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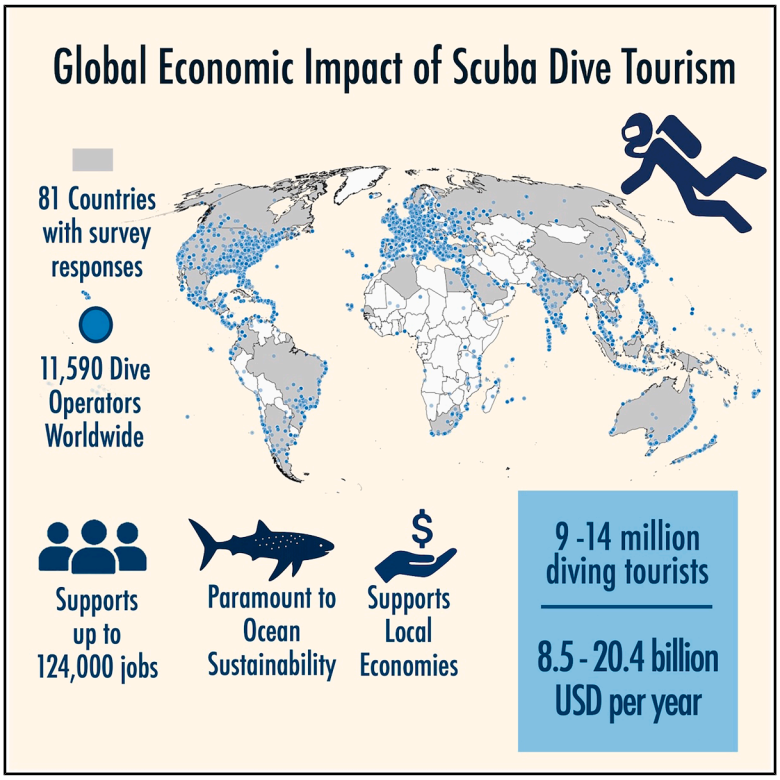
Global economic impact of scuba dive tourism

Graphical abstract



Highlights

- Scuba dive tourism generates between 8.5 and 20.4 billion USD globally each year
- The sector supports up to 124,000 jobs worldwide, with most employees being local
- Local dive operators overwhelmingly support conservation initiatives in their regions
- Marine ecotourism can align economic growth with sustainable marine management

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In brief

Scuba dive tourism is an increasingly popular global industry, supporting local economies and promoting marine conservation. Our study provides the first global estimate of its economic impact, revealing this sector generates between 8.5 and 20.4 billion USD annually while supporting up to 124,000 jobs worldwide.

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Global economic impact of scuba dive tourism

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SCIENCE FOR SOCIETY Scuba diving is not just an exciting recreational activity—it is also a significant contributor to the global economy. Our study provides the first global estimate of the economic impact of scuba dive tourism, revealing that the sector generates between 8.5 and 20.4 billion USD annually. This revenue supports local economies, creates jobs, and helps promote marine conservation. By highlighting the economic benefits of scuba diving, our research can help guide policies that balance ecological sustainability and economic growth in coastal communities.

SUMMARY

Marine ecotourism is increasingly popular and important for local economies, but its aggregated benefits to the global ocean economy are little known and often overlooked in policy discussions. Here, we present a first estimate of the global economic impact of scuba diving based on an online survey of scuba dive operators across the world. We estimate the global annual revenue of scuba diving (direct diving expenditure) at between 0.9 and 3.2 billion USD per year and a broader economic impact (direct and indirect expenditure) at between 8.5 and 20.4 billion USD per year. Marine ecotourism is one of the most promising ocean sectors that can incentivize local sustainable economies, and with 9–14 million marine diving tourists worldwide supporting up to 124,000 jobs, the scuba diving sector could be at the forefront of transformative change for local and global ocean sustainability.

INTRODUCTION

Marine and coastal tourism is a major segment of the ocean economy.[1] Recent studies have shown that ecotourism, particularly within Marine Protected Areas, can play a significant role in marine governance and conservation.[2] However, ecotourism's distinct identity and sustainable practices are often not separated from the broader tourism industry, limiting its recognition and integration in ocean conservation efforts.[3] While ocean-based tourism (e.g., beach- and hotel-based tourism) is often well organized and vigorously discussed in national and international political fora, local marine ecotourism activities are seldom considered and often disorganized and fragmented.[4] "Ecotourism" is used here to refer to activities where participants observe and interact with marine organisms in a way that intends to avoid harm to marine life and that specifically involves local benefits, education, and conservation initiatives,[5] and therefore, it has great potential to promote Sustainable Development Goal (SDG) 14 and Blue Economy development targets in local communities.[6–8]

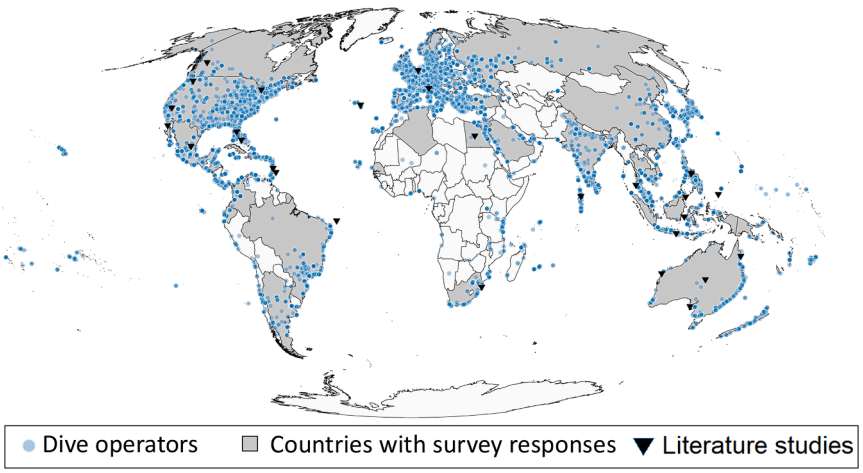

Figure 1. Global distribution of dive operators (blue dots) identified in this study
Countries in gray are represented in survey responses by operators. Black triangles show prior studies estimating local economic benefits of scuba diving and snorkeling activities.

