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Food for Thought

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Counting stars: contribution of early career scientists to marine and fisheries sciences

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Scientific careers and publishing have radically changed in recent decades creating an increasingly competitive environment for early career scientists (ECS). The lack of quantitative data available on ECS in marine and fisheries sciences prevents direct assessment of the consequences of increased competitiveness. We assessed the contributions of ECS (up to 6 years post first publication) to the field using an indirect approach by investigating the authorships of peer-reviewed articles. We analysed 118461 papers published by 184561 authors in the top 20 marine and fisheries sciences journals over the years 1991–2020. We identified a positive long-term trend in the proportion of scientific articles (co-)authored by ECS. This suggests a growing contribution by ECS to publications in the field. However, the mean proportion of ECS (co-)authors within one publication declined significantly over the study period. Subsequent tests demonstrated that articles with ECS (co-)authors receive fewer citations and that the proportion of ECS (co-)authors on an article has a significant negative effect on the number of citations. We discuss the potential causes of these inequalities and urge systematic support to ECS to achieve more balanced opportunities for funding and publishing between ECS and senior scientists.

Keywords: bibliometrics, early career researchers, scientometrics, scientific career, scientific publishing.

Introduction

Scientific careers and the nature of scientific publishing have changed radically in recent decades. Observed changes include an increase in the number of awarded PhD degrees (Larson *et al.*, 2014), earlier ending of scientific careers (Milojevic *et al.*, 2018), and exponential growth in the number of publications (Bornmann and Mutz, 2015). The pressure of the "publish or perish" model leads to an increasingly competitive environment for the whole scientific community, but especially for early career scientists (ECS). These face ever-increasing requirements while aspiring to a steadily limited number of job positions (Evans and Cvitanovic, 2018; Berenbaum, 2019). For example, if the number of faculty positions remains constant, only 12.8% of PhDs can attain a tenure-track academic position in the US (Larson *et al.*, 2014).

Concurrently, human activities and climate change are causing rapid alterations to marine and coastal ecosystems and fisheries (Doney *et al.*, 2012; Alimba and Faggio, 2019; Cheung *et al.*, 2021). Multi-dimensional approaches that integrate data across academic disciplines are becoming a requirement in order to adequately capture these changes during environmental monitoring and assessment (Tintoré *et al.*, 2019). These accelerated alterations and the urgency for science-based policy constitute defining challenges for the current generation of marine scientists. Consequently, building the capability and interdisciplinarity of early-career marine scientists

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is necessary to ensure their ability to address future challenges (Hildebrand, 2019; Andrews *et al.*, 2020).

The development of strategic plans to address future challenges would be supported by accurate quantification of ECS contributions to specific research areas. Metrics on the ECS contributions could improve the management of scientific activities, for example, defining priorities for training new generations of specialists towards urgent topics and knowledge gaps (Nicholas *et al.*, 2019; IOC-UNESCO, 2020). Identifying science sectors where ECS are underrepresented can encourage institutional changes (e.g. creating dedicated research funds, opening jobs for ECS, and supporting the formation of new research teams) and maximize the use of ECS expertise (Andrews *et al.*, 2020). These actions can improve opportunities and engagement of ECS in academia (Milojevic *et al.*, 2018) and increase career stability (Moslemi *et al.*, 2009). In addition, information on the number of ECS co-authored publications can reveal their relative contribution to science and their direct influences on dissemination and policy-making (Evans and Cvitanovic, 2018).

In fact, data on the number of ECS and their contributions are often lacking, scattered, or incomplete (Mellors-Bourne, 2021). This is the result of technical challenges, including privacy regulations related to the collection of personal data (Else and Perkel, 2022) as well as a lack of consensus on the definition of an "early career scientist". Across institutes and fields of study, ECS can be defined based on post-degree time or age limitations. These definitions often do not take personal situations into account, such as medical or parental leave, or indirect career paths. Despite these challenges, the ECS's contribution to science can still be estimated by using indirect methods—similar to the methods of counting millions of stars within a single photographic snapshot (Butler, 1955). Here we use a snapshot from the bibliometric data to estimate how many ECS have contributed to marine and fisheries sciences. Although we are seeing a shift in science being communicated more broadly and to a wider community in recent years, peer-reviewed publications remain the main platform for the exchange of scientific information. We indirectly evaluate ECS's contribution to science by quantifying their contribution to published papers and the subsequent citations of those articles.

The aims of this study are to (i) provide basic indices on the authorship of ECS in the field of marine and fisheries sciences, (ii) assess temporal trends in the contribution of ECS to the scientific output within the field, and (iii) compare the citation impact of articles led or co-authored by ECS with those which are authored solely by senior scientists. This information, provided for the first time in marine and fisheries sciences, helps define the current state as well as show changes in the contribution and citation impact of ECS in scientific publishing over time. Our results outline the need for research aimed at assessing potential adverse phenomena affecting the present and future careers of ECS.

Materials and methods

Data collection and pre-processing

Using Google Scholar Metrics, we obtained a list of the top 20 journals in the field of marine and fisheries sciences, ordered by their five-year *h*-index (Google, 2021). The *h*-index of a publication is the largest number *h* such that at least *h* articles in that journal were cited at least *h* times each (Hirsch, 2005; Montazerian *et al.*, 2019). Despite its shortcomings, Google Scholar Metrics is a helpful tool for authors and editors in identifying core journals (Delgado-López-Cózar and Cabezas-Clavijo, 2013). We used Google Scholar Metrics for the journal selection because we sought to evaluate contributions to journals that are the main platform for the exchange of scientific information of the highest quality. The h5-index used in the ranking was significantly correlated with the commonly used Journal Impact Factor (Pearson correlation $t = 3.36$, $df = 18$, and $p = 0.003$, Supplementary Table S1). The list of selected journals is presented in the "Supplementary Materials" (Supplementary Table S1).

