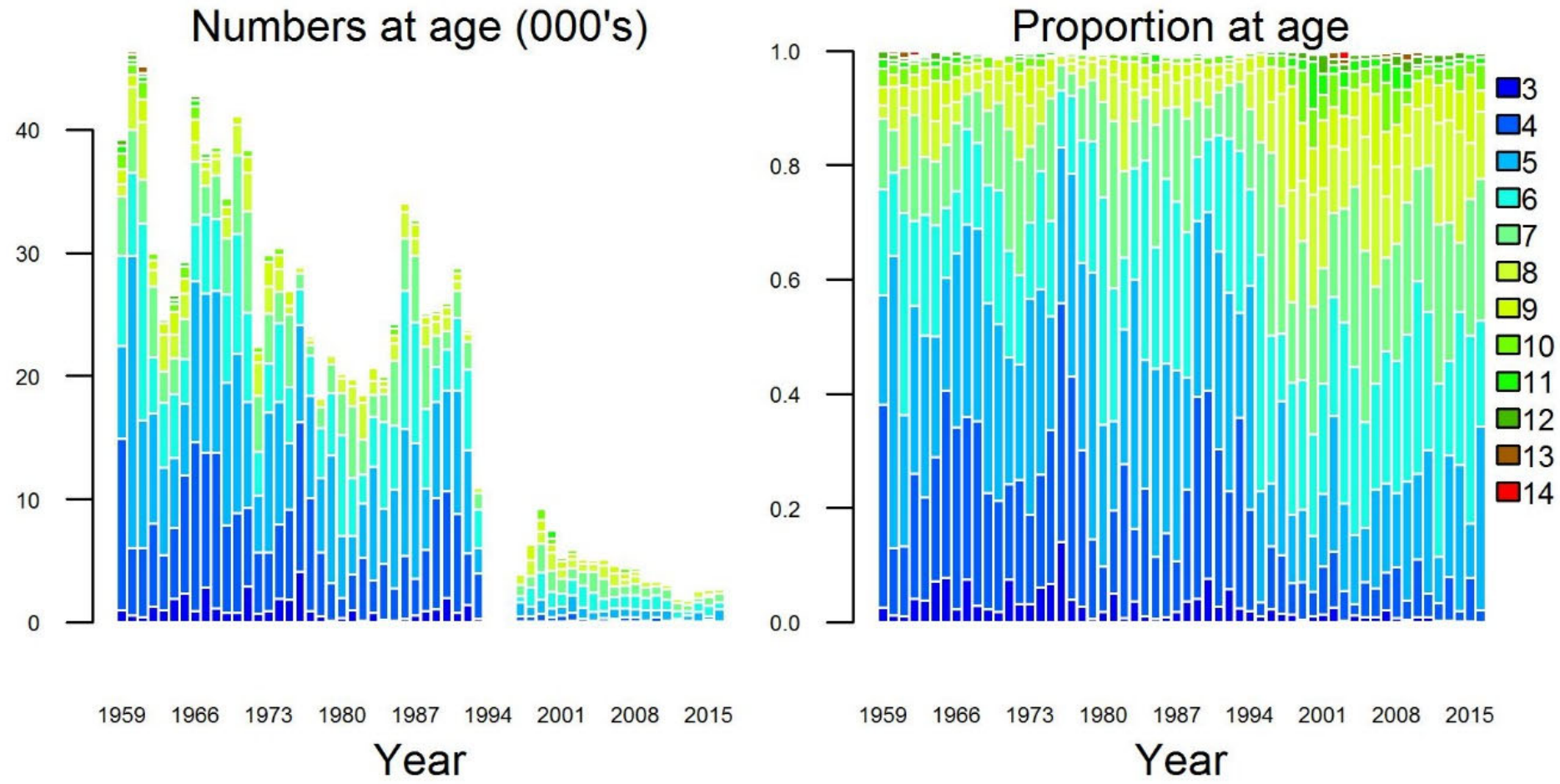
Catch-at-age-by-length

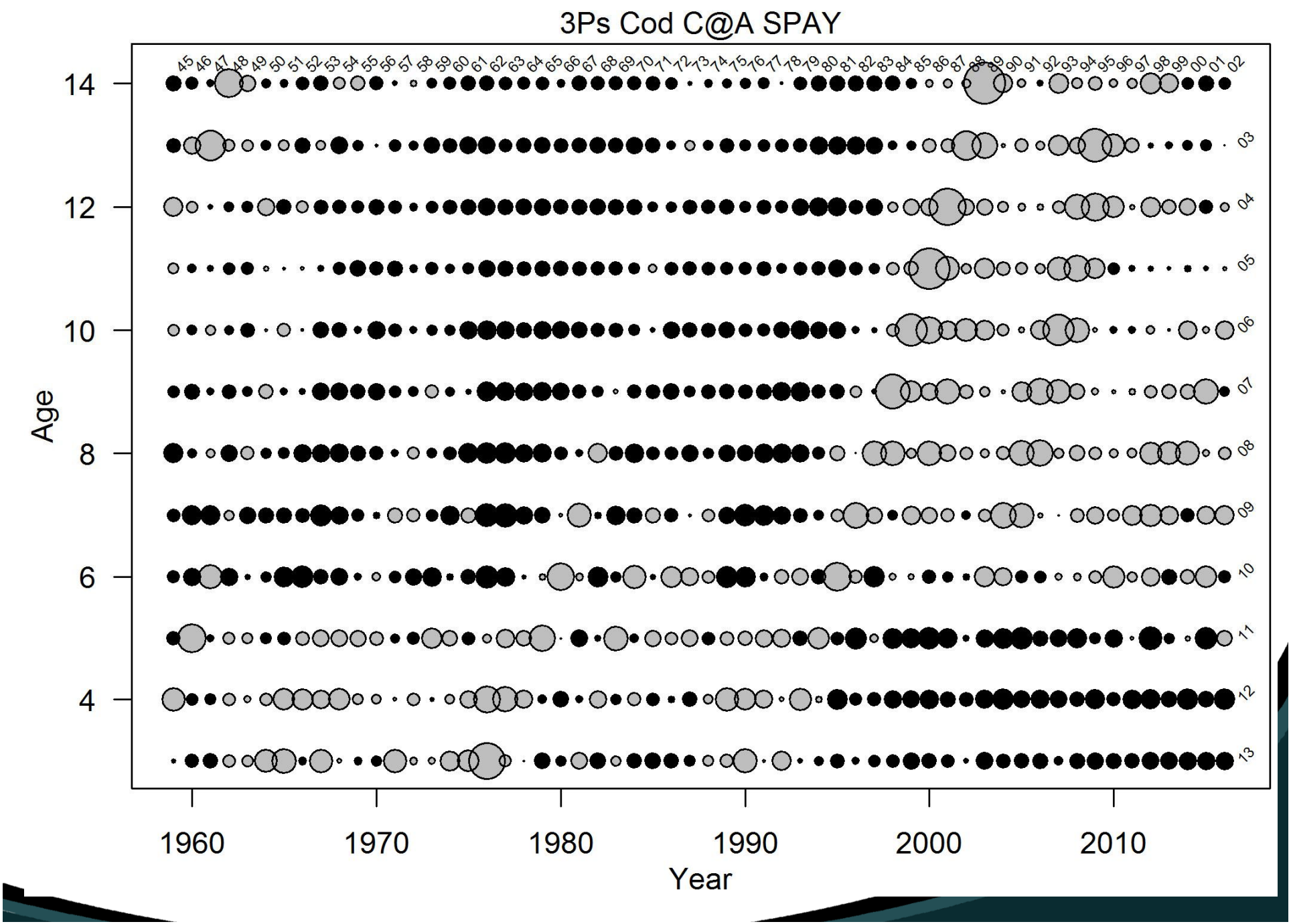
	ages																			
len group	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
10	0	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	33.3	117	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	12.5	163	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	145	105	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	180	108	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	75	171	32.1	21.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	10	100	160	20	10	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	34.3	286	68.6	11.4	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	129	129	118	23.5	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	15.8	94.7	111	47.4	31.6	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	28.1	93.8	65.6	84.4	18.8	9.38	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	50	100	50	60	20	20	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	20.8	31.3	72.9	93.8	31.3	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	15.6	93.8	46.9	78.1	15.6	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	19.2	19.2	19.2	115	57.7	0	0	19.2	0	0	0	0	0	0	0	0
25	0	0	0	0	0	66.7	0	33.3	33.3	66.7	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	75	50	50	0	25	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	150	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	50	0	0	50	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	50	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0
total	0	146	689	560	848	755	441	595	377	246	0	44.2	50	10	0	0	0	0	0	0

Sum over rows gives catch-at-age

Sum over columns is 4760 – the same as the sum of catch-at-length

3Ps Cod C@A


Numbers at age (000's)
40
30
20
10
0
1959
1966
1973
1980
1987
1994
2001
2008
2015
Year
Proportion at age
1.0
0.8
0.6
0.4
0.2
0.0
3
4
5
6
7
8
9
10
11
12
13
14
1959
1966
1973
1980
1987
1994
2001
2008
2015
Year


