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PRACTICE AND POLICY

Closing the gap between existing large-area imaging research and marine conservation needs

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Abstract
Emerging technology has immense potential to increase the scale and efficiency of marine conservation. One such technology is large-area imaging (LAI), which relies on structure-from-motion photogrammetry to create composite products, including 3-dimensional (3-D) environmental models, that are larger in spatial extent than the individual images used to create them. Use of LAI has become widespread in certain fields of marine science, primarily to measure the 3D structure of benthic ecosystems and track change over time. However, the use of LAI in the field of marine conservation appears limited. We conducted a review of the coral reef literature on the use of LAI to identify research themes and regional trends in applications of this technology. We also surveyed 135 coral reef scientists and conservation practitioners to determine community familiarity with LAI, evaluate barriers practitioners face in using LAI, and identify applications of LAI believed to be most exciting or relevant to coral conservation. Adoption of LAI was limited primarily to researchers at institutions based in advanced economies and was applied infrequently to conservation, although conservation practitioners and survey respondents from emerging economies indicated they expect to use LAI in the future. Our results revealed disconnect between current LAI research topics and conservation priorities identified by practitioners, highlighting the need for more diverse, conservation-relevant research using LAI. We provide recommendations for how early adopters of LAI (typically Global North scientists from well-resourced institutions) can facilitate access to this conservation technology. These recommendations include developing training resources, creating partnerships for data storage and analysis, publishing standard operating procedures for LAI workflows, standardizing methods, developing tools for efficient data extraction from LAI products, and conducting conservation-relevant research using LAI.

KEYWORDS
coral reef, conservation technology, large-area imaging, photomosaic, remote sensing, structure-from-motion photogrammetry

Reducción de la brecha entre la investigación actual de imágenes de gran superficie y las necesidades de la conservación marina

Resumen: Las nuevas tecnologías tienen un enorme potencial para aumentar la escala y la eficiencia de la conservación marina. Una de ellas son las imágenes de gran superficie (IGS), que se basan en la fotogrametría de estructura a partir del movimiento para crear productos compuestos, incluidos modelos ambientales tridimensionales (3D), cuya extensión espacial es mayor que la de las imágenes individuales utilizadas para crearlos. El uso de las IGS se ha generalizado en determinados campos de las ciencias marinas, principalmente para medir la estructura tridimensional de los ecosistemas bentónicos y realizar un seguimiento de los cambios a lo largo del tiempo. Sin embargo, el uso de las IGS en el campo de la conservación marina parece limitado. Realizamos una revisión de la bibliografía sobre el uso de las IGS en los arrecifes de coral para identificar temas de investigación y tendencias regionales en las aplicaciones de esta tecnología. También encuestamos a 135 científicos de arrecifes de coral y profesionales de la conservación para determinar la familiaridad de la comunidad con las IGS, evaluar las barreras a las que se enfrentan los profesionales en el uso de las IGS e identificar sus aplicaciones consideradas como las más interesantes o relevantes para la conservación del coral. La adopción de las IGS se limitó principalmente a los investigadores de las instituciones con sede en las economías avanzadas y se aplicó con poca frecuencia a la conservación, aunque los profesionales de la conservación y los encuestados de las economías emergentes indicaron que esperan utilizar las IGS en el futuro. Nuestros resultados revelaron una desconexión entre los actuales temas de investigación de las IGS y las prioridades de conservación identificadas por los profesionales, lo que subraya la necesidad de una investigación más diversa y relevante para la conservación mediante el uso de las IGS.

PALABRAS CLAVE
arrecife de coral, estructura a partir del movimiento, fotogrametría, fotomosaico, imágenes de gran superficie, tecnología de la conservación, teledetección

LARGE-AREA IMAGING AS CONSERVATION TECHNOLOGY

Technology has the power to transform the way the environment is studied (Allan et al., 2018; Lahoz-Monfort et al., 2019). For instance, before the advent of scuba diving in the 1950s, marine scientists had limited access to underwater spaces. The rise of scientific diving revolutionized many fields of marine science, especially in shallow subtidal coastal ecosystems, by providing a means for conducting directed observations and performing experiments underwater. In-water field techniques supported by scuba opened new avenues of study and changed how much of marine ecological research is conducted (Cattaneo-Vietti, 2021; Witman et al., 2012).