We obtained a comprehensive record of articles published in the years 1991–2020 for the selected journals from the Scopus database (Baas *et al.*, 2020), which is a widely accepted source of bibliometric data (Montoya *et al.*, 2018; Baas *et al.*, 2020; Van Der Wal *et al.*, 2021). We collected information on the year of publication, journal, list of authors, title, and number of citations. We selected three types of documents for further analysis for which complete bibliographic information was available: original articles, reviews, and conference papers. These three types of documents are considered typical contributions to the scientific literature (Didegah and Thelwall, 2013; Li *et al.*, 2019) and constituted 97.5% of publications in our database. Using unique author IDs, we summarized the historical publication record of each author (year of first publication, citation count, and publication count). We used the rscopus: Scopus Database Application Programming Interface (API) (Muschelli, 2021) package for R (R Core Team, 2020) to automatically obtain bibliographic data from the Scopus database based on programming scripts (Montoya *et al.*, 2018).

Because there have been varying definitions of ECS in the past, we accessed a list of ECS and their publication history. Here, we use the academic age of 122 researchers involved in the Strategic Initiative on Integration of Early Career Scientists in the International Council for the Exploration of the Sea (ICES-SIIECS) as a benchmark. These researchers have all self-identified as ECS. Given the information of the year of an author's first publication provided in the Scopus database, we calculated their "academic age" as years after their first publication (Supplementary Figure S1). The median academic age of the ICES-SIIECS group was 6 years. We take this to be a scientist's early career period (hereafter ECS6) and consider all authors over 6 years of academic age to be senior researchers. We tested the sensitivity of our results to this threshold by repeating the analysis using the 90th quantile of the academic age (11 years, hereafter ECS11). We assigned authors of all publications to either ECS or senior groups in the year of publication, similar to Milojevic *et al.* (2018) and Zhang and Yu (2020). This allowed us to assess whether ECS were present among the (co-)authors and calculate the proportion of ECS among all authors of a given publication. We further assessed the percentage of publications where ECS contributed as a first author or as a single author, as well as publications authored only by ECS.

Analysis of time trends

We visualized the proportion of publications (co-)authored by ECS and the mean proportion of ECS among all (co)-authors of a publication by year. We fitted a "least-squares" linear model (LM) to test the general time trends in the proportion of the publications (co-)authored by ECS using Equation (1).

$$y1_i = a_0 + \beta_1 \left(\text{Year}_i\right), \quad (1)$$

where $y1_i$ is the proportion of publications (co-)authored by ECS in the year i; a_0 is the overall mean intercept; and $\beta_1(\text{Year}_i)$ is a fixed effect of the year. Since the quadratic time trend was identified in the mean proportion of ECS among all (co-)authors of a publication, we used the LM with Equation (2).

$$y2_i = a_0 + \beta_1 \left(\text{Year}_i\right) + \beta_2 \left(\text{Year}_i{}^2\right), \quad (2)$$

where $y2_i$ is the mean proportion of the ECS (co-)authors in a publication in a year i and $\beta_2(\text{Year}_i{}^2)$ is an additional quadratic term for the year effect and other terms as in Equation (1).

We fitted a series of independent LMs for each journal (N for each journal given in Supplementary Table S1) using Equation (1) and Equation (2). The quadratic term was omitted from these LMs as nonlinearity was not identified at the journal level for the mean proportion of the ECS (co-)authors; thus, Equation (2) was reduced accordingly. We reported the estimates for the parameters of the year effects in the model ($\beta_1(\text{Year}_i)$) and assumed the effects were significant at $p < 0.05$. Further, we used linear mixed models (LMMs) to estimate the general field-wide trends in marine and fisheries sciences, taking into account inter-journal variation in mean values and magnitudes of trends. After an initial comparison of models with the Akaike information criterion, quadratic terms for the year were omitted in the LMMs We used the following Equation (3) to fit the models:

$$y1_{ij} \text{ or } y2_{ij} = a_0 + \beta_1 \left(\text{Year}_i\right) + \alpha_j^{\text{Journal}} + b_j^{\text{Journal}} \left(\text{Year}_{ij}\right), \quad (3)$$

where $y1_{ij}$ or $y2_{ij}$ are the proportion of the publications (co-)authored by ECS or the mean proportion of the ECS (co-)authors in a publication in a year i and journal j; a_0 is the overall mean intercept; $\beta_1(\text{Year}_i)$ is a coefficient for a fixed effect year; $\alpha_j^{\text{Journal}}$ is a random intercept for journal j; and $b_j^{\text{Journal}}(\text{Year}_{ij})$ is a random slope for a year for journal j, correlated with $\alpha_j^{\text{Journal}}$.

Analysis of citation impact

We followed the previous approaches for the citation count analysis, accounting for potentially confounding effects (Tahamtan *et al.*, 2016 and references therein). We applied generalized additive mixed models (GAMMs) with a negative binomial distribution to analyse the citation impact of the articles collected in the dataset ($n = 118461$). We used the citation count (reported in December 2021) of each article as the response variable. Both Poisson and negative binomial models have been used previously in analyses of citation counts (Deschacht and Engels, 2014; Forthmann and Doebler, 2021). However, after preliminary screening, we considered that the negative binomial model was better suited for this analysis because it coped better with over-dispersed data (Maurseth and Verspagen, 2002).

