2022 Report of WG 45: Joint PICES/ICES Working Group on *Impacts of Warming on Growth Rates and Fisheries Yields*

The Joint PICES/ICES Working Group on *Impacts of Warming on Growth Rates and Fisheries Yields* (WG 45/WGGRAFY) held its annual WG meeting on September 22 at 3 PM Central European Time during the ICES Annual Science Conference (ASC 2022) in Dublin, Ireland, under the joint chairing of Drs. Paul Spencer (USA, PICES), Alan Baudron (UK, ICES) and John Morrongellio (Australia). The purpose of the meeting was to discuss 1) updated progress from each of the ToR subgroups; 2) complementary projects and activities; and 3) future directions. The meeting was held as a hybrid type meeting between in-person and online.

AGENDA ITEM 1
Introduction by Co-Chairs

The meeting began with a brief review of the Theme Session J "*Temperature impacts on fish growth and consequences for fisheries*" at ICES ASC 2022. There were 33 pre-recorded presentations and the participants shared the scientific progresses related to WGGRAFY in advance of the theme session. In addition, during the theme session, an in-person discussion session was held. The presentations were categorized to each ToR and the speakers discussed with the participants as the panelists. Several early career scientists were included in the panelists and a PhD course student, Ms. Zhen Lin, supported by PICES, also acted as a panelist.

AGENDA ITEM 2
Introduction of members and adoption of agenda

After introduction of members (*WG 45 Endnote 1*), the agenda was adopted (*WG 45 Endnote 2*).

AGENDA ITEM 3
Progress from each of the ToR subgroups

ToR-1. Assess the capacity of statistical models to incorporate temperature dependency of growth, and then compare their predictions of growth variation across specific warming scenarios and locations.

The Sarla model (a state-space statistical model for fish length-at-age, written in the Stan language and packaged in the R package Sarla) has been developed and applied to length-at-age data from the California Current. This work was presented at ASC 2022. Work has been initiated on simulation modeling of the dynamics of fish size-at-age using two modeling packages: ss3sim (a large and commonly used program for stock assessment), and ProDynR (an independent program for conducting projections of fish recruitment, abundance, and growth). Additionally, a set of simulation scenarios has been identified, focusing on simulating either the temperature–size rule or constant growth, and simulating a range of sampling effort. These simulations will allow evaluation of various statistical estimation models for detecting the influence of temperature on fish size-at-age.

ToR-2. Analyse long-term growth patterns across multiple large marine ecosystems that are experiencing different trends in temperature, using a common modelling approach.

An analysis of how temperature and fishing affect the expression of juvenile and adult growth has been performed for the North Sea (13 species), Gulf of Alaska (7 species) and SE Australia (10 species). These

analyses, presented at ASC 2022, showed that in general, life-stage dependent growth patterns in the North Sea and Gulf of Alaska were consistent with the temperature size rule. Specifically, juveniles tended to grow faster in warmer waters, and adults grow slower. In the North Sea, where appropriate data were available, we also found that thermal sensitivity of growth was modulated by spawning stock biomass. In contrast, fish grow in SE Australia showed variable signals. This may be due to complex temperature effects or the result of growth bias induced by fishery-dependent sampling. These results are currently being prepared as a manuscript.

Elsewhere, a PhD student at the University of Melbourne is looking at the effects of extreme heat events on the annual growth of juvenile and adult fish across the Pacific. This analysis is utilising growth information stored in fish otolith increments. We continue to explore opportunities to expand analyses to a truly global scale but unfortunately progress here has been slow as project leads and data providers are operating on a voluntary basis.

ToR-3. Assess the impacts of warming on past yield per recruit of commercial fisheries, and forecast trends in future yield given plausible warming scenarios.

Work is continuing to improve the bespoke Yield-Per-Recruit (YPR) function developed by WGGRAFY members, which was presented last year and is now up-and-running and available on GitHub. The function has been successfully applied to a few selected data-rich stocks in three different ecosystems: Alaska (pollock, Pacific cod), North Sea (plaice, sole, whiting, haddock), and Barents Sea (saithe, cod, haddock). The function currently returns outputs of YPR and biomass-per-recruit. The next step for the YPR function is to incorporate covariates, starting with the impact of temperature on weight-at-age data used as input to the function. To do so, a literature review is currently under way. Unfortunately, progress has been slow since WGGRAFY members are working on a voluntary basis without dedicated funding. In an attempt to secure funding, the ToR 3 chair joined a consortium led by Prof. David Atkinson, University of Liverpool, bidding for a NERC large grant. Sadly, our attempt was unsuccessful and our project was not selected. However, upon receiving feedback from NERC, consortium participants are keen to consolidate the proposal and apply for future funding. Ideas were discussed during this year's WGGRAFY annual meeting which Prof. David Atkinson attended.