3Ps Cod C@A SPAY
Age
14
12
10
8
6
4
1960
1970
1980
1990
2000
2010
Year

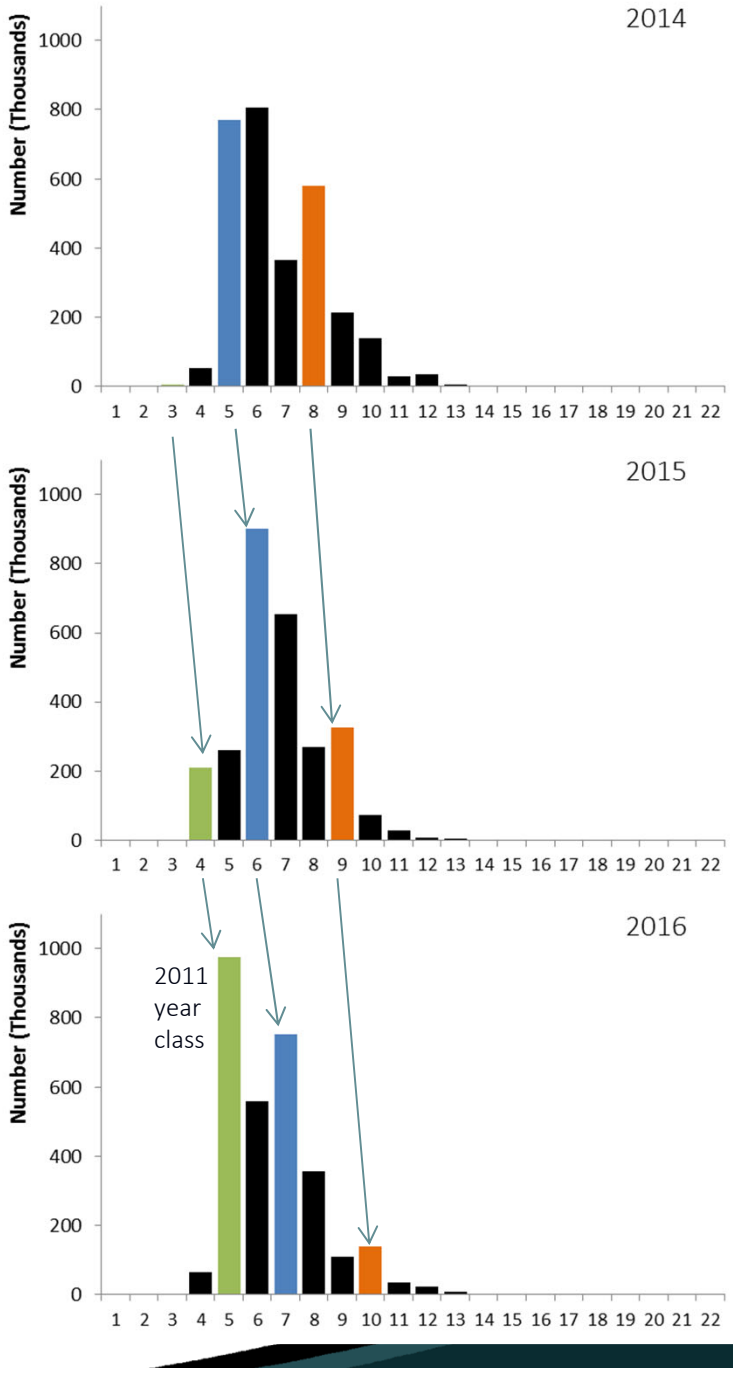
Catch at Age

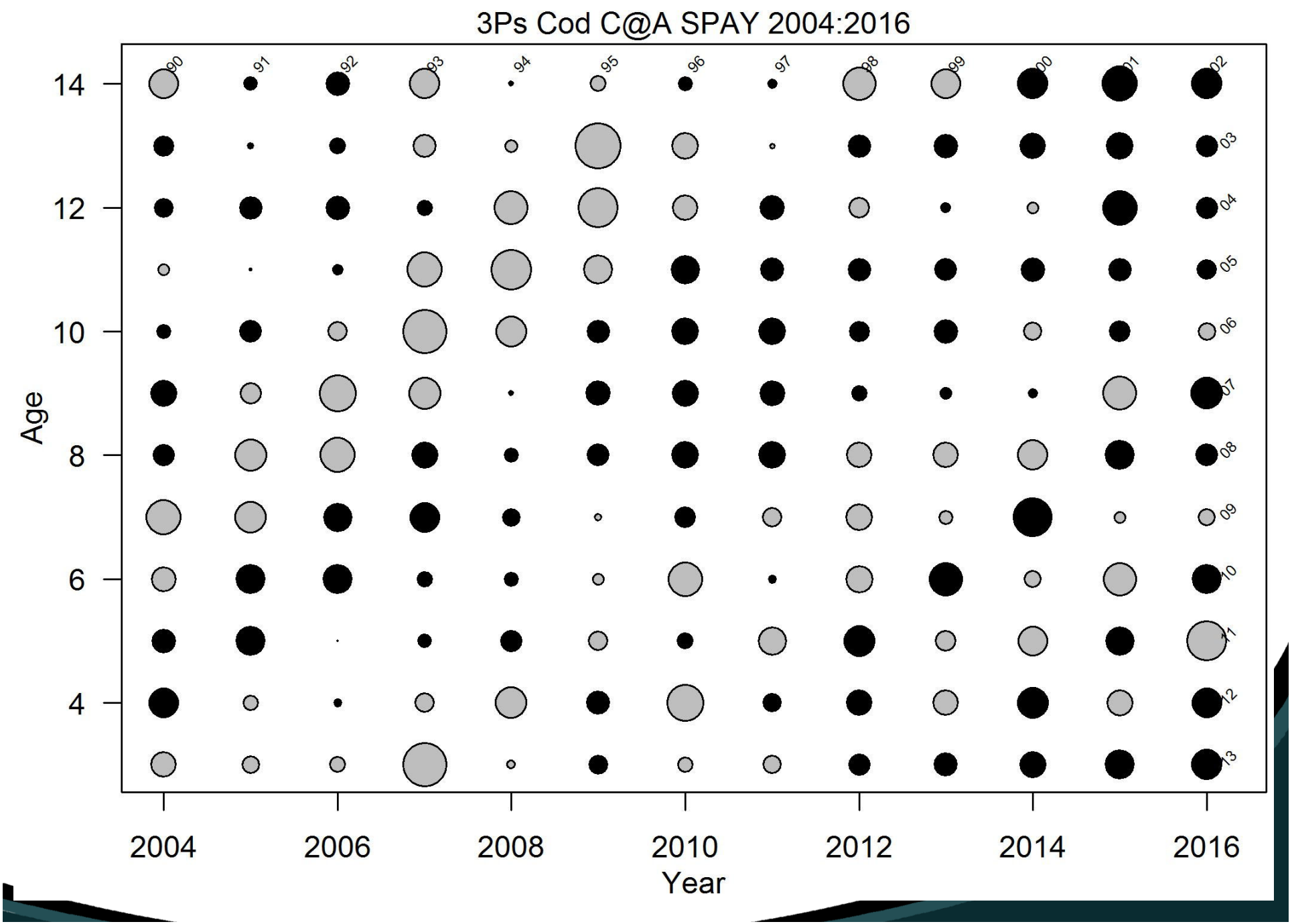