The two focal variables to be tested were the presence of ECS as (co-)author (binary variable, where 0 indicates absence and 1 presence of ECS) and the proportion of ECS (co-)authors (continuous variable, values between 0 and 1). We further included variables for year of publication, number of authors, mean "academic age" of authors, mean citation count per document of authors, and document type (article, conference paper, or review) to adjust for potential confounding effects. Initial visual examination of the relationships between non-focal covariates and the response variable indicated non-linear relationships. Thus, the GAMM was used to allow for smooth relationships. The maximal number of knots (k) was limited to six to prevent overfitting the model. The following Equation (4) was used to fit the models with a log link function and a negative binomial distribution of the response variable.

$$\log\left(y3_{ij}\right) = a_0 + f_1\left(X1_{ij}\right) + f_2\left(X2_{ij}\right) + f_3\left(X3_{ij}\right) + f_4\left(X4_{ij}\right) + \beta_1\left(X5_{ij}\right) + \beta_2\left(X6_{ij}\right) + \alpha_j^{\text{Journal}}, \quad (4)$$

where $y3_{ij}$ is the citation count of a publication i in journal j; a_0 is the overall mean intercept; $f_1(X1_{ij})$ to $f_4(X4_{ij})$ are the smooth terms for non-focal covariates; $\beta_1(X5_{ij})$ is a categorical term for document type; $\beta_2(X6_{ij})$ is a categorical term for the presence of ECS, or linear term for the proportion of ECS (co-)authors; $\alpha_j^{\text{Journal}}$ is a random intercept for journal j.

The LMs were fitted with the basic lm function of R, and LMMs with the lme4 package using restricted maximum likelihood (Bates *et al.*, 2019), and GAMMs with the mgcv package (Wood, 2021). The standard diagnostics (Zuur *et al.*, 2010) and DHARMA package (Hartig, 2020) were used to validate the models.

Results

Overall, we retrieved 118461 original articles (92.5%), conference papers (4.4%) and reviews (3.1%), and the unique IDs of 184561 authors from these articles. There was at least one ECS among the authors in 80.1% of the analysed articles, and ECSs were first authors of 54.0% of the articles. On the other hand, when compared to the overall 6.8% of single-author papers in the analysed set, only 2.3% of the articles were authored by a single ECS (single-author papers), and 5.4% were (co-)authored solely by ECS (i.e. without the involvement of senior authors). Of the three document types, review papers had the lowest rate of ECS (co-)authorship (63.2% of documents), with conference papers (70.3% of documents) and articles (81.1% of documents) each being more likely to be (co-)authored by an ECS. Detailed information on the contribution of ECS by document type and type of authorship is presented in Supplementary Table S2.

The proportion of total publications (co-)authored by ECS increased by ~11% from 1991 to 2020 (Figure 1a), and the mean number of ECS (co-)authors per article increased from 1.15 to 2.20 in the same period (Supplementary Figure S2a). Additionally, the proportion of publications with ECS as a leading author increased during this period from 52% to 57% (Supplementary Figure S2b). These positive trends align with a more general increase in the mean number of all authors per article from 2.36 to 5.92 (Supplementary Figure S2a). However, the mean proportion of ECS (co-)authoring a paper decreased asymptotically from 48% to 35% during the same period (Figure 1b).

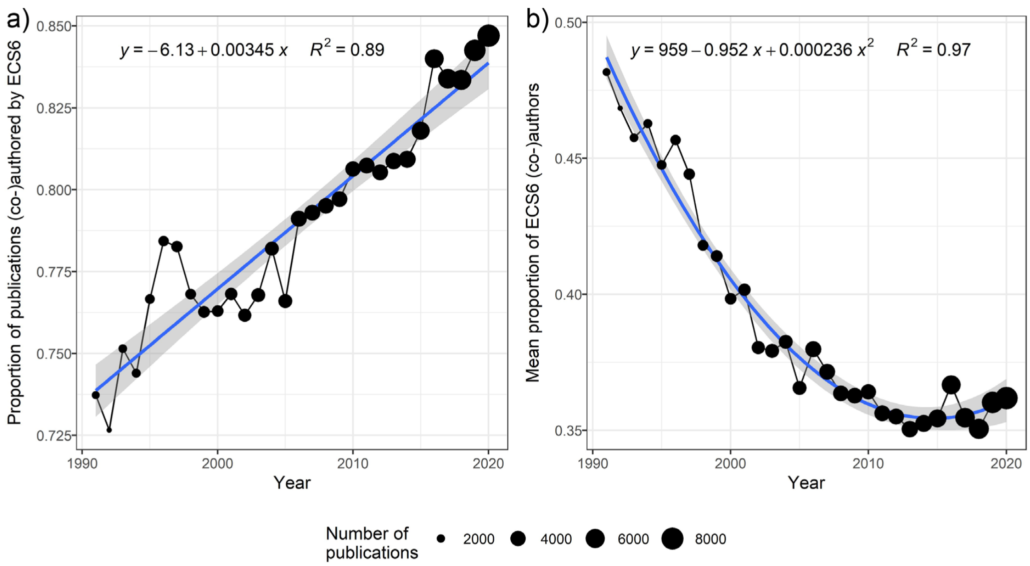

Figure 1. Estimates of the proportion of publications (co-)authored by ECS (within 6 years of first scientific publication = ECS6) (a) and the mean proportion of ECS (co-)authors in a publication (b) in the scientific articles published in the selected 20 journals in the period 1991–2020. Datapoint size relates to the number of articles published in a given year. The blue line and grey areas indicate a "least-square" LM fitted to the data with 95% confidence intervals.