More recent technological advances have similar potential to transform the way researchers and practitioners access, monitor, and study marine environments. One such technology is large-area imaging (LAI), a form of multiview photogrammetry in which overlapping images are used to generate composite digital reconstructions of objects or environments. LAI reconstructions include 3D point clouds and meshes, 2D composite images (e.g., photomosaics), and digital elevation models (DEM). These data products are large relative to the footprint of the individual components used to generate them (i.e., individual photographs). The object being reconstructed with LAI may be as small as a single organism (Conley & Hollander, 2021; Olinger et al., 2019) or as large as an entire community or landscape (Westoby et al., 2012). Readers may be familiar with LAI as *structure from motion*, a term that technically refers to 1 of multiple steps required to generate 3D LAI reconstructions, or *photogrammetry*, a general term that refers to the entire field of image-enabled measurements. We prefer more targeted language and use the term *large-area imaging* to describe the overall workflow of imaging, assembly of 3D and 2D data products, and extraction of ecological information (Figure 1) (Edwards et al., 2017).

LAI has myriad potential applications for marine conservation (Bongaerts et al., 2021; Johnston, 2019; Rossi et al., 2021). Among the most powerful applications is tracking and visualizing change in benthic ecosystems over time. Coregistered imagery of the same environment collected at different times provides unique information of organism- and community-level change that can transform the way researchers and practitioners document ecosystem recovery or decline (Kaplanis et al., 2020; Sandin et al., 2020; Thornton et al., 2016) and can inform restoration efforts and other management interventions (Ferrari et al., 2021; Merlino et al., 2020; Richaume et al., 2021; Voss et al., 2019). Importantly, these visual products can be used to communicate conservation needs or outcomes and help decision makers and the general public form a connection with an ecosystem they might never experience in person (van den Bergh et al., 2021). For researchers, LAI creates a powerful data set of virtual ecosystems that can be reused to answer a variety of research questions, creating an economy of scale that can reduce fieldwork costs (Couch et al., 2021). Furthermore, high-resolution imagery captured over the extent of 100s of square meters to several square kilometers can be used to answer novel scientific questions, develop new ecological metrics, create fine-scale habitat maps, and expand the footprint of long-term monitoring programs (Palma et al., 2017; Piazza et al., 2019).

LAI 3D reconstructions are based on the principle of parallax, the apparent displacement of an object when viewed from 2 or more perspectives. Once images are collected, typically with a drone (Chirayath & Instrella, 2019), autonomous under-