Prominent examples of ecotourism include whale and shark watching, nature viewing, and scuba diving, and several global studies have highlighted the benefits of these sectors for ocean livelihoods and sustainability.[7,9,10] Research on marine tourism often focuses on broad economic activity in ocean areas, such as coral-adjacent tourism,[7] gross domestic product (GDP) in the Caribbean or South Pacific Islands,[11] or the benefits of cruise tourism for their ports of call.[12] Ecotourism and diving activities (e.g., snorkel and scuba diving businesses, schools, and charters), however, have been studied mainly at local or national scales[9,13,14] and usually for specialty activities such as shark diving.[13,15,16] For example, in Palau, shark diving generates US$18 million per year (~8% of the country's GDP)[17]; in the Maldives, annual total direct business revenue from divers is estimated at ~US$43 million[18]; and Mexican diving generates revenues of up to US$725 million annually.[6]

The scuba diving sector has been growing steadily, but there is little information available on its global economic benefits—even though some meta-analyses suggest it may have millions of participants per year.[10,19–21] This study aims to help fill this research gap by providing the first global estimate of the economic expenditure generated by marine dive tourism. More specifically, we are asking the following questions: what is the global total revenue generated by marine dive tourism? How could the economic benefits of scuba dive tourism contribute to ocean conservation and local livelihoods?

RESULTS

After manually validating web-scraped and industry data, we identified 11,590 dive operators worldwide (Figure 1), deployed a web-based survey in 2021–2022, and applied a meta-analytical (value transfer) approach to interpolate missing data (see methods). An estimated 8.9–13.6 million divers and snorkelers participate in marine dive tourism activities worldwide, generating an estimated global revenue of US$0.9 billion to US$3.2 billion annually (median of US$1.5 billion) (Table S1).

This range represents the direct dive-related expenditures received by scuba diving operators and was estimated using 425 responses from survey data (see Methods S1 for the questionnaire) and 249 additional data points for daily tour prices from secondary data searches (see data collection) across 81 countries. This sample size is sufficient for a ±5% error margin at the global level, but we recognize high uncertainty in results in this first baseline study. This is particularly important at regional and local scales, which may have wider uncertainty due to fewer responses and greater differences in local dive tourism structures. We therefore report confidence intervals throughout, representing the range within which the results from our economic analysis are likely to fall. They account for variability in operator responses, differences in regional pricing, and the extrapolation of missing data using meta-analytical techniques. Therefore, while the midpoint (median) of our results provides a useful benchmark, stakeholders in the diving and conservation sector as well as policymakers should interpret the results as a range of possible outcomes instead of a single definite figure. We present these upper and lower bounds in our results.

Our estimates focus on direct economic impacts from dive-related expenditures, including the total annual revenue dive operators receive from participants for scuba dive certification, day trips and liveaboard trips (including snorkeling), and gear rental (for scuba diving and snorkeling). Based on the annual number of participants and tourist expenditure data from the UN World Tourism Organization,[22] global indirect expenditure from scuba dive tourism was estimated to be between US$7.6 billion and US$17.2 billion annually. These expenditures are made by participants in marine diving activities, including lodging and other local expenses (excluding international travel). Including both direct and indirect expenditures by dive tourists, the wider economic impact of global scuba dive tourism is estimated to be between US$8.5 billion and US$20.4 billion per year. Note this does not include indirect and induced impacts from the dive tourism industry (spending by scuba operators and their employees) and does not address any other values that divers may give to their experience beyond what they have actually spent.[23]

Recognizing uncertainty in the estimated total annual revenue (total direct expenditure) of dive tourism for the countries included in the analysis, these results are shown in aggregate for the 22 UN geographic subregions (Figure 2). Results show regions with the highest total revenues are Northern America, Central America, Southern Europe, and Southeastern Asia. In addition, 24 literature studies were identified that had at least partial estimates of the economic impact of scuba diving, which helped us contrast our estimates and gain a better understanding of economic patterns at local and national scales (Figure 1; Table S2).

Data were separated between operators who offer day-trip tours (including night dives, shore dives, and any excursions

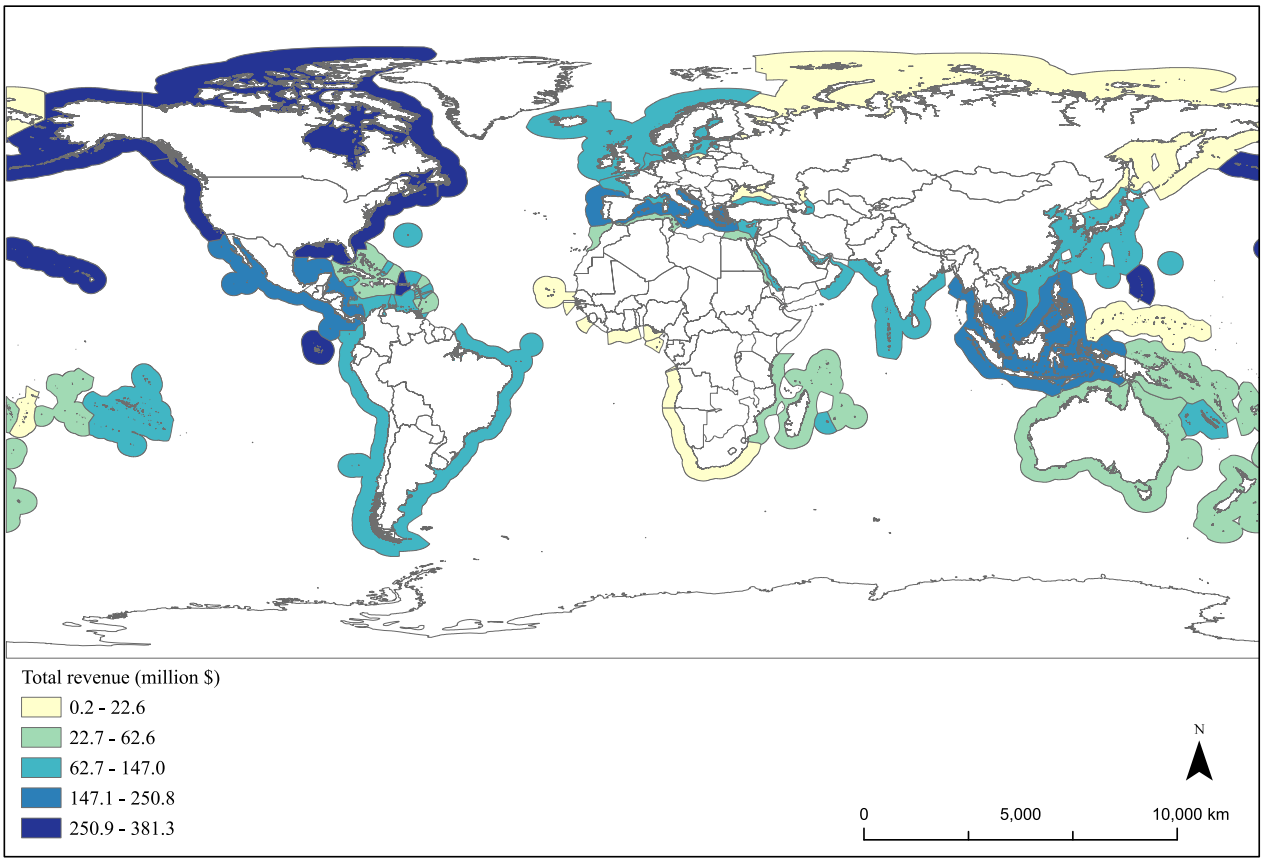

Figure 2. Estimated total direct annual revenue from scuba dive and snorkel tourism