When accounting for the journal random effects in LMMs, the average increase in the proportion of total publications (co-)authored by ECS is 0.3% per year, while the average decrease in the mean proportion of ECS (co-)authors is 0.4% per year (Table 1, Figure 2), which corresponds to a ∼9% increase in the presence of ECS and a ∼12% decrease in the mean proportion of ECS (co-)authors in each article over the 30-year period. In both models, the random journal effects were associated with high variance, and journals differed significantly ($p < 0.05$) in terms of the mean levels of the investigated metrics and the time trends observed. Moderate correlations ($p = -0.33$) between random intercepts and year-slopes were present, indicating that a slower temporal increase in the proportion of the publications (co-)authored by ECS was observed in journals with a higher average proportion of such publications (Table 1, Figure 2). The proportion of publications (co-)authored by ECS increased significantly ($p < 0.05$) for the study period in 7 and decreased significantly ($p < 0.05$) in 1 of 20 journals (Supplementary Figure S3). The mean proportion of ECS (co-)authors in articles decreased significantly ($p < 0.05$) and increased significantly ($p < 0.05$) in 14 and 1 out of 20 journals, respectively (Supplementary Figure S4).

There was a positive relationship between the number of publications in a given journal and year, and the proportion of publications (co-)authored by ECS (Supplementary Figure S5a). In the years when >900 articles were published per journal, the proportion of publications (co-)authored by ECS was >80% in each case, while it was only <60% in journals that published <100 articles. Similarly, there was a positive relationship between the number of publications in a given journal and year, and the mean proportion of ECS (co-)authors (Supplementary Figure S5b).

The non-focal variables and estimated smoothed functions in the citation impact analysis were similar in the model for the presence of ECS and for the proportion of ECS (co-)authors. These effects were therefore presented only for the first model (Figure 3). Effect plots for the second model are presented in the "Supplementary Materials" (Figure S6). Smoothed functions fitted to the data indicated a variety of non-linear relationships between selected predictors and citation count (Figure 3, Table 2). Papers published from 1991 to 2012 had the highest citation count, which declined sharply for papers published between 2012 and 2020 (Figure 3a). The number of authors per paper had a positive effect on its citation count up to ca. 30 authors, but increasing the number of authors beyond 30 had no clear effect (Figure 3b). There was a higher citation count for the mean academic age of authors up to ca. 10 years. The citation count was lower between 10 and 20 years. A similar citation level was found for the higher mean academic ages, but the estimates were uncertain (Figure 3c). The mean citation count per document of the authors had a positive effect on the citation count showing a logarithmic shape of the fitted function (Figure 3d). Review papers were cited the most frequently, followed by conference papers and standard research articles (Figure 3e). The presence of ECS (co-)authors had a significant negative effect ($p < 0.001$) on the citation count (Figure 3f). Similarly, the proportion of ECS (co-)authors had a significant negative effect ($p < 0.001$) on the citation impact (Figure 3g). A large part of the variation in the citation count was attributed to the random effect of the journal—systematic deviations from the average number of citations.

As expected, the proportion of ECS (co-)authored publications and the proportion of ECS (co-)authors per publication were higher in the sensitivity analysis where 11 years was used as a threshold for the academic age of ECS (ECS11). However, the time series (Supplementary Table S3 and S4, Figures S7–S12) had similar trends to the results of the main analysis presented herein. In the citation impact analysis, the presence of ECS (co-)authors also had a significant negative effect ($p < 0.001$) on the citation count, while the proportion of ECS (co-)authors no longer had significant effects ($p = 0.093$) (Supplementary Table S5, Figures S13–S14).

Table 1. Summary statistics of the LMM.

Predictor	ECS6 present		Proportion of ECS6 (co-)authors	
	Estimate (SE)	*p*-value	Estimate (SE)	*p*-value
Intercept	0.767 (0.024)	<0.001	0.363 (0.017)	<0.001
Year	0.003 (0.001)	0.003	-0.004 (0.001)	<0.001
Random effects				
SD intercept for journal	0.106		0.076	
SD year-slope for journal	0.002		0.004	
SD residuals	0.058		0.039	
Corr	-0.330		0.050	

SE—standard error, *SD*—standard deviation associated with the random effect, Corr—correlation between random intercept, and random year-slope for the journal. ECS within 6 years of first scientific publication = ECS6.