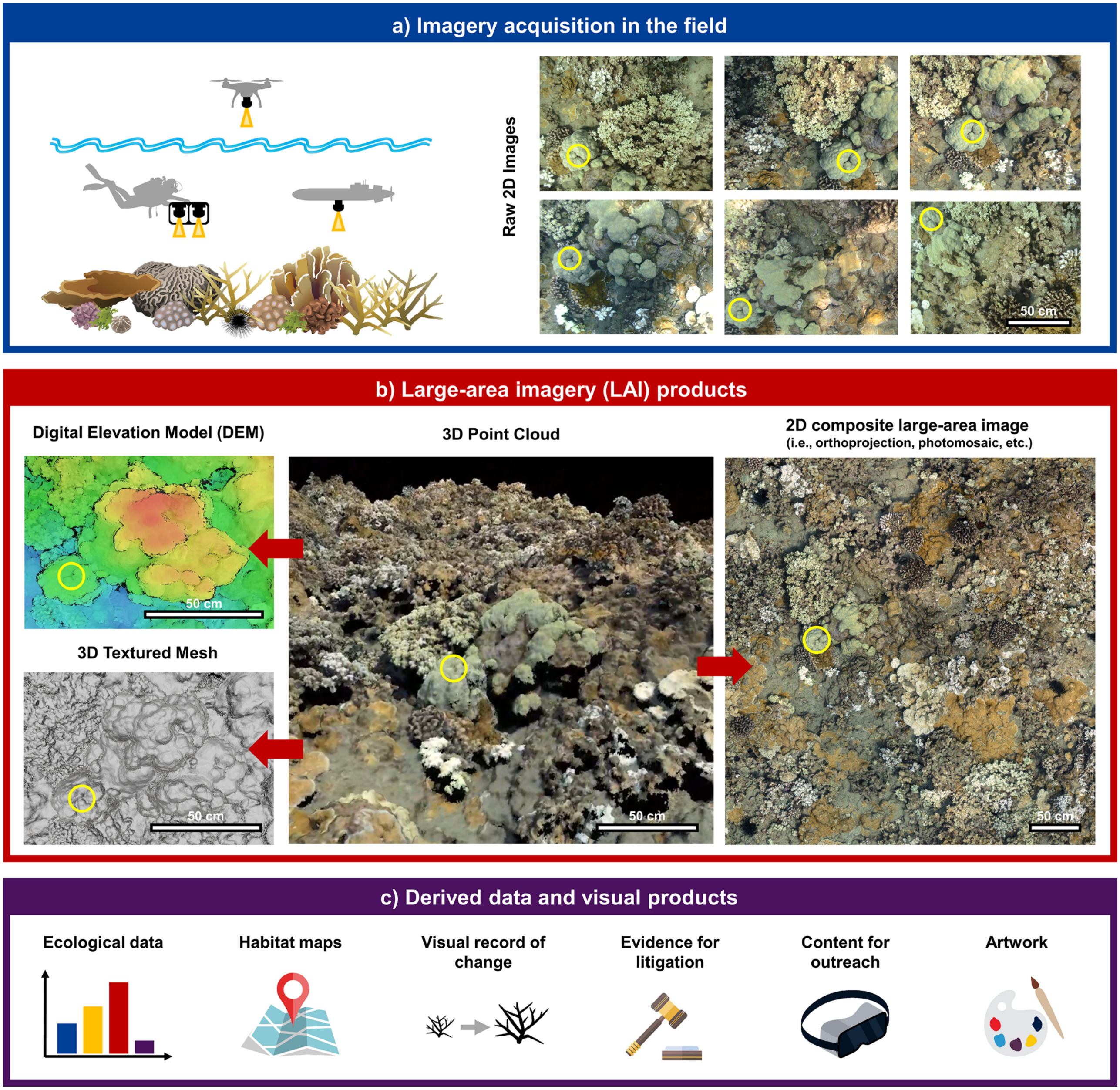

FIGURE 1 Large-area imagery (LAI) data products and their use. (a) A collection of 100s to 1000s of component images of an object or environment are collected, typically using a digital camera operated by a diver, autonomous underwater vehicle (AUV), or airborne drone. (b) Component images are used to create a 3-D reconstruction called a point cloud, which covers a larger area than visible in any single image. The point cloud is computed using a process known as structure from motion (SfM), implemented with modern photogrammetric and computer vision software. This process relies on the position of fixed features that show up in multiple overlapping component images (represented here by a yellow circle). Multiple data products can be produced from the point cloud such as digital elevation models, 3D textured mesh surfaces, and 2-D composite image products. (c) A nonexhaustive representation of data and visual products that can be derived from LAI.

water vehicle (AUV) (Parsons et al., 2018), or diver-operated camera (Bayley et al., 2019a), an algorithm identifies fixed features that appear in multiple photographs to first align the images relative to one another and then to create a geometrically accurate 3D reconstruction of the photographed object or environment (Figure 1). The 3D reconstruction, or point cloud, is a series of millions to billions of points with Cartesian coordinates and other associated information (e.g., RGB values). The point cloud can be converted into a 3D meshed surface or DEM or exported into a 2D composite image such as a photomosaic or orthoprojection (i.e., an orthographic projection of the point cloud). Users can conduct virtual field work by designing in-silico natural experiments and collecting data directly from LAI data products, which are digital archives of benthic ecosystems. Ecological data extracted from LAI may include species density and abundance, habitat structural complexity metrics, and the size and location of sessile organisms (Figure 1).