2014 – 2016

Number (1000s) at age

- 2006, 2009 year classes tracking through

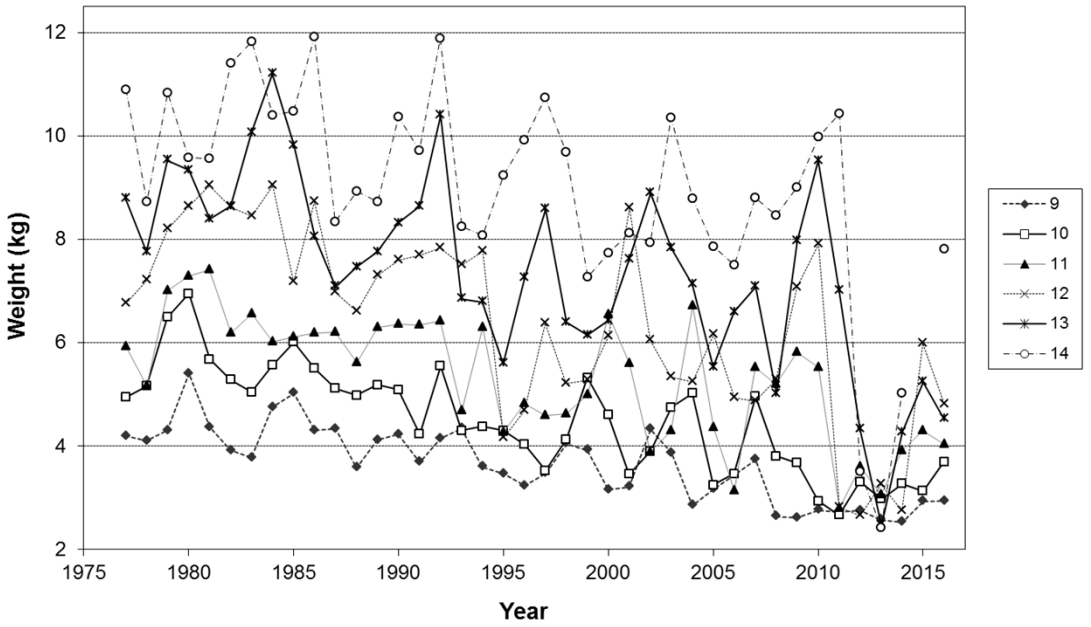
- strong entry of 2011 year class into the fishery