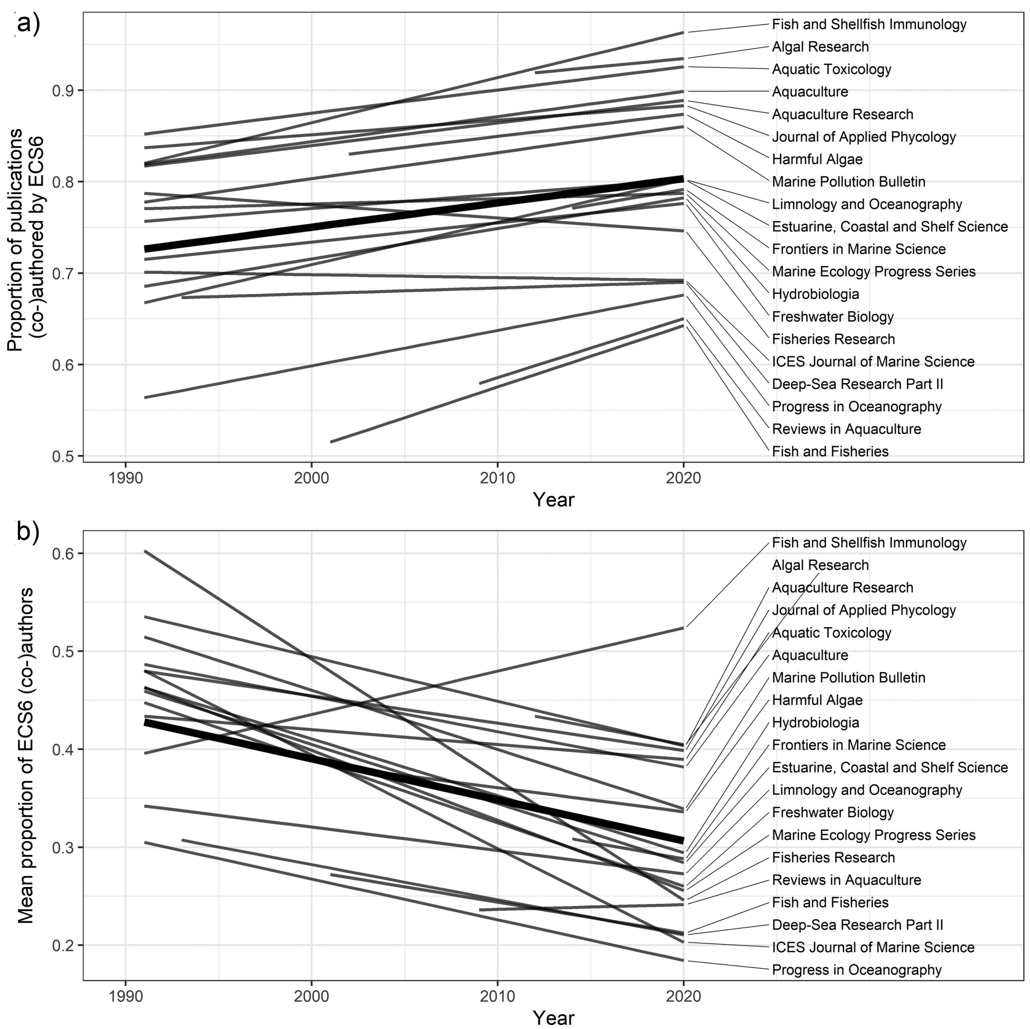

Figure 2. Predictions of the linear mixed-effects model fitted to the data on the proportion of publications (co-)authored by ECS (within 6 years of first scientific publication = ECS6) (a) and the mean proportion of ECS (co-)authors (b). The fitted model allowed for the random year effects (time trends) for each journal. The black line indicates the average trend (fixed effect).

Discussion

In this paper, we show that ECS, defined as scientists within 6 years of their first publication, make increasingly significant contributions to the marine and fisheries sciences literature. In the top 20 selected journals in the field, ECS (co-)author roughly four out of five publications and are lead authors in more than half of all publications. Other scientific disciplines show a comparable proportion of ECS (co-)authorship (e.g. Nicholas *et al.*, 2017). The substantial contributions of ECS have been emphasized in other fields (Bégin-Caouette *et al.*, 2020), and the temporal dimension of this analysis highlights that ECS contributions to the scientific literature have increased steadily since 1990.

In our analysis, we observed four growth trends: (1) the total number of publications being produced each year, (2) the