Throughout the 20th century, LAI was used for both terrestrial (Colwell, 1983) and marine applications (Martin & Martin, 2002), but widespread adoption of this technology for marine science was limited because images needed to be aligned to one another by hand, or at least with a great deal of human guidance. However, in the 2000s, improvements in underwater cameras, computing power, digital storage, and computer vision algorithms enabled automated construction of underwater image mosaics (Lirman et al., 2007). The ability to collect and process thousands of images without manual alignment enabled new uses of the technology that could exploit a "landscape view" of the seabed (Gleason et al., 2007; Lirman et al., 2010). Starting in the 2010s, commercial software made this technology widely available, expanding the types of studies and the number of people using LAI (Carrivick et al., 2016).

While use of LAI in marine science has increased over the last decade (Anderson et al., 2019; D'Urban Jackson et al., 2020), a number of factors have limited access to LAI in the marine conservation sector. These barriers include access to the equipment needed to collect and process imagery (e.g., cameras and computers) and the cost of computers and software required to construct 3-D models (Raoult et al., 2016; Roach et al., 2021). Collecting the large volume of ecological data that can be extracted from LAI products requires specialized training and personnel time, which can create staff capacity bottlenecks. These challenges could be more acute for researchers and practitioners based at institutions in the Global South (emerging economies primarily in the tropics and Southern Hemisphere) than in the Global North (advanced economies primarily in the Northern Hemisphere, with the exception of Australia and New Zealand) (Supporting Information Appendix S1). Given LAI's diverse range of applications, it has the potential to be a powerful tool for marine conservation. However, these barriers could severely limit the widespread, equitable use of LAI.

We addressed the following questions: How has LAI been used to date, and by whom? Is there alignment between LAI applications and conservation practitioner priorities? What barriers currently limit LAI applications? And, finally, what steps can current LAI users take to increase the accessibility of this technology for those in the conservation community? To answer these questions, we used tropical and subtropical shallow coral reefs as a case study to examine the trends in LAI literature and evaluate the perspectives of potential and current LAI users. We reviewed 151 coral reef LAI studies published from 2010 to 2021 and complemented our literature review with a 25-question online survey, which was completed by 135 coral reef scientists and conservation practitioners. We also conducted 30-min videoconference interviews (hereafter semistructured interviews) with 45 survey participants who volunteered to be contacted to further discuss their survey responses (survey responses and interview details in Supporting Information Appendices S1 and S2). The survey and semistructured interviews were conducted under the oversight of the UC San Diego Institutional Review Board (project 801952).

Coral reefs are an ideal case study for answering questions regarding the use and accessibility of conservation technology because LAI is being adopted relatively rapidly to study them (Burns et al., 2015; Couch et al., 2021; Edwards et al., 2017; Figueira et al., 2015; Sandin et al., 2020; Young et al., 2017) and because coral reefs represent an ecosystem in urgent need of conservation (Carpenter et al., 2008; Hughes et al., 2018). Although our findings are most directly applicable to the coral reef science and conservation fields, our recommendations for how to increase LAI accessibility are likely to be broadly applicable across the fields of marine science and conservation.

CURRENT APPLICATIONS OF LAI

Potential applications of LAI in coral reef science have been described (Bongaerts et al., 2021; Calders et al., 2020; Ferrari et al., 2021; Rossi et al., 2021); here, we reviewed the coral reef LAI literature to identify common research themes, gaps where additional use of LAI could have greater impact, and alignment between existing research and conservation priorities.

We found that LAI has been gaining popularity in the coral reef field; >66% of all studies in our literature review were published since 2018 (Figure 2a). Furthermore, a majority of survey respondents in nearly every demographic group (sector, Global North vs. South, self-described scientist or conservation practitioner, and previous LAI experience) reported that they were likely or very likely to use this technology in the future, even though only 40% of survey respondents had experience with LAI (Supporting Information Appendix S2). Together, these results suggest LAI is rapidly becoming an industry standard for coral reef researchers, though this transition is likely still in the early stages.

Although use of LAI has been increasing, application of this technology remains concentrated on a few key topic areas (Figure 3a) including method development (i.e., validating the technology's precision and accuracy, 60% of studies), measuring habitat 3D structure (34% of studies), documenting change over time (24% of studies), and quantifying benthic community composition (20% of studies). Given the advantages of LAI (e.g., the ability to track change with precisely aligned models, the ability to quantify 3D structure), the popularity of these research topics is hardly surprising. However, we found that other research topics that are seemingly well suited for study with LAI are relatively underexplored, such as quantifying coral demographic rates (6% of studies) or tracking the fate of coral restoration projects (6% of studies).