Note results are displayed in aggregate for 22 UN-based subregions and displayed in countries' exclusive economic zones (EEZs).

where the client does not sleep on board the boat) and liveaboard operations (businesses designed for clients to sleep on board for a multi-day trip). Prices between day trips and liveaboard trips per person per day differ greatly, with a global average of US$76–114 for a day trip and US$208–270 per day for a liveaboard trip (Figure 3). Importantly for the robustness of model estimates, day-trip prices across regions were relatively uniform, with slightly higher prices in the Americas, Asia, and Oceania. Liveaboard prices show much more variation across and within regions, likely due to the smaller sample size and differences in the onboard accommodations. However, liveaboard trips accounted for less than 1% of the total revenue generated per trip for all dive operators identified in this study; hence, price variation is not an important contributor to uncertainty in overall results.

Employment varies greatly, especially between the high and low seasons, and ranges from the lowest data point in the low season with 28,000 jobs to 124,000 as the highest range in the high season (including both full-time and part-time employment). Survey results show that, globally, 80% of all employees are local nationals of the country the business operates in, and the remaining 20% are hired from abroad. Employment of local nationals was slightly lower, though still quite high in Asia and Oceania, at 71% and 78%, respectively.

While our survey requested that operators consider their business pre-COVID-19 pandemic, we included a question about the economic impacts of the pandemic on their business. Operators generally responded negatively (n = 222), but some also responded positively (n = 107) and stated that their revenue had increased since the beginning of the pandemic in 2020. Our analysis did not reveal any significant trends or geographical patterns in operators' responses, but we include some example quotes for context. A dive operator from Central America, for example, stated that "business in 2021 & 2022 is better than ever, and revenue is up 100%." Other comments were not specific to the economic situation of the business but explained how COVID-19 has impacted the ecosystem. For example, a dive operator from a South Pacific island stated that reefs themselves were healthier, but fish populations were not: "Reefs have improved dramatically since COVID-19 lockdowns. Fish life has decreased dramatically since COVID-19 lockdown due to villagers needing to support and feed family after losing jobs." Other operators have clearly been struggling since the beginning of the COVID-19 pandemic. For example, an operator from South Asia wrote, "COVID-19 didn't just change our business. It destroyed it. We have effectively started a new business in 2021. Our past experience in operations and budgeting has no value in the present market. It has

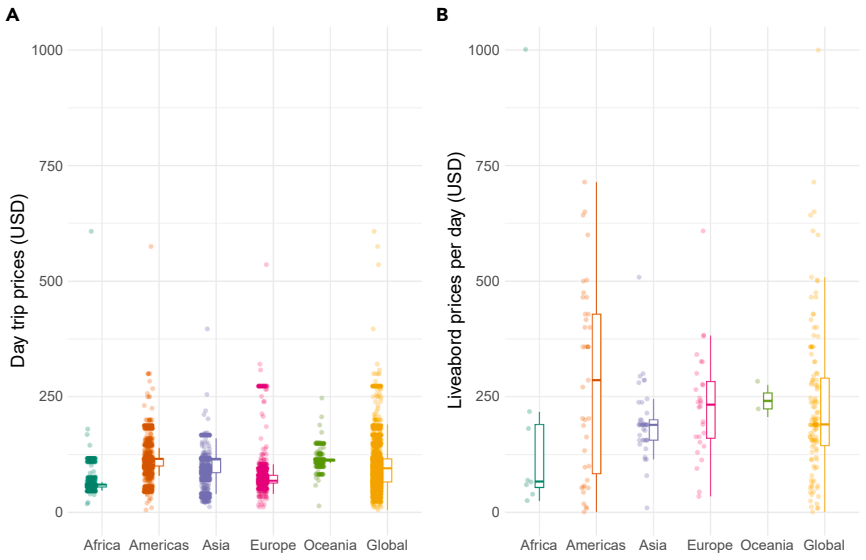

Figure 3. Prices (per day per person) for scuba-diving day trips and liveaboard tours

(A) Prices for scuba-diving day trips.

(B) Prices for liveaboard tours.

Individual points represent observed and estimated operator prices. Box-and-whisker plots summarize regional and global price distributions: the box spans the inter-quartile range (IQR) from the first quartile (Q1) to the third quartile (Q3), with a horizontal line marking the median; whiskers extend to the most extreme values within 1.5 × IQR; points beyond that range are plotted individually as outliers.

been devastating. We are still hopeful, as this is our passion and we feel also our calling."

Dive operators were also surveyed regarding the environmental characteristics of their dive sites, including the most important natural attractions for their businesses. Figure 4 shows these results, separated by tropical and temperate dive operations. Operators in tropical areas clearly highlighted reefs and the biodiversity associated with them, including corals, fishes, turtles, and sharks (Figure 4). Dive attractions in more temperate regions showed a wide range of attractions, from reefs to kelp to ice and marine mammals (Figure 4). Operators were also asked about environmental changes at the dive sites they have observed over the last 10 years. Based on the 315 answers to this question, operators located in tropical areas reported more negative environmental change on their dive sites than operators located in temperate regions (Figure 5), but, notably, there were many examples of positive perceptions of local change in both tropical and temperate ecosystems. Operators that elaborated on their environmental change scores generally focused on changes in biodiversity, species abundance, coral bleaching, pollution, and water quality.

DISCUSSION

The results of this study bring a unique value to the academic and policy discourse and highlight the global significance of scuba diving as a key component of marine ecotourism. The local nature of ecotourism operations, as identified in this study, includes 11,590 dive operators and up to 124,000 jobs, with businesses overwhelmingly employing local nationals distributed across 170 different countries (Figure 1). The 8.9–13.6 million diving tourists per year and the US$8.5–20.4 billion in total expenditures that they generate similarly bring very local benefits but add up to global impact. A comparable ecotourism sector is whale watching, which has been estimated to generate around US$2.1 billion in 2003 (around US$3.4 billion in 2022 dollars, accounting for inflation)[24] from 3 million whale watchers, supporting ~13,000 jobs and contributing to marine mammal conservation efforts around the world.[25]

Limitations of the study

This study provides important insights for ocean policy but has important limitations that must be addressed in future work.