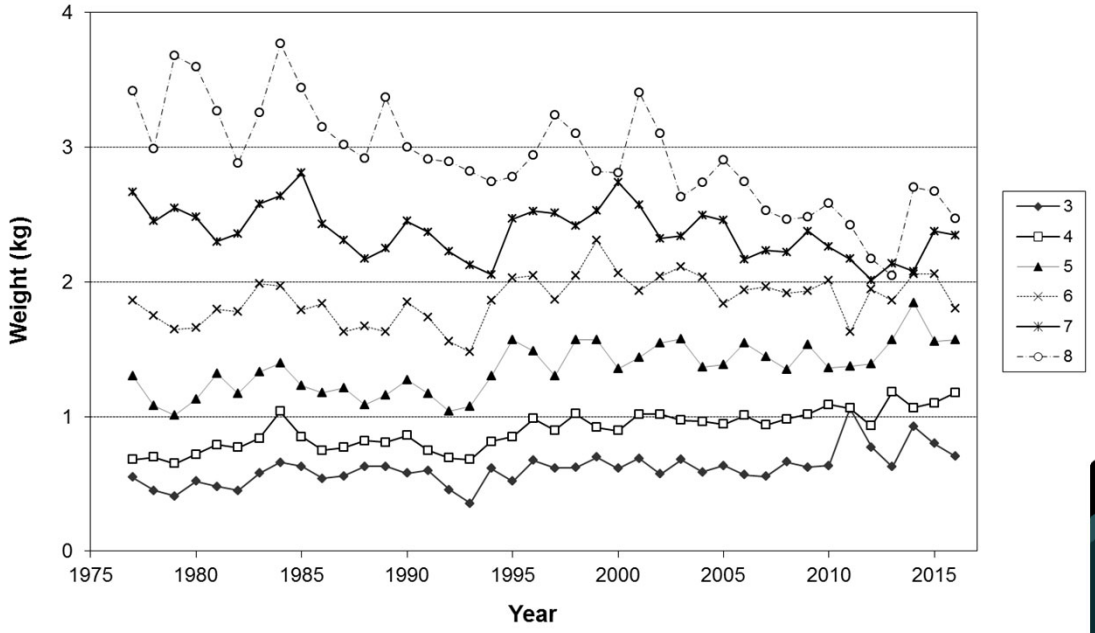



3Ps Cod C@A SPAY 2004:2016
Age
Year
14
12
10
8
6
4
2004
2006
2008
2010
2012
2014
2016
90
91
92
93
94
95
96
97
98
99
00
01
02
03
04
05
06
07
08
09
10
11
12
13

Commercial Catch Weights at age

Ages 3-14





Stock assessment data

- Science samples the catches for size, age, and other biological characteristics (sex, body weight, …).
- Really complicated stratified multi-stage (i.e. cluster) sampling designs, with lots of missing sample cells
- Difficult to implement designs in practise, and designs change frequently from year to year
- Can usually estimate catch-at-length (C@L), by quarter and sometimes by gear type.
- Estimate catch-at-age (C@A) using age-length key
- Age really important: allows us to follow what happens to a cohort

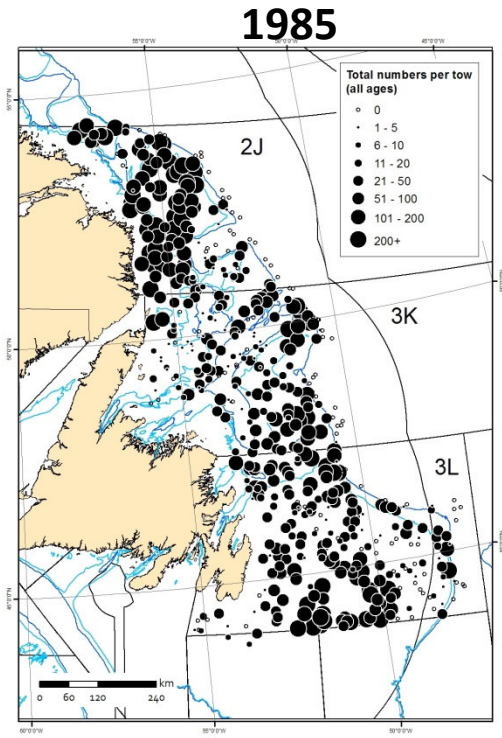
Stock assessment data

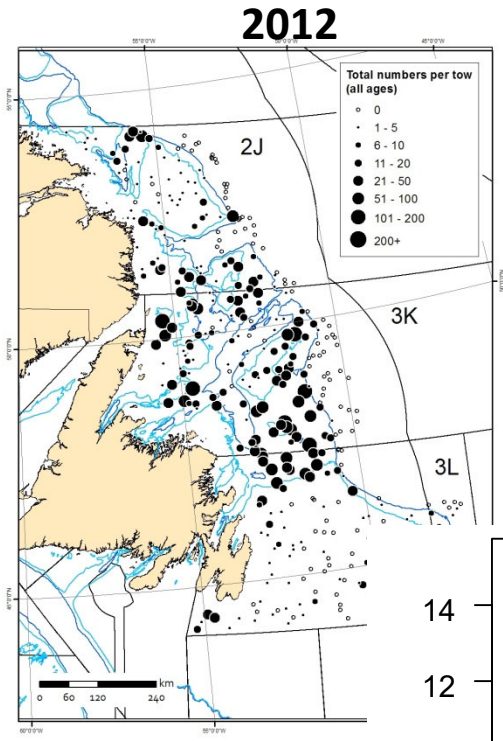
- Surveys involve random (usually stratified) fishing throughout the stock area.
- The average survey catch is expected to indicate the trends in the stock;
- That is, average catch is an index
- Detailed sampling of catches for size, age, condition, maturity, species composition, etc.