ToR-4. Identify options for expanding scientific community access to global length-at-age data that are routinely collected by fisheries agencies worldwide.

Work is continuing to expand possible data sources to be included in the metadata table of WGGRAFY. Data from Canada, China, Mediterranean, Canary Islands, Falklands, New Zealand, Peru and Japan were potentially listed. From Japan, age-specific weight data for 17 (6) populations of 13 (4) fish species around Japan were compiled from 1995 (1978) to 2018. In some cases, fish size data are difficult to share internationally. To solve the issue, ToR 1 will contribute to have local modellers engaged in the model fitting process for some large marine ecosystems (LMEs).

AGENDA ITEM 4
Complementary projects and activities

As mentioned above, convening an ICES/PICES Theme Session at the ICES ASC 2022, which garnered high quality contributions, helped promote WGGRAFY, and provided ideas for future research and collaborations for WGGRAFY.

WGGRAFY is part of the ICES Ecosystem Processes and Dynamics Steering Group (EPDSG), and attended all the meetings organised. WGGRAFY's purpose and ongoing work were presented during these meetings, and potential collaborations with other WGs were identified (although these are still to materialise).

WGGRAFY provided input requested by the ICES/PICES Strategic Initiative (Section) on Climate Change Impacts on Marine Ecosystems (SICCME/S-CCME) whose task is to report back to ICES and PICES on ongoing climate research. WGGRAFY provided an overview of the ongoing work which was reported to SCICOM by SICCME.

WGGRAFY became part of a consortium led by Prof. David Atkinson (University of Liverpool) in order to target sources of external funding which would secure valuable research time for WGGRAFY. A research proposal was submitted for a NERC Large Grant (UK funding) but sadly our attempt was unsuccessful. However, the consortium is still in place and Prof. David Atkinson attended this year's WGGRAFY meeting to discuss ideas for future projects.

AGENDA ITEM 5
Future directions

WGGRAFY Co-Chairs were pleased with the quality of the research presented during our Theme Session at the 2022 ICES ASC, and the insightful discussion that followed. However, while this in-person event sparked ideas for collaborations, it became evident that such event was held too late in this term. Moving onto the next term, efforts will be made to host a workshop over several days (possibly a week-long, hopefully hosted by ICES HQ in Copenhagen) in order to carry out work in person and promote external achievements, *i.e.*, publications.

AGENDA ITEM 6
Requests and other business

WGGRAFY submitted a proposed topic session "*Understanding the implications of body size change for stock productivity and fisheries management*" for PICES-2023 and request for travel support for two invited speakers (*WG 45 Endnote 3*).

WGGRAFY also is planning to submit a new resolution relating to WGGRAFY to ICES (*WG 45 Endnote 4*). On the PICES side, the start time of WG 45 was delayed about 1-year. Therefore, WGGRAFY is planning to submit a request to extend the duration of WG 45 for 1 year to match up with the new ICES resolution- related WG.

WG 45 Endnote 1

PICES/ICES joint WG 45 meeting participation list

Members

Shin-ichi Ito (Japan, Co-Chair/PICES)
Paul Spencer (USA, Co-Chair/PICES)
John Morrongellio (Australia, Co-Chair/ICES)
Alan Baudron (UK, Co-Chair/ICES)
Yue Jin (PICES, China)
Saang-Yoon Hyun (PICES, Korea)
Christine Corlett Stawitz (PICES, USA)
Asta Audzijonyte (ICES, Australia)
Henry Wootton (ICES, Australia)
Sarah Willington (ICES, Australia)
Einar Hjörleifsson (ICES, Iceland)
Ralf van Hal (ICES, The Netherlands)
Max Lindmark (ICES, Sweden)

PICES members unable to attend

Canada: Sean Anderson
China: Shuyang Ma, Yongjun Tian
Japan : Kunihiro Fujiwara, Takeshi Tomiyama
USA: Melissa Haltuch

Observers

Jennifer Bigman (Canada)
Zhen Lin (Japan)
Jessica Randall (Australia)
Enrico Nicola Mrmelloni (Ireland)
Ieire Ibaibarriaga (Spain)
Szymon Smolinski (Poland)
David Atkinson (UK)

WG 45 Endnote 2

PICES/ICES joint WG45 meeting agenda

1. Introduction
2. Introduction of members and adoption of agenda
3. Progress from each of the ToR subgroups
4. Complementary projects and activities
5. Future directions
6. Requests and other business

WG 45 Endnote 3

Proposal for a Topic Session on
"*Understanding the implications of body size change for stock productivity and fisheries management*"
at PICES-2023

Convenors: Shin-ichi Ito (Japan), Paul Spencer (USA), John Morrongiello (Australia), Chenying Guo (China)