First, the scope of the estimation comprises only expenditures on dive trips, gear rentals, dive certifications, and associated travel and lodging but does not include broader economic impacts from gear manufacturing and sales or other revenue streams generated through international scuba associations (e.g., the Professional Association of Diving Instructors [PADI], National Association of Underwater Instructors [NAUI], and Scuba Schools International [SSI]).

Second, indirect expenditures by participants (travel, food, and accommodations) were estimated assuming their average trip costs are equal to general tourism data collected and available through UNWTO.[22] Local economic studies of dive tourism (Figure 1) were not enough to adjust expenditures in our model, though they suggest that generally the mean trip expenditures of scuba dive tourists, especially for foreign tourists, are higher than those of tourists in general. For example, based on Haas et al. (2017),[26] a scuba dive tourist spends ~US$1,200 on average per day in The Bahamas, where the WTO reported an average spending per tourist per day of ~US$500 (both values in 2019 USD) (see Table S2). In Colombia, general tourists spend US$1,500 per trip, whereas Trujillo et al. (2017)[27] report that scuba dive tourists spend almost US$2,000 (see Table S2). This means that our estimates of the total diving industry's economic impact are very likely conservative. For example, our global revenue estimate (0.9–3.2 billion USD per year) and past estimates for Mexico (up to 725 million USD annually) are comparable in magnitude, although differences in methodology contribute to the observed variation. In Mexico, extensive field surveys provided near-complete coverage of diving operators with revenue estimates based on arithmetic means—sensitive to high-revenue operators (with figures declining to 456 million USD when excluding large businesses)—whereas the global analysis employed quantile-based techniques to address variability and uncertainty across diverse markets. In addition, a lack of responses in some countries that are known for a large scuba dive sector contributed to a likely underestimation of results, as our method made conservative assumptions at every step of estimating missing data. For example,

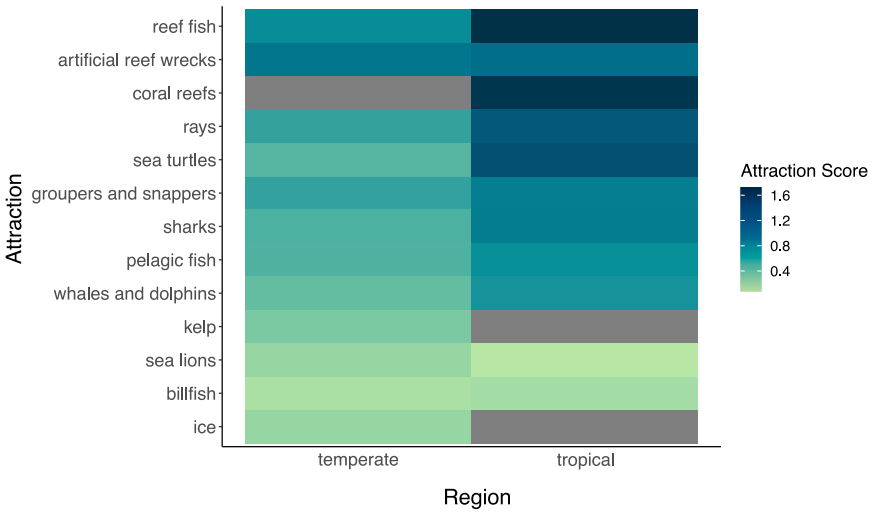

Figure 4. Operators scored the importance of a set of natural attractions from most important to least important for divers in their location

Answers are grouped into tropical and temperate regions of the world, with the mean weighted by the number of operators per subregion.

Australia is famous as a scuba dive destination; however, based on our estimates, it contributed less to total global revenue compared with countries such as Indonesia or Spain for which a lot more data were available.

Third, our web-scraping approach to identify dive operators was based on Google data, and while a global list of operators provided by PADI (the largest scuba dive association in the world) was a useful addition for cross-validation (see methods), we were very likely unable to capture all existing dive tour operators (i.e., those without any formal affiliation or public web presence).

Fourth, in conducting this global survey, our approach aimed to maximize reach and inclusivity among dive operators worldwide, particularly during and following the COVID-19 pandemic, leveraging the extensive network accessible through Google, the most comprehensive search engine available. Online survey methods may favor operators with a stronger online presence and accessibility, though given the practical challenges of identifying and engaging a diverse array of dive operators, this methodology represents a significant effort toward creating a comprehensive global overview of dive operations. Though the resulting sample allowed for estimates with a narrow error margin of ~4% at the global level, in-person interviews and workshops would have greatly improved our data coverage and enabled more useful insights for local and national discussions (a key gap in current results). In addition, we focused our survey on economics and ecological components only to avoid survey fatigue and decided not to include demographic-related questions. Acknowledging this, our study presents a foundational global perspective, highlighting the need for future research to refine and deepen country-specific analyses.

Fifth, our results are based on business operation data before the onset of the COVID-19 pandemic and may therefore not be completely representative of present-day impacts. Our survey results showed that the pandemic had largely negative impacts on dive operators. The decline in general in tourism-related revenue following the start of the COVID-19 pandemic is further corroborated by case studies on Bali dive operators and other marine protected area (MPA) tourism operators.[28–30] International tourism is still recovering to pre-pandemic volume with regional differences. International tourism arrivals in 2024 have rebounded to 93%, 107%, and 88% of 2019 levels in North America, the Caribbean, and Southeast Asia, respectively.[31] The Caribbean has seen a rapid recovery of marine tourism since the onset of COVID-19[32] and dive tourism in one MPA in Hawai'i has rebounded to pre-pandemic volumes.[33] Though more data from other regions are needed, it appears that dive operators, who are generally familiar with within-year variation between low and high seasons, were resilient to the COVID-19 shock. Moreover, we observed that despite perceived long-term declines in environmental conditions of dive sites by the survey respondents (Figure 5), the number of annual entry-level certifications issued remained largely stable between 2015 and 2019, indicating a continued growth in the dive industry. Whether dive operators continue to meet and adapt to both long- and short-term changes in demand will partly depend on their position in adaptive ocean management. Regardless of future changes, our estimate of the dive tourism industry's economic impact is at least informative to our contemporary understanding of its relative contribution in comparison to other marine tourism industries.

Scuba dive tourism and the Blue Economy

It has become apparent that major transformations are needed across all marine sectors to successfully establish Blue Economies that are socially equitable, ecologically sustainable, and economically viable.[34–38] However, despite increased research on the economic benefits of ecotourism,[10,39–43] the sector as a whole is often regarded as an adjacent rather than central asset in the Blue Economy discourse.[8] We argue that the ecotourism sector can be a key player with its local-based activities, such as scuba diving, providing benefits and lessons important for needed transitions toward a successful Blue Economy[44] and enabling progress on broader UN Sustainable Development Goals.