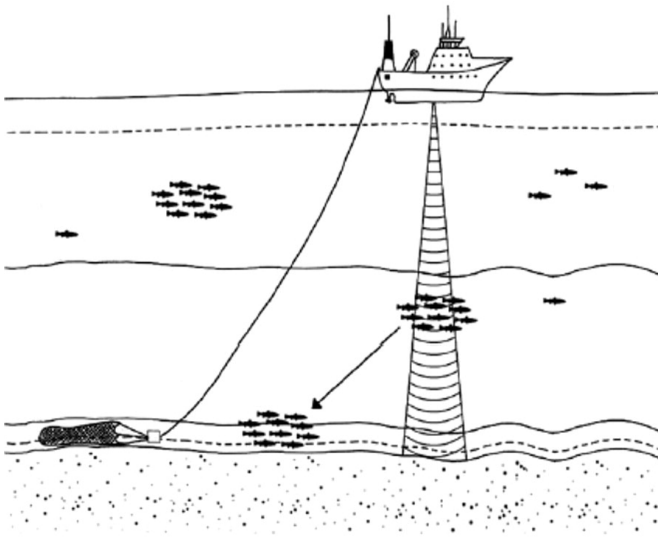
Stock assessment data

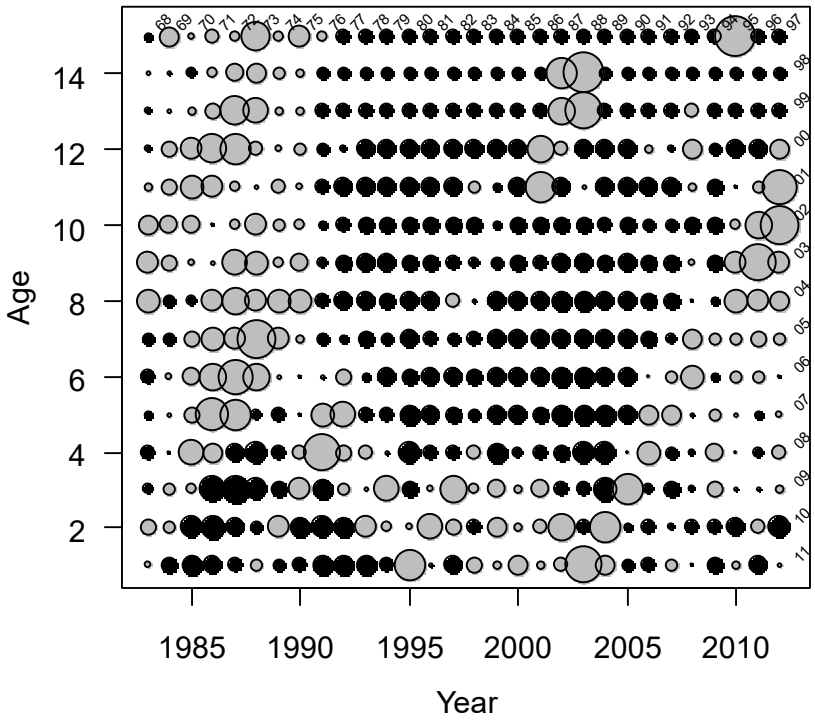
- Can usually estimate numbers at length and at age, and by sex.
- Problems: survey coverage, and time frame.
- Survey indices of stock size are often noisy, and it can be difficult to detect short-term trends