Our survey of coral reef scientists and conservation practitioners revealed a considerable disconnect between the research interests of survey respondents in the conservation sector and existing coral reef LAI literature (Figure 3b). Understudied research topics that emerged as priorities for conservation respondents included coral disease, coral demography, coral restoration, succession and recovery dynamics, coral recruitment, and water quality. Some of these topics are not well suited for study with LAI alone (e.g., water quality), but could be investigated in novel ways if LAI were used in concert with other forms of data (e.g., fine-scale temperature, nutrient, or turbidity measurements). Use of LAI to study these and other conservation topics could help fill knowledge gaps

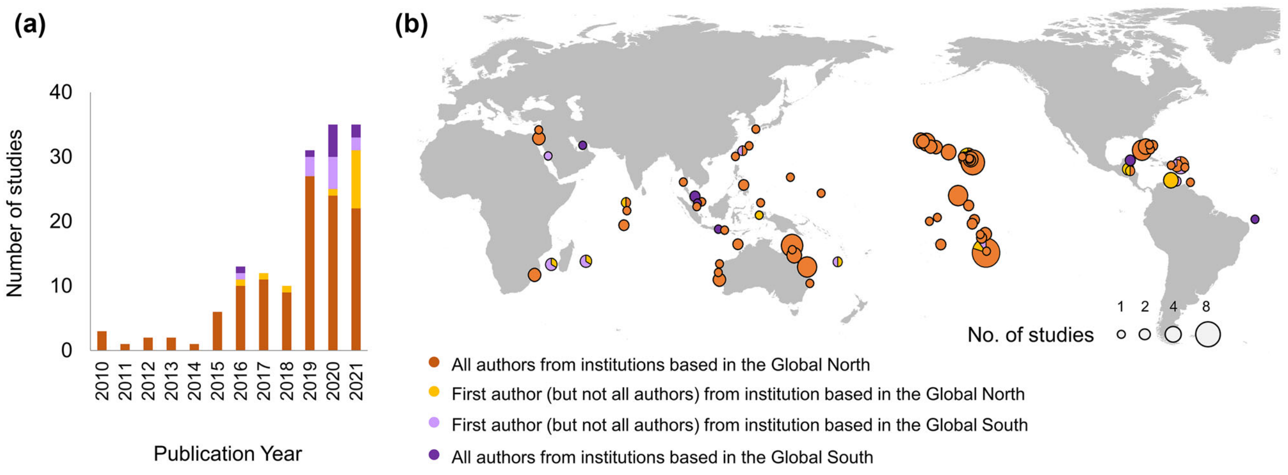

FIGURE 2 Coral reef studies that used large-area imagery (LAI) by (a) publication year and (b) location of study sites. Studies were categorized based on the location of the research institutions that the study authors hailed from at the time of publication. Studies that spanned multiple locations have multiple points on the map.