This study further highlights that the scale of economic impacts from marine ecotourism is globally significant, yet the better alignment between social and ecological goals in ecotourism is just as significant for its role and influence within a Blue Economy. This is similar to related discussions on the outsized role that artisanal (small-scale) fisheries have in a Blue Economy, given that they are already better aligned with social equity goals compared with larger industrial operations.[36] This alignment already exists in ecotourism but may also be relevant to other forms of marine tourism. For example, annual expenditures of surf tourism have been estimated at between US$31.5 billion

and US$64.9 billion (this includes travel costs) from 17–35 million surfers annually.[45] Surfing does not require marine living resources but could be included within ecotourism given its overwhelming focus on local benefits and conservation education and actions. Recreational fishing also has significant economic impacts, with approximately 58 million anglers spending ~US$39.7 billion in 2003 (US$65 billion in 2022 dollars).[10] Of course, recreational fishing requires more specific guidelines to be sustainable,[46] yet it has the potential for large positive impacts on marine ecosystems and local economies. The global cruise ship industry generates a total estimated output of US $150 billion and supports 1.18 million jobs[12]; however, there are significant criticisms over its environmental and cultural impacts[47] as well as the economic volatility of the business itself.[48] This underlies the fact that most of the income from marine tourism still comes from mass tourism developments that are very often unsustainable. In China, one of the biggest ocean-based economies across the world, coastal tourism has been identified as the biggest contributor to the overall value of the ocean economy, with growth rates of over 20% each year throughout the last 10 years.[49] With large-scale negative effects from land displacement, habitat destruction, and pollution observed in coastal destinations globally,[50–52] it will be difficult to credibly include all mass marine tourism within the intended goals of a Blue Economy. Yet positive transformations are possible and should be widely pursued, and this study highlights another possible option to support this process.

Scuba diving ecotourism, conservation, and local economies

Ecotourism has long been proposed as an alternative livelihood in coastal regions, particularly given the possibility of converging local economic and conservation goals.[41,43,53,54] Tourism as the main income source for coastal communities can be risky, as the tourism sector exposes vulnerability to changes in demand and shifts in the global economy, clearly highlighted through the COVID-19 pandemic and supported by our results, which show how dive operators have been struggling. These are considerable drawbacks that need to be taken into account when discussing the potential of scuba dive tourism as a driver for local economies and ecotourism. Knowledge and perspectives from local dive operators need to be included in marine spatial planning processes. Survey results show that most operators are concerned about negative environmental changes around their dive sites (Figure 5). But observed positive changes, both in temperate and tropical regions, also need to be further highlighted, as this type of information should be collected to learn where conservation endeavors have potentially been successful. Diving has also undergone important shifts that must be understood by policymakers to better integrate the sector within wider efforts to implement Blue Economies. For example, while the most important ecosystem attractions are still large marine species, such as sharks, dolphins, or coral reefs, the wider accessibility of underwater photography coupled with diver experience and specialization[53] has increased interest in small or unusual organisms and ecosystems, and this can be observed in photography contests with more common macrophotography categories. Muck diving (i.e., scuba diving along the muddy sediment of the ocean floor) alone has been estimated to contribute ~US$150 million in Indonesia and the Philippines, attracting over 100,000 divers annually.[55]

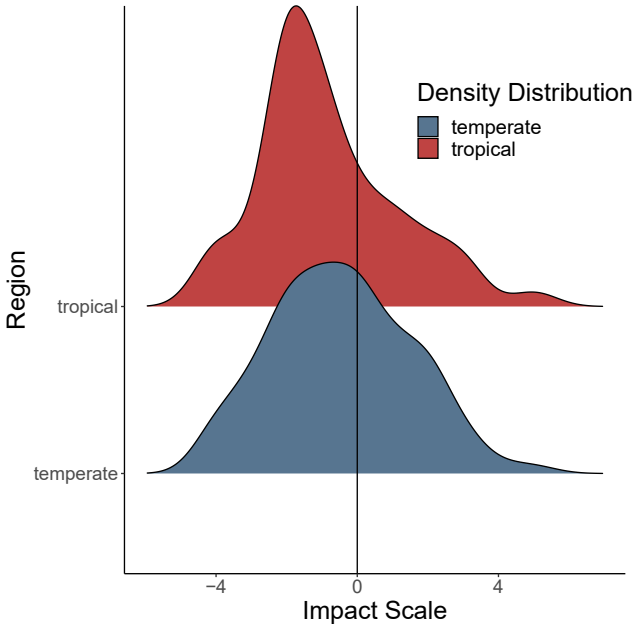

Figure 5. Perceived change of environmental conditions of dive sites over the last 10 years provided by 315 survey responders

Values above zero are perceived positive changes (1–5), and values below zero (from –1 to –5) reflect perceived negative change over time, divided into tropical and temperate regions of the world. Results are weighted by the number of dive operators per subregion.

Although MPAs have shown potential for successful marine conservation, such as in coral reef ecosystems,[56] the majority of MPAs are top-down (similar to other conservation approaches) and designed in a few countries alone, making them inadequate conservation strategies for countries where most coral reefs are located.[57] Bottom-up approaches such as community-based conservation initiatives and locally managed marine areas have been shown to lead to higher success rates,[19,57,58] particularly when traditional, Indigenous, and local knowledge leads adaptive management and decisions on whether and what areas to "protect."[34,59,60] Our survey revealed that the vast majority of scuba dive operators are already contributing to local, regional, and national conservation initiatives, with the remainder expressing willingness to be involved. Importantly, though we do not have information about ownership and benefits sharing, 80% of employees in our surveys were reported to be local nationals and not hired from abroad, and the perspectives of these local people are essential for considering the benefits and impacts of dive tourism for communities around the world. This, together with the economic potential of scuba dive tourism around MPAs,[61] could support a socially equitable, ecologically sustainable, and economically viable dive tourism industry.

Recommendations

This study demonstrates the relevance of meta-analytical techniques to assess the global status of valuable industries,

including scuba diving tourism. Data can provide useful input to guide the appropriate management strategies to ensure that ecosystems are protected, revenue is generated, communities are involved, and tourists continue to support local economies while having enriching and environmentally responsible experiences. Given the challenges faced in the process of collecting global data to characterize the diving industry and its trends, it remains imperative that standardized monitoring programs allowing regions/nations to collect data about the diving industry are implemented.