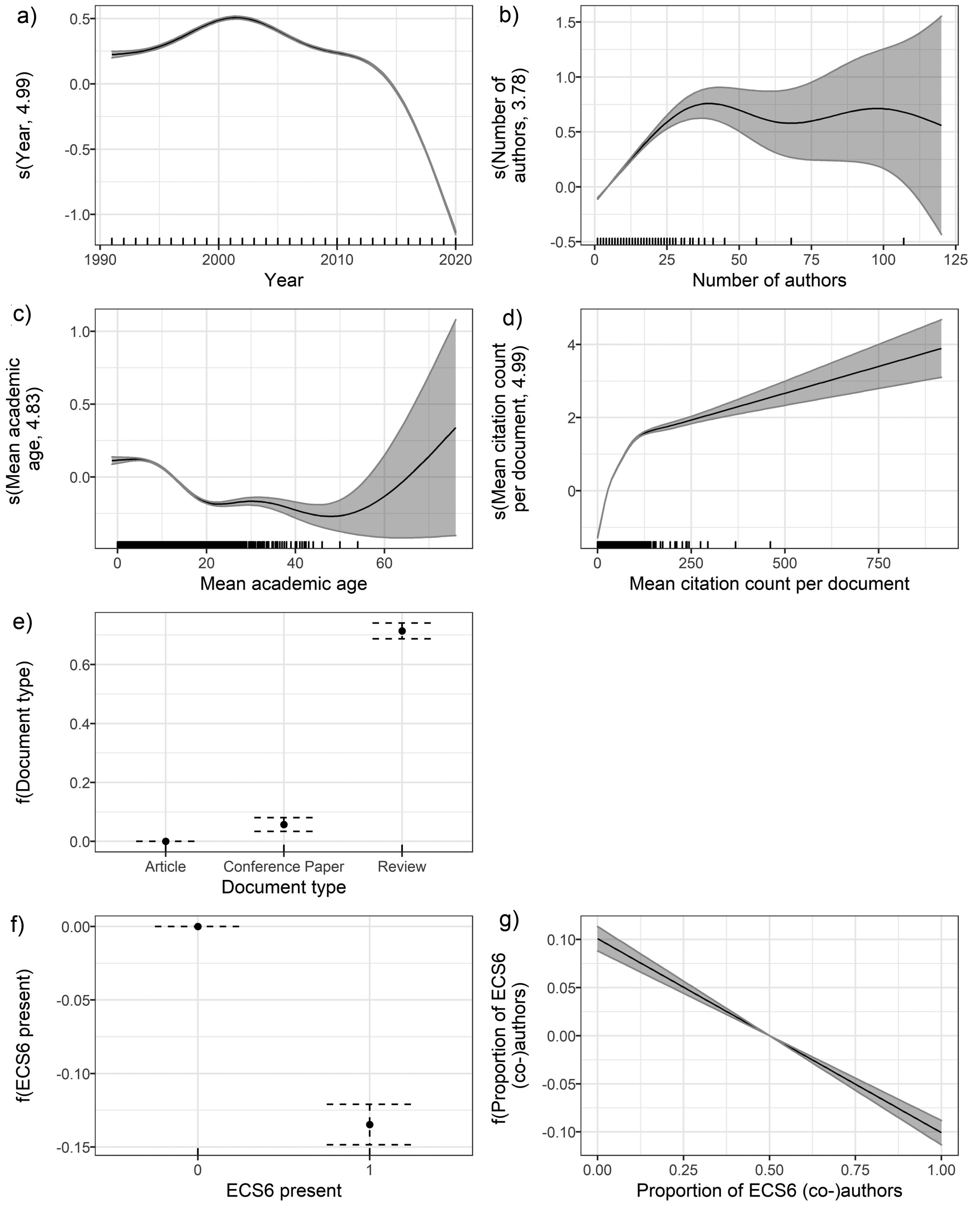

Figure 3. Citation impact analysis of ECS (within 6 years of first scientific publication = ECS6) in marine and fisheries sciences journals. Lines and dots indicate predicted effects, while grey bands and error bars are 95% confidence intervals. Panels a–f present effect plots predicted with the GAM model incorporating the effect of ECS6 presence, while panel g shows the effect predicted with the GAM model incorporating the proportion of ECS6 (co-)authors. Effect plots obtained with the latter model for the non-focal terms (panels a–e) are presented in Supplementary Figure S6.

number of authors per publication, (3) the number of publications in which at least one ECS is author, and (4) the number of papers with an ECS first-author. We interpret the net increase in publications to be a function of the general growth in scientific output over time (Bornmann and Mutz, 2015). The growing number of co-authors per publication is a result of modern and more globalized research increasingly relying on multidisciplinary approaches with diversified analytical techniques (Andrews *et al*., 2020; Olson and Da Silva, 2021), which leads to increasing diversity of the research teams (Wuchty *et al*., 2007) and thereby more authors per publication (Fanelli and Larivière, 2016). In addition, several other developments in academia and modern scientific practices, such as valuing more diverse scientific contribution, proof of mentorship in grant applications, as well as increasing the geographic coverage of the study outcomes have led to a higher number of authors per article (Chapman *et al*., 2019). The growing number of articles with ECS authors can partially be explained by

Table 2. Citation impact analysis.

	ECS6 present			Proportion of ECS6 (co-)authors		
A. Parametric coefficients	Estimate (SE)	*t*-value	*p*-value	Estimate (SE)	*t*-value	*p*-value
Intercept	3.329 (0.047)	70.473	<0.001	3.222 (0.047)	68.51	<0.001
Document type: conference paper	0.057 (0.012)	4.842	<0.001	0.059 (0.012)	4.998	<0.001
Document type: review	0.714 (0.014)	52.579	<0.001	0.717 (0.014)	52.753	<0.001
ECS6 present	-0.135 (0.007)	-19.143	<0.001			
Proportion of ECS6 (co-)authors				-0.059 (0.004)	-15.589	<0.001
B. Smooth terms	EDF	*F*-value	*p*-value	EDF	*F*-value	*p*-value
s(year)	4.994	26 401.572	<0.001	4.995	26 484.497	<0.001
s(number of authors)	3.782	1021.524	<0.001	4.036	838.878	<0.001
s(mean academic age)	4.833	1411.902	<0.001	4.795	1212.077	<0.001
s(mean citation count per document)	4.99	33 037.693	<0.001	4.989	32 923.816	<0.001
s(journal)	18.895	5518.690	<0.001	18.895	5528.126	<0.001

Summary statistics of the GAMM. SE is the standard error and EDF is the effective degrees of freedom. ECS within 6 years of first scientific publication = ECS6.

the first two trends (namely that there are more publications with more authors). Considering that ECS increasingly take the role of the leading author, we argue that it also signals the growing participation of, and dependence on, ECS to produce valuable peer-reviewed science.

We observe that the growing number of authors per publication outpaces the growth in ECS authorship. In the "publish or perish" academic framework, which affects scientists at all levels, we believe that additional factors offset ECS authorships: a limited number of ECS funded in a typical research project, disincentives for ECS to collaborate with one another, and the "dilution" of ECS contributions by senior co-authors. The current model of science is mainly based on funding research projects from national agencies catered towards senior-level researchers (Gibson *et al.*, 2020). The number of ECS (usually MSc or PhD students and postdocs) in these projects is limited in contrast to the senior researchers involved as the principal investigators, project participants, collaborators, or external experts. Moreover, candidates in many PhD programmes are obliged to demonstrate that they can work independently. The associated requirements for first-authorship in dissertation papers may disincentivise ECS from collaborating with each other (Hagen, 2010). Furthermore, PhD researchers have more supervisors than in the past (Vanstone *et al.*, 2013), which may inflate the number of senior authors in publications. ECS are less aware of existing authorship rules and conventions and are more vulnerable to authorship abuse, including ghost, honorary, or gift authorships (Cronin, 2001; Weltzin *et al.*, 2006; Teixeira da Silva and Dobránszki, 2016; Harvey, 2018). Even when formal rules are in place, many ECS report encountering problems with co-authorship (Nicholas *et al.*, 2017). The increase in the number of unwarranted co-author statuses is likely to benefit senior authors and penalize ECS, thus contributing to the observed decrease in the mean proportion of ECS (co)-authors (Cronin, 2001).