Survey indices



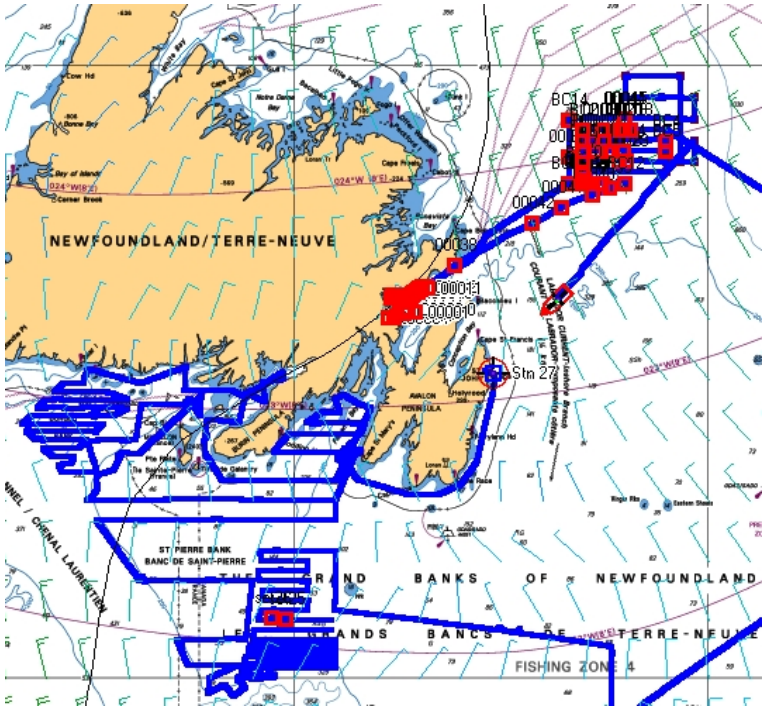


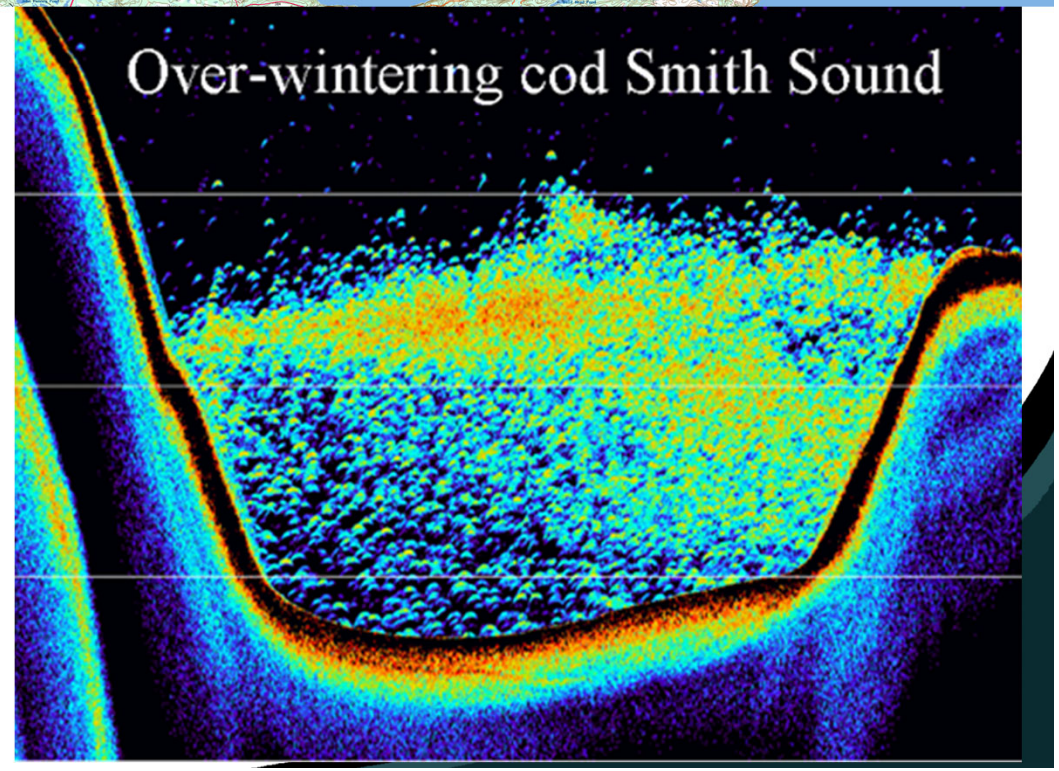




Length at age (L@A)
Weight at age (W@A)
Relative Condition Index
Relative Liver Index
Age at maturity