The results of this study have important implications for policy on the development and governance of scuba dive tourism (and are also likely applicable to other well-established sectors of the marine ecotourism industry, such as whale watching and recreational fishing). First, scuba dive tourism is a very large sector in the global ocean economy and has the potential to significantly impact well-being in local communities and local conservation outcomes. Ensuring that these impacts are positive requires concerted efforts to coalesce economic benefits and conservation actions. Scholars have suggested implementing such programs in areas such as the Mediterranean Sea,[62] including the introduction of dedicated dive staff at dive centers who would not only coordinate citizen science programs but also conduct other types of work—surveys, community engagement, safety protocols, and liaising with local authorities using standardized methods that would allow data comparisons across regions. Organizations like Divers Alert Network (DAN), PADI, Green Fins, and Reef Check could also be involved in the collection and provision of standardized data to collaborate and coordinate on establishing guidelines that can limit adverse environmental impacts, promote participation in sustainable tourism, and keep stakeholders engaged over time.

While the global economic benefits of scuba dive tourism are clear, it is important to recognize that the vast majority of scuba dive operations benefit and are run within local communities that must also be leaders in broader scuba diving governance. The integration of local stakeholders in decision-making processes includes, for example, Indigenous peoples, local dive operators, and broader community members that enjoy the same seascapes and can inform decision-making and community interests. This can contribute to a fair distribution of benefits stemming from the dive tourism sector so that funds can be reinvested in local infrastructure, environmental management, and community development projects. Together with better ongoing monitoring as highlighted above, a focus on tangible community benefits can also foster collaboration to deal with ongoing challenges such as climate and ecosystem change or system shocks that emerge unexpectedly.

Future research is needed to continuously improve the understanding of the economic benefits and the economic impact of scuba dive tourism at a global scale. This includes aiming to also quantify additional indirect impacts such as supply chain effects, gear manufacturing, and downstream economic multipliers. In addition, understanding the actual costs to calculate profit margins from diving will be interesting to understand, as well as how these profits are distributed across the sector.

Conclusion

With diving operators spread across all coastal countries and having a stake in healthy marine ecosystems, the diving sector should play a key role when it comes to integrated coastal management and the establishment of a Blue Economy. Importantly, the local knowledge of both owners and workers of dive businesses should be fully included in coastal management decision-making processes. Like other marine sectors, government oversight is important to ensure that the social, ecological, and economic goals associated with diving corporations are indeed aligned and contributing to equitable and sustainable communities. Mass coastal tourism has often been shown to contribute to the marginalization of local communities and the degradation of coastal and marine environments. In a Blue Economy that aims for socially equitable and environmentally sustainable marine industries, the economic scale and lessons of dive tourism and other forms of ecotourism can be essential for guiding the expansion of new ventures and transforming other ocean sectors.

METHODS

To estimate the economic impact of scuba diving and snorkeling tourism globally, we applied a similar approach used, for example, in global estimates of recreational fishing and shark-watching expenditures, economic impacts from commercial fisheries, global fisheries subsidies estimates, and regional estimates of ecotourism expenditures.[10,39,63,64] Here, we developed a methodology that comprises six main steps: (1) identification of dive operators; (2) implementation of a survey and compilation of secondary data sources; (3) meta-analysis of survey results; and estimation of (4) direct, (5) indirect, and (6) total global diving expenditure per year (Figure 6). The sections below expand on each of the methodological steps. Code and data to reproduce our results are available at a dedicated repository: https://doi.org/10.5281/zenodo.15499633.

The first step aimed to create a database and geographic map of all scuba diving operators, compiled through a combination of web scraping and manual review and our collaboration with PADI (see data collection). This database represents the baseline for information gathering and subsequent economic analyses. The second step entailed developing and distributing an online survey across all identified scuba diving operators, with survey design and key questions drawn from methodologies (and key gaps) in available research. These geo-mapping and data collection steps are detailed in "data collection" below.

The third step developed a meta-analysis (benefit transfer) model across regions and countries to fill data gaps where no information was available. Benefit transfer is a well-established method for estimating economic impacts and values at large scales, under the key assumption that partial missing data for one unit (in this case, dive operators) can be inferred to be similar to existing data for similar units. This method is particularly appropriate for providing baseline estimates of complex themes such as ecosystem-based activities and natural capital,[65–68] but the uncertainties inherent in the method mean that assumptions and variation in existing data must be acknowledged and ideally incorporated in sensitivity analyses.[65] These various steps to

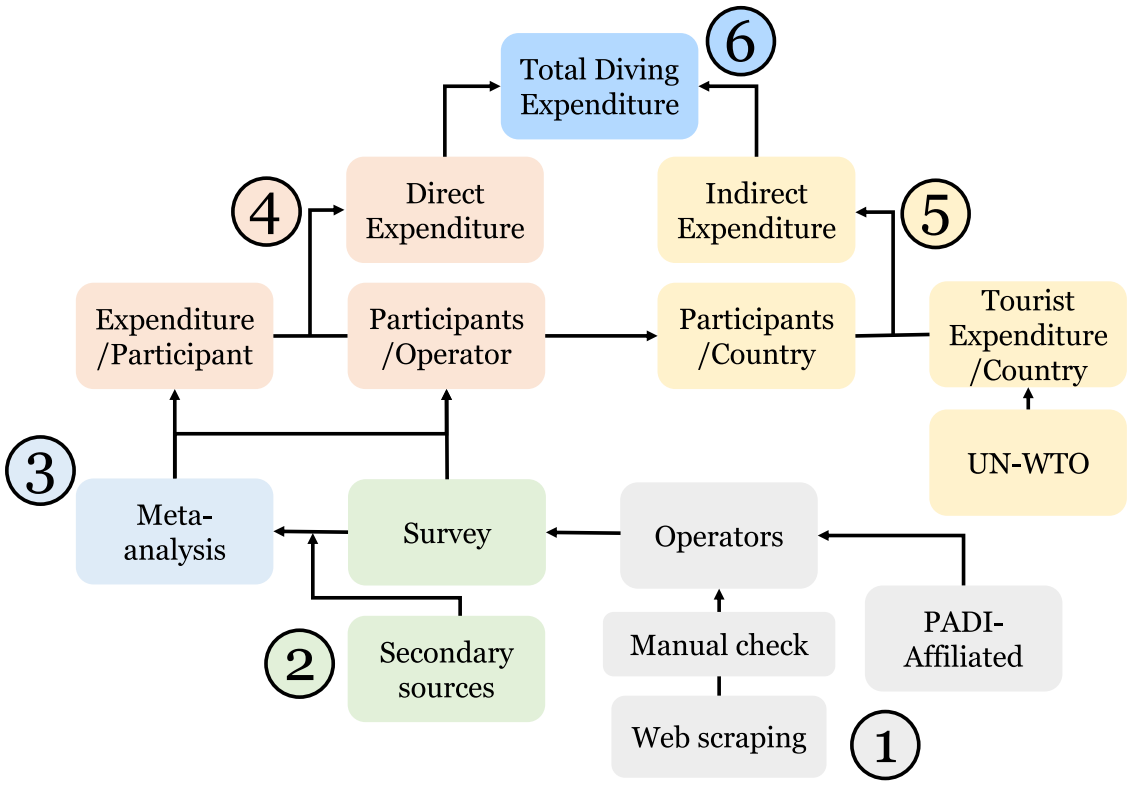

Figure 6. Overview of data collection and analysis as described in the methods section, including (1) identification of dive operators, (2) implementation of the survey and secondary data sources, (3) meta-analysis of survey results, and estimation of (4) direct, (5) indirect, and (6) total global diving expenditure per year

validate estimates and incorporate different layers of sensitivity analyses in our model are specifically outlined in the estimation methods below.