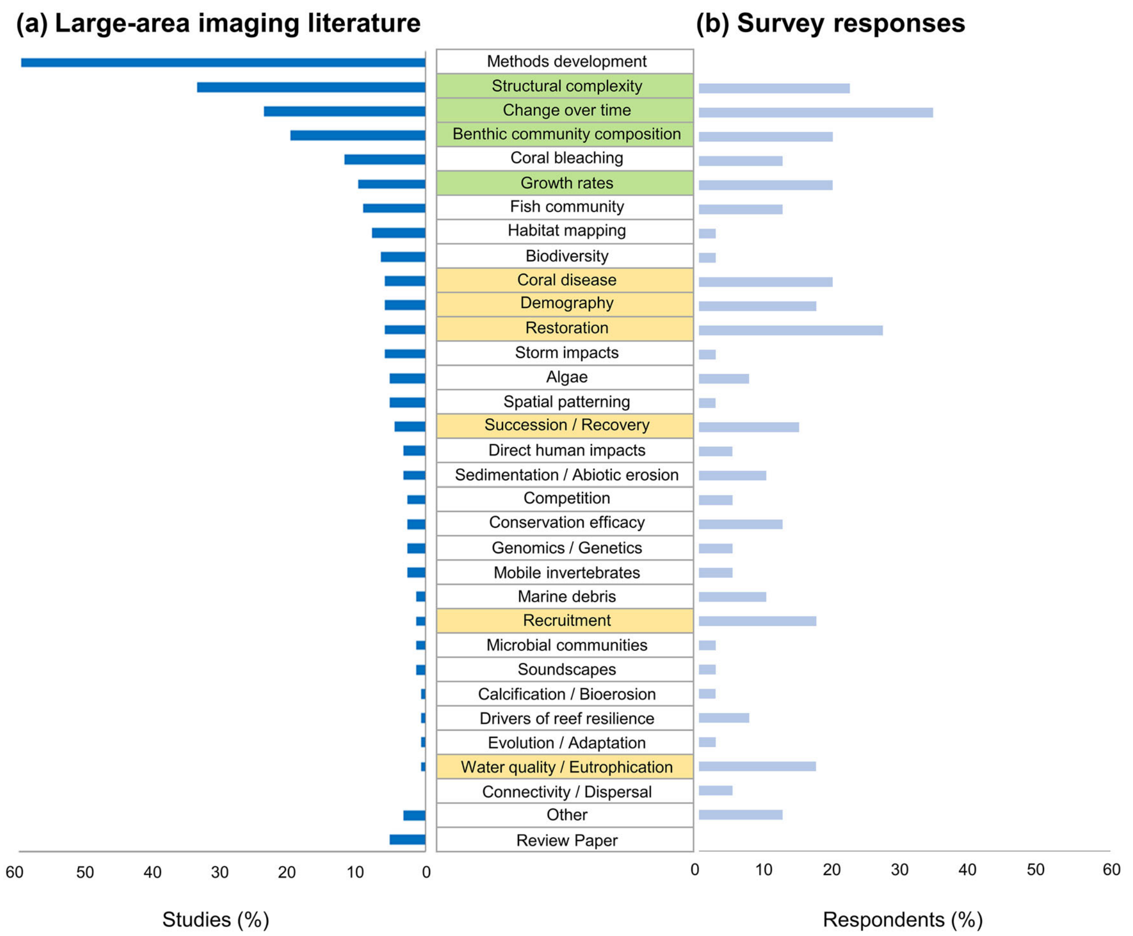

FIGURE 3 Comparison of (a) the topics covered by coral reef studies published from 2010 to 2021 in which large-area imaging (LAI) was used ($n = 151$) and (b) research interests of surveyed conservation practitioners ($n = 41$) (shading, 10 topic areas most frequently identified as priorities for research by conservation practitioners; green, topic covered in >10 published LAI studies; yellow, topics currently understudied using LAI). Most studies were assigned to multiple topic areas.

and produce data with direct relevance to resource managers and conservation practitioners. Furthermore, survey respondents chose "visualizing and communicating reef condition" as the second most important application of LAI (Supporting Information Appendix S2), suggesting that future work should capitalize on the communications potential of LAI visuals (Figure 1c).

One potential explanation for the gap between conservation practitioner interests and existing LAI literature is a lack of equitable access to LAI technology. Through our online survey and semistructured interviews, we found that respondents working in conservation, the nonprofit sector, or at institutions in the Global South were more likely to face barriers to using LAI (Supporting Information Appendix S2). This accessibility gap was reflected in the geographic representation of LAI study authors. Only 6% of studies in our literature review were published by authors based solely at Global South institutions, whereas 78% of studies were published by authors based solely at Global North institutions (Figure 2b,c). This discrepancy exists despite the fact that Global South countries contain a majority of coral reef area globally (UNEP-WCMC et al., 2021). Furthermore, among coral reef LAI studies conducted in Global South countries, 59% did not include any researchers from the country where the data were collected. This exceeds the rate of parachute science (i.e., research conducted by individuals from a country other than the country of the study site without investment in or collaboration with local scientists and community members) in the broader coral reef literature (40% [Stefanoudis et al., 2021]), suggesting that parachute science has been more prevalent in coral reef research in which LAI is used than in coral reef research writ large. This is likely due to challenges related to the accessibility of LAI technology and reveals the extent to which LAI remains out of reach for a large swath of coral reef researchers globally. Unless concerted efforts are taken to make LAI more accessible, researchers in the Global South are likely to be excluded, perpetuating parachute science and research that is out of step with the needs of conservation practitioners as use of LAI becomes mainstream.