Acoustic Surveys

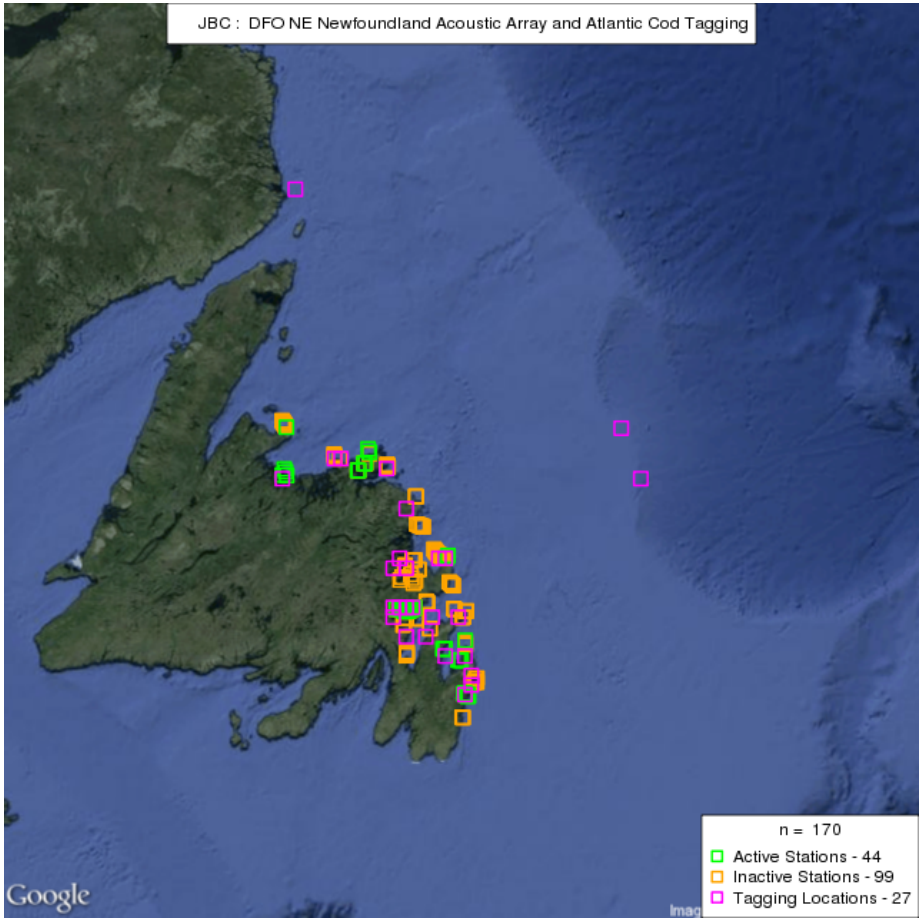


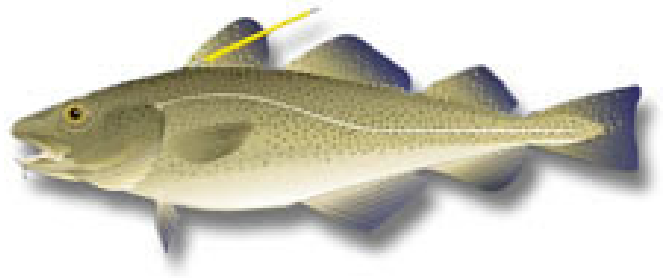


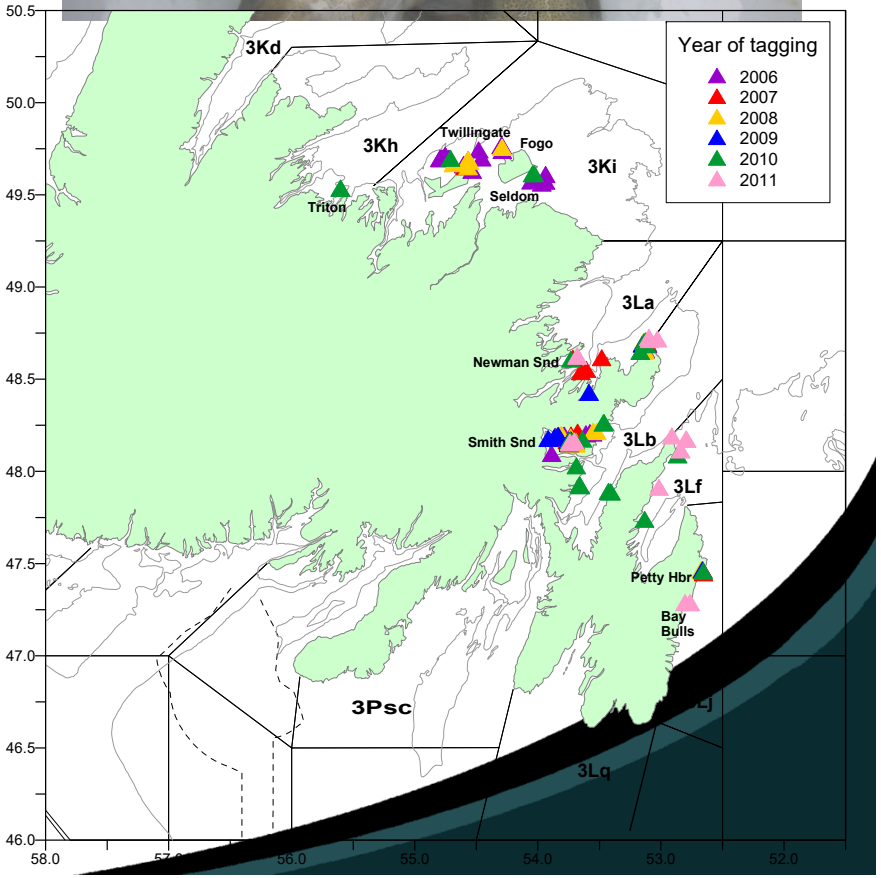
Stock assessment data

- Tagging: mark fish and ask fisherman to return tags (for a reward)
- A fishery on a known population
- Especially good for stocks that are difficult to survey
- Not good when there is not much fishing
- But recent technology is helping

Data: Tagging data







Acoustic Tags

MEOPAR
MARINE ENVIRONMENTAL OBSERVATION PREDICTION & RESPONSE NETWORK

Ocean Gliders and Marine Observation

Home | Deployments | Data | Slocum Gliders | Wave Gliders

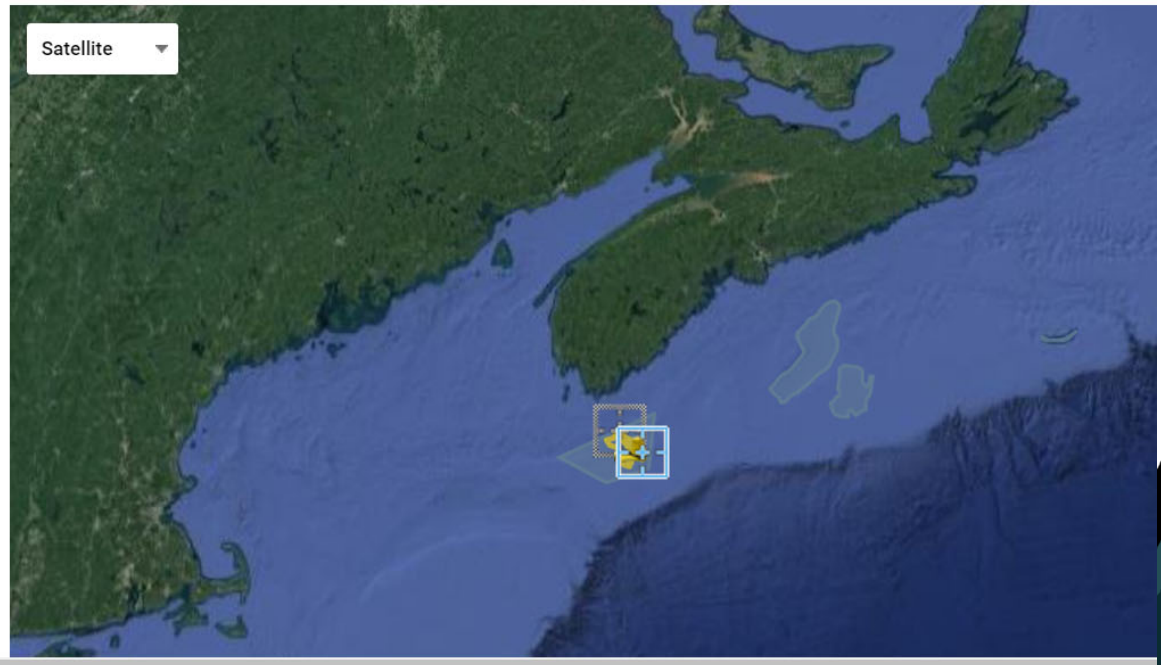
The Ocean Glider Program

The world's oceans are vast and cannot be properly described using research vessels only. Satellite technology has greatly improved our ability to obtain global coverage of some environmental variables but satellites cannot see into the ocean's interior. Autonomous gliders can help to fill the gaps between shipboard sampling and satellite imagery.