Based on this information, step four calculated direct expenditures by participants with dive operators. Indirect expenditures, that is, spending by dive tourists on local travel and accommodations aside from their spending on the dives themselves, were calculated in step five based on survey results and data downloaded from the UN World Tourism Organization public Tourism Statistics Database website.[22] In the sixth and final step, all expenditures were combined and formed the basis for the subsequent presentation of results at various geographic scales. Estimation methods are presented below in "estimation methods" and "total economic impact."

Data collection

To compile an initial list of dive operators, we used a technique called "web-scraping," which indicates a process to programmatically obtain information from the World Wide Web and store data in a human-readable format (e.g., a data table). We web-scraped Google Maps and obtained diving operator names, contact information, and other metadata about their businesses. Each of the final web-scraped operator data points was manually checked to determine if the business was an actual dive operator, if it was still active, and whether it offered liveaboard trips or day-trip activities. With the help of collaborators from Tourism Research in Economics Environs and Society (TREES), North-West University, Potchefstroom, South Africa, an additional 571 operators across Africa were identified and added to the web-scraped dataset. Another manual search revealed 39 dive operator businesses in mainland China, which the web-scraping activity did not pick up due to Google limitations within the country. Additionally, we received a global dataset containing around 6,000 dive businesses from PADI that we merged with our operator datasets, where almost 4,000 of those were new entries that had not been captured in our dataset. While web scraping is a valuable and powerful tool for obtaining large amounts of data, its utility is constrained by the content available on specific database sources (in this case, Google Maps). Consequently, it generates a sample of existing diving operators. This might be a limitation in countries where Google services are not widely used (e.g., China), and in addition, overlook businesses that do not have an online presence. Nevertheless, it serves as an effective sampling tool and, despite its potential for bias, represents a significant effort toward creating a comprehensive global overview of dive operations (see limitations of the study). As this database is published and further enriched by contributions from local and regional researchers, future assessments will undoubtedly enhance its accuracy and output.

We designed a survey that investigates the economic impact of local dive businesses and assesses their attitudes toward different conservation regulations. This survey was built using SurveyMonkey. Accompanying the survey is a frequently asked

questions (FAQs) page in which participants can find additional information on why a specific question is being asked. The survey adheres to the principles of free, prior, and informed consent (FPIC). It clearly informs potential participants about the study's objectives, specifies that the survey data will be used to assess the economic impact of scuba diving, emphasizes that participation is entirely voluntary, and clarifies that participants provide consent by choosing to continue with the survey (see Methods S1, first page of the survey). The ethics boards have approved this survey at the University of California, San Diego (UCSD) (2010112XX) and the University of British Columbia (UBC) (H21-00687). A data agreement has been signed among UCSD, Centro para la Biodiversidad Marina y Conservación (CBMC), and UBC to access data resulting from these surveys. The questionnaire can be found in Methods S1.

The questionnaire contained 44 questions and was sent out to all unique email addresses obtained from the diving operator web-scraping activity and has been promoted with the help of PADI and DAN Europe, among others. Given the global scope of this study, the survey was designed to collect as much information as possible and, at the same time, avoid survey fatigue. The survey was tested through a focus group, during which we collected feedback and subsequently refined the survey. This group included 10 European, 5 South African, 10 Mexican, and 10 North American diving operators, alongside academic peers and colleagues who provided structural advice and review. Languages tested within the groups were Italian, French, Spanish, and English, according to the mother tongue of the participants. Once finalized, the survey was translated into 12 different languages (English, French, Italian, Spanish, German, Traditional Chinese, Arabic, Portuguese, Japanese, Korean, Dutch, Russian, and Polish). In addition to the economic part of the survey, we also asked the dive operators to provide their opinions about ecological perceptions of their dive sites, the impact the COVID-19 pandemic has had on their business, and whether they had any interest in participating in conservation-based initiatives (Methods S1).

Besides the survey, a dataset was added that provided a total of 145 additional data points for prices of scuba diving day-trip activities that were acquired by visiting individual websites of about 1,000 dive operators by collaborators at the Environmental Markets Lab (EmLab) at the University of California, Santa Barbara. As these data initially presented the price per dive and the survey asked for the price per day trip, we assumed, after some online research and talking to experts in the field (in addition to the authors' expertise), that an average day trip comprised two dives. We therefore multiplied the price per dive by two to match the survey results and integrate the data. Another 104 data points exclusively from Mexico were added from Arcos-Aguilar et al.,[6] presenting scuba and snorkel clients and the price per dive and snorkel for each operator.

Survey data collection lasted 2 years (2021–2022). Respondents were asked to provide answers corresponding to the time before the beginning of the COVID-19 pandemic, and all final monetary values have been converted from their original currencies into 2021 USD. The full dataset of diving operators combined with their anonymized survey responses is available at https://doi.org/10.5281/zenodo.15499633.

Estimation methods

This step estimates the total gross revenue of dive operators worldwide, the number of annual participants, and the total number of jobs directly supported based on results from the global online survey. Based on the literature and the author's experience with dive and snorkel tourism operations, we first grouped survey responses into day trips and liveaboard trips. Day trips are diving and snorkeling tours lasting less than 24 h, including single- or half-day trips (including day and night dives, shore dives, boat dives, or other activities that include snorkeling or diving). On the other hand, liveaboard trips are overnight tours that last more than one day. The reason for doing this split is that we assume total revenues and costs will be very different for dive operators running a liveaboard business, which is usually an all-inclusive type of dive trip package (similar to a cruise ship), compared with an operator who offers day trips.

As noted above, benefit transfer methods are based on the assumption that missing data points can be derived using available data from similar cases, in our case geographic proximity and type of operator (day trip or liveaboard). First, all primary data from operators (i.e., from the data collection step above) were analyzed to calculate the median and quantile values at the level of country, subregion, region, and globally. For each operator and data category for which no original data point was available, these three formed the mid, low, and high figures (for example, for price per day) used in the estimation model. Thus, missing data for operators were imputed using available data for operators in the same country, subregion, or region.