BARRIERS TO ADOPTION

To transform LAI from a niche methodology into an accessible and impactful form of conservation technology, barriers to LAI adoption need to be identified and removed. Our survey results showed that funding, equipment, training, and staff capacity are perceived as major barriers to LAI adoption. Conversely, opposition from funders or community groups, a lack of potential applications, and a lack of interest in LAI were less commonly perceived as barriers (Supporting Information Appendix 2). Across all demographic groups, adequate funding was ranked as the largest barrier to LAI adoption, although it was perceived to be a greater barrier by respondents who self-identified as part of the conservation community (Supporting Information Appendix 2).

Barriers faced by potential LAI users

Through our semistructured interviews, we found that individuals and organizations faced a distinct set of barriers at each stage of LAI adoption (Figure 4). Respondents who had yet to start using LAI but were planning to use the technology in the near future commonly cited challenges with securing adequate funding and articulating specific goals for their LAI research program. They tended to lack information about how the technology worked or how to collect imagery in the field. and they expressed a desire for training resources to close these knowledge gaps. Those in this initial scoping phase frequently identified the cost of camera equipment as a barrier but were less likely to mention other impending costs, such as the price of computers, software, or salaries for staff dedicated to constructing 3D models and collecting ecological data from the resulting LAI data products. Instead, these costs were more often cited as barriers by respondents who had already begun to implement LAI.

Barriers faced by novice LAI users

Novice LAI users (respondents who had recently begun using LAI and were among the only researchers at their institution using LAI) identified the cost of software licenses as a major obstacle, particularly those from small nonprofit organizations that lacked access to discounted licensing options available to academic organizations. Staff capacity to conduct LAI field work was also cited as a major barrier, as was adequate training in software and data extraction methods. In particular, a lack of established and efficient data collection pipelines was cited as a barrier for data extraction, especially for those without access to training resources. This barrier was compounded by the time lag between image collection, point cloud reconstruction, and data extraction and analyses, especially for respondents who lacked access to high-speed computing or internet bandwidth for sharing large data sets with partners. Due to this time lag, which could last for months to years, respondents cited difficulty with using LAI for rapid surveys or disturbance event response, compared to in situ survey data that are ready for analyses when divers exit the water (Couch et al., 2021; Urbina-Barreto et al., 2021).

Barriers faced by experienced LAI users

Experienced LAI users (those from organizations with well-established LAI research programs) identified a distinct set of challenges related to scaling up data collection (Figure 4). These barriers included adequate storage to back up image and 3D model data sets, staff capacity to collect ecological data from LAI products, and the ability to maintain funding for long-term or large-scale monitoring efforts. The previously mentioned time lag of model construction and data processing tended to compound as organizations scaled up LAI efforts, suggesting