Potential Invited Speakers: Alan Baudron (UK), Asta Audzijonyte (Australia)

Everyone loves photos of the big fish that didn't get away. However, warming oceans often mean that young fish grow more quickly but reach smaller adult sizes. This equates to a loss of yield in commercial fisheries. Scientists are working together to assess the magnitude of the shrinking fish problem in different regions and determine what this means for sustainable fisheries management now and in the future. Warming seas can affect fish body sizes, with major implications for size-structured marine ecosystems, species interactions and fisheries productivity. Synchronous shifts toward smaller adult body sizes in marine fish have already been detected in several rapidly warming areas. Yet, the mechanisms underpinning the temperature size rule (TSR;

higher temperatures result in smaller body sizes) remain debated and most fisheries models do not routinely account for the expected temperature-dependent trends in growth. Understanding the impacts of temperature-driven changes in body size on reproduction and maturity is critical if we want to predict shifts in stock productivity. Novel monitoring programs are needed to provide managers with the appropriate information to detect and quantify any body size change that is occurring. Lastly, fisheries management plans need to adequately account for the implications of shifting fish body sizes and ensure harvest strategies are flexible enough to ensure stock productivity in a rapidly changing world. We propose a session that will:

1) Synthesise ecological and empirical knowledge about trends in fish and other ectotherms' growth rates and body sizes, and how this can be incorporated into monitoring programs;
2) Explore the utility of new assessment models that allow for time-varying and environmentally driven trait parameters
3) Assess the potential impacts of temperature-induced body size change on fisheries yields in the future ocean
4) Discuss management options to addressing the impacts of rapid temperature-induced changes in stock productivity

WG 45 Endnote 4

New resolution submitted to ICES
Working Group on Impacts of Climate Warming on Growth Rates and Fisheries Yields

Working group meeting draft resolution for fixed-term working groups

A **Working Group on Impacts of Climate Warming on Growth Rates and Fisheries Yields** (WGGRAFY), chaired by Alan Baudron, UK, Paul Spencer, USA, John Morrongiello, Australia, and Shin-ichi Ito, Japan, will work on ToRs and generate deliverables as listed in the Table below.

This resolution is proposed for the second term of WGGRAFY. The first term of WGGRAFY (2020-2022) has seen considerable interest, with our numbers growing to 52 members worldwide who have relevant expertise and access to data. WGGRAFY has several analyses currently in progress, some of which are nearing publication stage. Unfortunately, progress during the first term has been hampered by COVID restrictions, with no physical meeting possible until the last year of the term. This second term aims at building upon the ongoing work and establish network of WGGRAFY to expand our understanding of the impact of warming seas on fish growth and fisheries yield.

	Meeting dates	Venue	Reporting details	Comments (change in Chair, etc.)
Year 2023	September	Bilbao, Spain	Interim report by December 2023	
Year 2024	TBA		Interim report by December 2024	
Year 2025	TBA		Final report by April 2026	

ToR descriptors[1]

ToR	Description	Background	Science Plan Codes	Duration	Expected Deliverables
	This should capture the objectives of the ToR	Provide very brief justification, e.g. advisory need, links to Science Plan and other WGs	Use codes *(max 3 per ToR)*	1, 2 or 3 years	Specify what is to be provided, when and to whom
a	Review the current knowledge on the impact of temperature on fish growth and knock-on effects on fisheries yields, and identify possible sources of funding to target to pursue further research		1.3, 1.7, 6.4	3 years	Review paper, report to ICES/PICES Strategic Initiative on Climate Change impacts on Marine Ecosystems, develppment and submission of research project proposal to relevant funding sources
b	Assess the capacity of statistical models to detect temperature-dependency of growth and evaluate their predictive abilty, and demonstrate model results across specific warming scenarios and locations		1.3, 1.7, 2.5	3 years	Paper suitable for peer-reviewed fish journal, model code sharing through GitHub.
c	Quantify the impacts of ocean warming and fisheries harvest on long-term patterns of mean, maximum and CV of body size across multiple species and large marine ecosystems		1.7, 5.2, 6.1	3 years	Papers suitable for peer-reviewed, high impact generic journal
d	Assess the knock-on implications of warming impacts on fish growth for fisheries yield by investigating changes in yield per recruit, and perform model simulations using size spectrum models		1.3, 5.2, 6.1	3 years	Paper suitable for peer-reviewed, high impact generic journal

[1] Avoid generic terms such as “Discuss” or “Consider”. Aim at drafting specific and clear ToR, the delivery of which can be assessed

e	Identify options for expanding scientific community access to global size-at-age data that are routinely collected by fisheries agencies worldwide	3.2	3 years	Strategic plan assessing options for widening access to size(length/weight)-at-age data collected routinely (portal site development or similar to how data can be accessed via Datras)