The conceptual outline of the model and the datasets used as input information are presented in Figure 7. Uncertainties in estimates have been explicitly highlighted by including confidence intervals for each estimated result. In addition, we applied a jackknife loop, a resampling method that randomly excludes a set of data points to recompute the final estimates systematically. Medians and quartiles were then calculated based on the new recomputed estimates (data showing the jackknife loop can be found in Figures S2, S3, and S4). In addition, we calculated the margin of error to help gauge the reliability and accuracy of our sample size using the following formula:

$$\text{Margin of error} = z \times \sqrt{\frac{p \times (1 - p)}{n}}.$$

z: *Z* score, which corresponds to the desired level of confidence. In our case, for a 95% confidence level, z is equal to 1.96. p is the estimated proportion of the population, and *n* is the sample size.

For creating a global map of scuba diving revenue, the attribute table of the total annual revenue per country was joined with geographical data on the exclusive economic zones (EEZs). The natural breaks classification method was used to classify countries based on their revenue into five groups. This method puts similar values of annual revenue together to maximize the differences between classes (Figure 2).

To help evaluate the credibility and accuracy of our metrics, we secured an official database from PADI detailing the trends in certifications by country from 2018 to 2022. We calculated the average number of certifications per year for each country

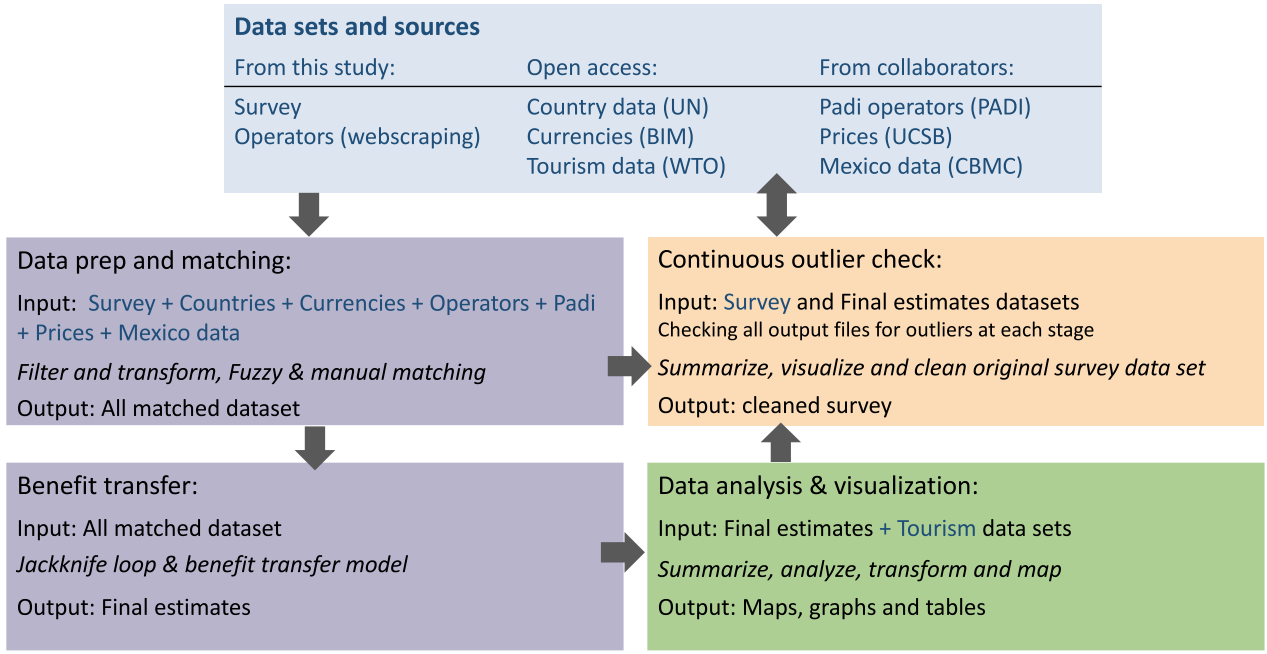

Figure 7. Concept of the model to estimate global impact, and datasets include all data used as input and their sources

and compared these figures with our own estimates of certifications per year as presented in Figure S5. We assessed the correlations using a Pearson test (Table S3), and all results were found to be significant. The correlation with an independent database for this trait suggests that our metrics are highly credible, despite the relatively small sample size. In any case, we provide conservative estimates.

Total economic impact

Total annual revenue consists of the monetary values of scuba dive certification, day trips and liveaboard trips (including snorkeling), and gear rental (for scuba diving and snorkeling). A combination of part-time and full-time equivalent employment is presented for low and high seasons. The number of scuba dive tourists is also presented for low and high seasons, including all-day trips and all liveaboard scuba diving clients.

With additional data from independent secondary sources, we also estimate the indirect expenditure of scuba dive tourism and the total economic impacts of the global dive tourism industry. First, we estimated the average annual spending per tourist per country. This was done based on international tourist arrivals and annual expenditures using global datasets from the UNWTO.[22] Inbound tourism is defined as arrivals of non-resident visitors (overnight visitors and same-day visitors or excursionists) at national borders and the expenditures as in total annual expenditure in USD. The mean tourist expenditure per day was then multiplied by the total number of scuba dive tourists derived from our study first to estimate the total indirect expenditure of all tourists globally. We then continued to add the result of this value to this study's global total revenue estimate to compute the broader economic impact that scuba dive tourism has worldwide

RESOURCE AVAILABILITY

Lead contact

Requests for further information and resources should be directed to and will be fulfilled by the lead contact, Anna Schuhbauer (acschuhbauer@gmail.com).

Materials availability

All produced datasets are available through https://doi.org/10.5281/zenodo.15499633 or https://github.com/annaschu/Global_scuba_dive_economics.

Data and code availability

All code is accessible through Zenodo (https://doi.org/10.5281/zenodo.15499633) or (GitHub) https://github.com/annaschu/Global_scuba_dive_economics.

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AUTHOR CONTRIBUTIONS

Conceptualization: A.S., F.F., O.A.-O., E.S., U.R.S., A.H., M.P.de L.C., and A.M.C.-M.; data curation: A.S. and F.F.; formal analysis: A.S., F.F., and T.W.; funding acquisition: M.P.de L.C., O.A.-O., and E.S.; investigation: A.S., F.F., T.W., K.D.M., R.B.C., and S.L.; methodology: A.S., F.F., and A.M.C.-M.; project administration: M.P.de L.C.; validation: A.M.C.-M., F.F., and O.A.-O.; visualization: A.S., F.F., and T.W.; writing – original draft: A.S., F.F., and A.M.C.-M.; writing – review and editing: T.W., O.A.-O., E.S., K.D.M., U.R.S., S.L., M.N.T., and A.M.C.-M.

DECLARATION OF INTERESTS

The authors declare no competing interests.

SUPPLEMENTAL INFORMATION

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