Although interdisciplinary collaborations can also lead to increasing numbers of senior co-authors per publication, they create opportunities for greater ECS co-authorship of publications and, thus, may benefit ECS's careers (Van Der Wal *et al.*, 2021). While there are clear benefits for ECS to participate in larger research efforts with multiple supervisors (Andrews *et al.*, 2020; Van Der Wal *et al.*, 2021), this may also affect them negatively. Increasing the complexity and time needed to conduct the research results in additional time pressure on ECS during short-term research contracts (Stokols *et al.*, 2008). Publications produced under the supervision or cooperation of multiple senior researchers require ECS to integrate feedback from different or even opposing perspectives, which is especially difficult when ECS has not yet developed a strong position within the research group and lacks experience in mediation and finding consensus (Leeming, 2019).

As expected, journals that publish review and perspective papers had a lower proportion of papers co-authored by ECS and a lower mean proportion of ECS (co-)authors. In many disciplines, reviews and perspectives on current status of knowledge are left to senior authors who are presumed to have a more comprehensive overview of the research topic (Lewison, 2009). However, the increase in the proportion of papers (co-)authored by ECS was greatest in these review-oriented journals, which we see as a future opportunity for young scientists. According to our results, journals that publish more articles per year also showed a higher contribution of ECS, both in terms of presence and the mean proportion of ECS (co-)authors. Publishing in rapid, high-output journals is understandable given that ECS have to achieve specific outputs (e.g. number of peer-reviewed publications) within their short contracts (see e.g. Runde, 2021 for the comparison of the mean turnaround times of the journals in the field). This poses a trade-off between publishing in high-output journals that have a higher acceptance rate and high-reputation journals that can have a positive impact on careers in the long term (Zhang and Yu, 2020).

In the citation impact analysis, we included additional variables in the models to control their potentially confounding effects when estimating the focal effects (i.e. the presence of ECS or the proportion of ECS co-authors). For example, the effect of year of publication is associated with the time needed for publications to gain citations (Tahamtan *et al.*, 2016). Our results show that most of an article's total citations in the marine and fisheries sciences are obtained within the first 8 years following publication. To a certain extent, citation count was also positively correlated with the number of (co-)authors. This effect had multiple explanations, including: a higher diversity of expertise, which stimulates dynamic ideas (Fanelli and Larivière, 2016); facilitated "knowledge diffusion," visibility and dissemination, which increases exposure of presented findings (Bosquet and Combes, 2013); or self-citing

(Amjad *et al.*, 2020). Interestingly, we found that the mean academic age of the authors is negatively correlated with citation impact, supporting previous findings that average citation impact per paper decreases linearly with age of the scientist until about age 50 (Gingras *et al.*, 2008). As expected, the mean citation count per document of each of the co-authors had a positive effect on the citation impact of the evaluated publications, as highly cited authors tend to receive yet more citations due to the prominence and prestige within their field of study (Bjarnason and Sigfusdottir, 2002). Differences in the mean number of citations obtained between article types were also observed. Review papers continue to provide a broad overview of the research topic and remain attractive to many researchers (Didegah and Thelwall, 2013). Review papers may also be used as baselines, leading to a high citation count for a given publication until the field is reviewed again some years later. Conference papers also had more citations than standard research articles on average, demonstrating the benefit of ECS attending scientific conferences. Since conference papers are usually published within proceedings collections or special issues, this could promote visibility of a given research result to scientists in the same field, increasing the likelihood of citation.

It is concerning that we observed lower citation impact if ECS were present as (co-)authors of the publication. Similarly, the proportion of ECS (co-)authors had a significant negative effect on the citation impact. Unfortunately, methodological differences make it difficult to compare our results with previous findings. However, Sinatra *et al.* (2016) showed that there is no temporal pattern in the citation impact of the work of most frequently cited scientists in selected disciplines, while Thelwall and Fairclough (2020) reported a decrease in average citation impact through the scientific career. We are not able to identify the causal mechanisms of the reduced citation impact of the papers (co-)authored by ECS in marine and fisheries sciences, but we suspect it may be associated with the limited scope of studies conducted in early career stages, which is often associated with the educational role of early research projects. We suspect that it could also be caused by a lack of sufficient reputation of the leading ECS author in the right network needed to attract attention to their work. The level of novelty that may appear in the papers (co-)authored by ECS (Trapido, 2015) could result in a low number of citations in a short time window. However, it is likely that a given paper will be cited more often over time (Wang *et al.*, 2017). This effect is not fully captured in our analysis. This finding contrasts with the previous results, which indicate that papers written by co-authors that are on average younger (<10 academic years) receive more citations than papers written by co-authors that are on average older. Papers with a lower mean academic age include a larger proportion of mid-aged co-authors (e.g. tenure-track and young professors) that earn more citations. However, impact is not a simple function of age and the collaborative aspects of scientific research should be taken into account (Gingras *et al.*, 2008).