The Ocean Tracking Network (OTN) deploys two Teledyne Webb Research Slocum electric gliders (OTN200 and OTN201) near continuously along the Halifax Line, running from Chebucto Head to approximately 250 km offshore. Their mission is to provide oceanographic context for the animal tagging efforts of OTN. Ultimately, data from the gliders will provide foundations for models of ocean dynamics that will be related directly to the activities of tracked species.

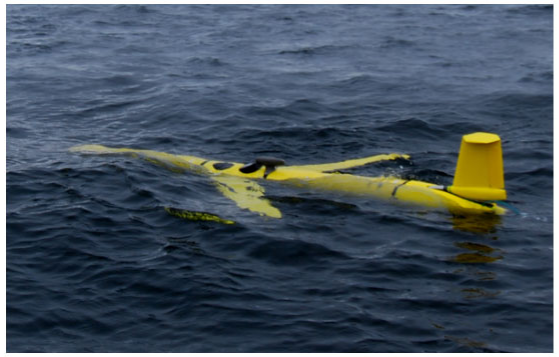
In addition OTN operates a Liquid Robotics wave glider (SO174, codename 'DL') whose primary mission is to

Current Deployments



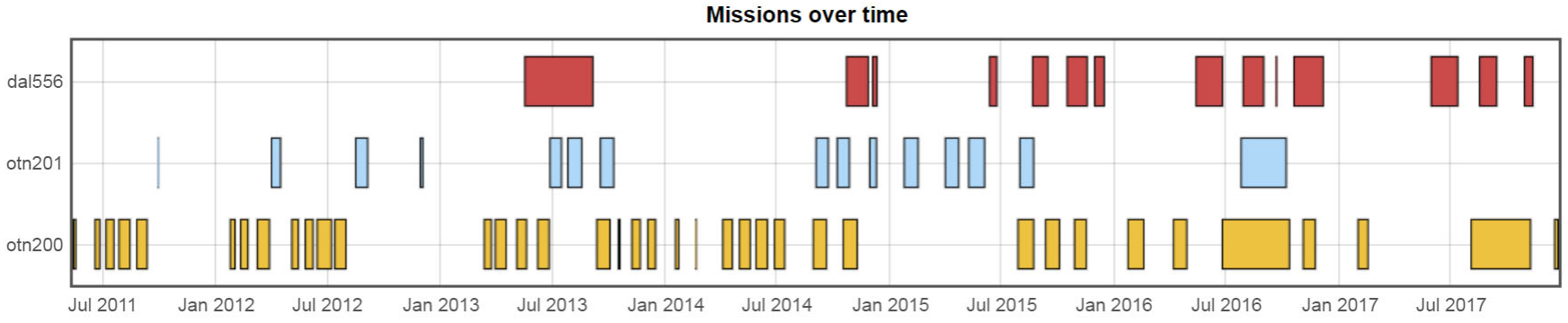
Acoustic Tags

Our Platforms



Teledyne Webb's Slocum Glider

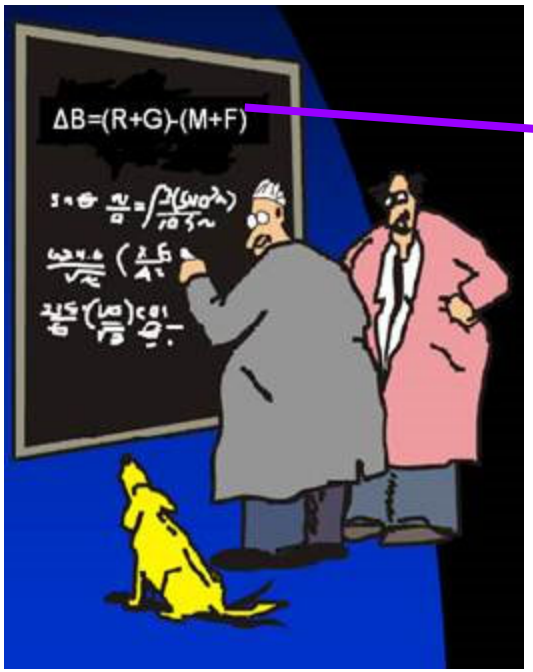
Liquid Robotics' Wave Glider



Stock assessment models

- Based on information on fishery catches and also indices of stock size (e.g. surveys)
- They work better when there is a long annual time series of data, and age and size sampling.
- Can be for populations totals, or by length, by age, by sex, by region, with mixed stock/species interactions …..
- Tagging sometimes used.

Stock assessment models



ΔB-variation in biomass
R-recruitment
G-growth
M-natural death
F-fishing removal

The future:

i. State-space, with process errors

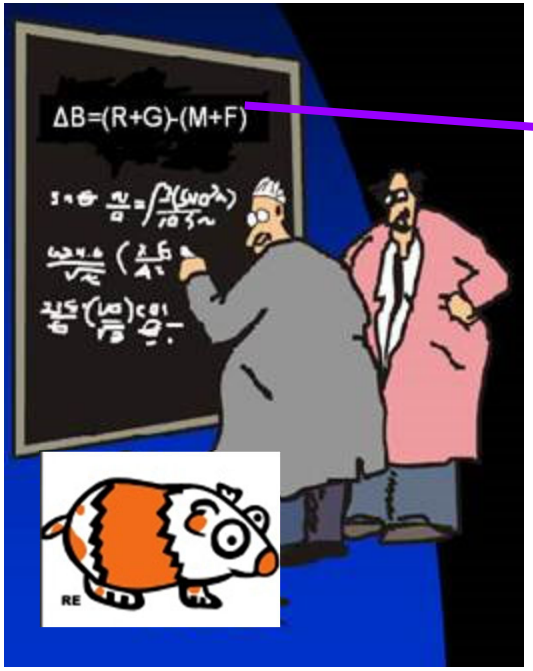
ii. Integrated

iii. Spatial

iv. Meta stock/species

v. Ecosystem

Stock assessment models



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You need to first learn how to walk before you can run!

The future:

i. State-space, with process errors

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