Summary of the Work Plan

YEAR 1	A MEETING WILL BE HELD DURING THE ICES ASC TO PRESENT AND DISCUSS THE OUTCOMES OF TOR A, AND REVIEW PROGRESS OF TORS B-E. SUB-GROUPS WILL MEET AS REQUIRED TO PROGRESS ON TORS. A THEME SESSION PROPOSAL WILL BE SUBMITTED FOR THE SUBSEQUENT ICES ASC.
Year 2	A Theme Session at the ICES ASC will be convened by WGGRAFY chairs. A meeting will be held during the ICES ASC to present and discuss the outcomes of ToR a, and review progress of ToRs b-e. Sub-groups will meet as required to progress on ToRs.
Year 3	A meeting will be held during the ICES ASC to present and discuss the outcomes of ToR a, and review progress of ToRs b-e. Sub-groups will meet as required to progress on ToRs. A workshop will be organised to finalise progress on all ToRs and plan the writing of the results obtained for publication. New resolution for the next term will be agreed upon, with a possible change of chairs (ECR participation will be encouraged).

Supporting information

Priority	The Temperature Size Rule (TSR) proposes that fish at warmer temperatures have rapid early growth and lower adult size (Forster et al. 2012). Several North Sea fish stocks have exhibited a synchronous, common trend towards smaller maximum body sizes that was correlated with increasing temperature. This "shrinking" decreased per-capita yields of those stocks by ca. 23% (Baudron et al. 2014). Similarly, it has been projected that by 2050 global fish yields will decrease by 14-24% due to shifting biogeography and the TSR (Cheung et al 2012). However, other studies have found only equviocal support for the temperature size rule in wild fish populations (Audzijonyte et al. 2020) The aim of WGGRAFY is to determine whether temporal trends in individual growth rates of marine fish are consistent with the TSR and, if so, evaluate the impacts for fish yields. Length and age have been routinely measured for many commercial fish stocks on time scales that are associated with warming. These substantial data have never been compiled as a single, analytical resource for climate change research on global scales. The WG will compile size (length/weight) at age datasets for large marine ecosystems experiencing differential rates of warming or cooling or no overall trend (e.g., upwelling regions). A customised statistical approach for modelling growth will be developed to specifically test whether there is a component of the total variation in growth rates that can be attributed to temperature, and then determine whether other portions are related to the impacts of fishing. This knowledge could provide a empirical foundation for forecasting the impacts of future climate warming on yields. The unique spatial and temporal scale of size-at-age data are valuable resource for ecological research. The WG will also develop a strategic plan for archiving size-at-age data similar to how ICES archives data for European waters (Datras) or how global data on recruitment and catch are reported and maintained (e.g., RAM Legacy). This will require engaging with various agencies (ICES, EMODnet, FAO, universities, tech specialists) and national fisheries laboratories as well as potential funding sources

References

Audzijonyte, A., S. A. Richards, R. D. Stuart-Smith, G. Pecl, G. J. Edgar, N. S. Barrett, N. Payne, and J. L. Blanchard. 2020. Fish body sizes change with temperature but not all species shrink with warming. Nature Ecology & Evolution 4:809-814.

Baudron, A.R., Needle, C.L., Rijnsdorp, A., Marshall, C.T. 2014. Warming temperatures and smaller body sizes: synchronous changes in growth of North Sea fishes. Global Change Biology 20: 1023-1031.

Cheung, W. W. L., et al. 2012. Shrinking of fishes exacerbates impacts of global ocean changes on marine ecosystems. Nature Climate Change, 3:254–258.

Forster, J., Hirst, A.G., Atkinson, D. 2012. Warming-induced reductions in body size are greater in aquatic than terrestrial species. PNAS 109:19310 LP-19314.

Resource requirements	None anticipated due to nature of remote working.
Participants	The Group currently has 52 members from across the globe (ICES and PICES coutries)
Secretariat facilities	The group will request meeting rooms / times associated with the ASC. This will require some assistance from members of the secretariats organizing those events. It is envisioned that video conferencing facilities will be required such that non-attending WG members can participate.
Financial	Funds may be requested to support travel of key participants to the final and only meeting.
Linkages to ACOM and groups under ACOM	The group will identify how climate has influenced the productivity and yields of commercial fish stocks within ICES areas retrospecitively. In addition, it will develop knowledge relavant to forecasting future impacts on fish growth rates. This information is compatible with the evolving knowledge base relating to climate-driven distributional shifts. This information will be useful to ACOM in recommending adaptation options for fisheries management.
Linkages to other committees or groups	WGGRAFY is highly relevant for SICCME. Possible interactriosn with other WGs have been identified: WGEVO and WGSPF.
Linkages to other organization	