In the citation impact analysis, other potentially important effects were not incorporated into the model. For example, there are many publication-related factors, such as title length, number of references or page count; and author-related factors, such as the number of affiliations, or countries of origin that could explain additional variability in the number of citations (Demeter, 2020; Zong *et al.*, 2020). Moreover, indices that relate to the number of citations of a scientist, publication, or journal do not necessarily correlate with the quality of science, nor the scientific impact, and tend to have inherent biases (Kurmis, 2003). Even though the *h*-index benefits from being able to include the number of publications and citations in a single index (Costas and Bordons, 2007), it cannot be considered completely unbiased. For example, cross-disciplinary comparison between different fields of science is often problematic, as certain fields of science may require much more extensive reference lists than others (Costas and Bordons, 2007).

Since citation-based metrics are often used to evaluate researchers (Bradshaw *et al.*, 2021), the lower citation impact of papers (co-)authored by ECS may further exacerbate the stratification of ECS and senior scientists and reinforce the "rich get richer and the poor get poorer" effect in scientific careers (Petersen *et al.*, 2011). Unequal opportunities for co-authorship between ECS and senior researchers and a lower chance of ECS citations should be considered when comparing the productivity and quality of publications between ECS and senior researchers (Sutherland, 2017). On the other hand, it is also plausible that some researchers only experience a form of "breakthrough" publication that solidifies their expertise in a given field after multiple years of researching it, which may fall just outside of the "academic age" used in this study (6 years since first publication). Considering that funding is shifting away from younger researchers (Gibson *et al.*, 2020), funding agencies should strengthen programmes targeting ECS that have a lower citation impact factor than senior scientists (e.g. NSF postdoctoral fellowship, Marie Skłodowska–Curie Action or grants that fall under the "Young Investigator" umbrella).

While this study provides one of the first quantitative evaluations of ECS contributions to the field of marine and fisheries sciences, we acknowledge that our analysis is not free of biases. We analysed only published papers, neglecting monographs, scientific reports, and the grey literature, which form a large portion of the publications and have a unique impact on science and policy-making. Furthermore, we selected the top 20 journals in the field, while for example, Runde (2021) selected 85 journals for the analysis of the scientific literature solely in fisheries science. It is possible that the contribution of ECS to scientific publishing is underestimated in this study as ECS may be publishing in other, lower-ranked journals due to intense competition among authors and high manuscript rejection rates discouraging submission at higher-ranked journals. The selected 20 journals focus mainly on disciplines of natural marine sciences that have historically achieved the most citations. As the focus shifts towards interdisciplinarity within marine and fisheries sciences (e.g. marine social science), there will be a need to include interdisciplinary journals that may not be considered in the top of any single field in future analysis of ECS' contributions. Further analysis should also recognize differences in the protocols that determines which contributions merit co-authorship in a paper. Such variability across disciplines can affect the assessment of the ECS contribution. Finally, future studies should also consider other types of bias in science, like a linguistic bias towards English (Di Bitetti and Ferreras, 2017), geographical (Demeter, 2020), or gender bias (Burdett *et al.*, 2022), and analyse how they impact on ECS' contributions specifically (see e.g. Squazzoni *et al.*, 2021).

Conclusions

Our counting of stars showed that ECS are important to the scientific firmament of marine and fisheries sciences, displaying positive trends in the proportion of publications with ECS as (co-)authors, and often as leading authors. We attributed this positive trend to the general increase in the number of publications per year, and the number of co-authors per publication, as well as the requirements for first-authorships in numerous ECS contracts. However, we found a considerable decrease in the mean proportion of ECS (co-)authors over the last three decades, which we conclude may be the result of limited number of ECS funded within one project, disincentives for collaboration among ECS, dilution due to many senior scientists co-authors, and additional complexity of interdisciplinary projects. Moreover, we identified a concerning lower citation impact for articles (co-)authored by ECS, which we suspect is the result of the limited scope of studies conducted by ECS, the lack of reputation within a research area (especially for first-author ECS), and the use of novel approaches, which may require additional time to translate into high citation rates.

Our extensive literature review pointed to phenomena and difficulties that likely contribute to the observed patterns, and we conclude that the general situation for ECS authorship probably results from the combination of several factors, including educational, funding, scientific, and publishing practices. Identifying direct causal effects is therefore difficult. By counting the youngest stars in the marine science landscape, we were able to provide some first food for thought and outline potential problems worth consideration. We now count on the brightest stars to help implement some much needed systemic change in marine and fisheries sciences.

We urge the scientific community to systematically support ECS in an era of high competitiveness and unstable academic opportunities. We believe that doctoral and postdoctoral programmes should simultaneously encourage collaboration between ECS and ensure that ECS can be equally involved in non-leading positions in the articles. This approach would contribute to an optimal balance of ECS and senior scientists in research activities, better use of scientific potential, and improved knowledge transfer. Effective mentoring and support structures for ECS, including the active promotion of their published research, are crucial elements for achieving a better balance between ECS and senior scientists. There is also a need for fairer and more holistic performance evaluation procedures that consider the disparities described in this study.

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Supplementary Data

Supplementary material is available at the *ICESJMS* online version of the manuscript.

Competing interests

The authors declare no competing interests.

Author contributions

Conceptualization: SS, CD, MZ, RMo, and DO. Data acquisition: SS, AS, and AW. Formal analysis: SS. Writing—original draft: SS, CD, MZ, and OO. Writing—review and editing: SS, CD, MZ, RMo, RMu, GP, DO, AS, AO, LF, EHV, OO, FL, GS, AW, and VM.

Data availability statement

The bibliometric data underlying this article are available from the Scopus database (https://www.scopus.com). The record of articles published in the selected journals has been downloaded on 18 November 2021. Due to the limit of export records of the Scopus Database API Interface, the historical publication record of the authors has been downloaded in batches from 18 November 2021 to 13 January 2022.

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