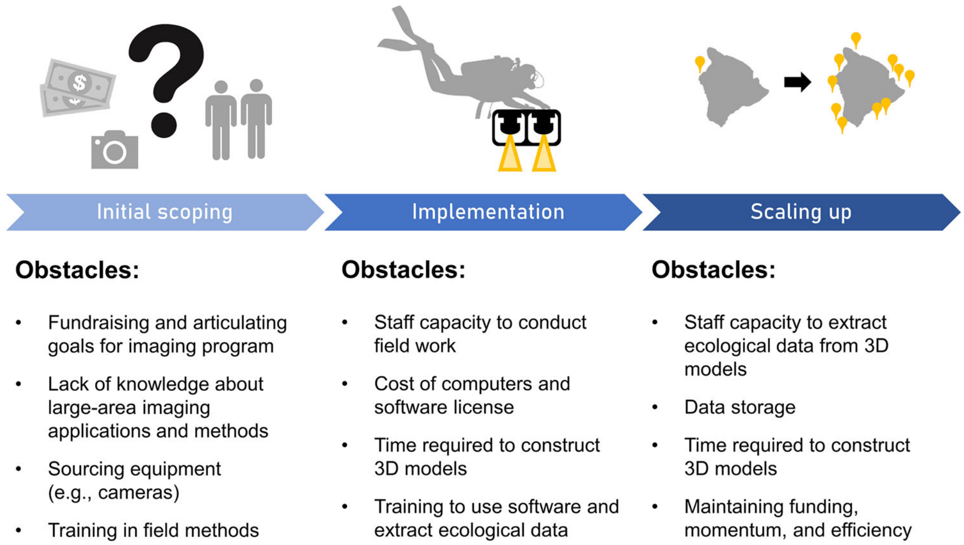

FIGURE 4 Most common barriers to adopting large-area imaging faced by coral reef researchers and conservation practitioners, derived from semistructured interviews with 45 survey respondents. Barriers to adoption differ among phases of technology adoption.

that this particular barrier to adoption could increase, rather than decrease, as organizations continue using LAI.

Ethical considerations

The barriers to LAI adoption we documented are broadly similar to those facing other conservation technologies (Lahoz-Monfort et al., 2019; Speaker et al., 2021), from emerging technologies, such as AUVs and eDNA, to more established technology such as GIS. We assert that having a comprehensive understanding of potential barriers at the outset of LAI adoption will help new users account for resource and staffing needs to better navigate said barriers. However, we acknowledge that some organizations will never be able to bear the cost of adopting LAI, and others may only be able to afford a streamlined version that relies on low-cost equipment (e.g., GoPros instead of DSLR cameras) or freeware that might not meet data quality standards. This imbalance in resources and capacity raises equity and social justice concerns that need to be addressed by the marine science community as LAI becomes an industry standard. Scientists at well-resourced organizations should consider where they can fit into this sequence of barriers to help alleviate obstacles and facilitate onboarding of this technology.

RECOMMENDATIONS TO INCREASE ACCESSIBILITY OF LAI

Although there are a number of logistical, monetary, and technical challenges that currently limit the accessibility of LAI, these challenges are by no means insurmountable. We recommend actions that current LAI users (or their institutions) can take to increase LAI accessibility for new users and those in the conservation community. These recommendations were developed based on feedback solicited in our semistructured interviews and can be broadly categorized as investments either in training and capacity building or in research and development (Table 1).

Develop and fund workshops and trainings

Interviewees commonly expressed the desire for more LAI training workshops, extension courses, or video tutorials, with modules focused on each step of the LAI process, the technology's potential applications, and associated costs. Institutions that currently use LAI at scale should dedicate a portion of their budgets to providing LAI trainings and workshops. These workshops will be most useful if they are tailored to multiple audiences to reflect the different uses of LAI, if they are updated periodically to reflect advances in both LAI software and hardware, and if they include funding for trainees to purchase their own LAI equipment.

Create partnerships for image storage, processing, and analysis

Partnerships with government agencies, big nongovernmental organizations (NGOs), or universities can increase the capacity of small organizations or individual researchers. These partnerships would allow new LAI users to outsource the computational or time intensive steps of LAI (i.e., image matching and point cloud generation) and provide access to LAI expertise and equipment. One example of such a platform is GeoNadir (https://geonadir.com/), a website for organizing, processing, and storing drone imagery.

TABLE 1 Investments in training, capacity building, and research and development recommended for increasing the accessibility of large-area imaging (LAI) technology for the coral reef conservation community based on semistructured interviews with 45 survey participants.

Type of investments	Recommendations
Training and capacity building	Develop and fund workshops and trainings.
	Create partnerships for photo storage, processing, and analysis.
	Build a community of LAI users and create a LAI knowledge hub.
	Recognize the diversity of user goals.
Research and development	Publish LAI research pipelines.
	Develop standardized LAI methods.
	Develop machine learning tools to efficiently collect data from LAI products.
	Improve software accessibility, speed, and usability.
	Conduct conservation-relevant research using LAI.

Build a community of LAI users and create a LAI knowledge hub

Once initial partnerships have been formed to support new LAI users, steps should be taken to formalize those partnerships and expand collaboration across sectors. One avenue for this collaboration would be a LAI knowledge hub, which would serve as a forum for users to interact with a broad community of practitioners. This hub could also provide trainings, process and store image and 3D model data, and host workshops with practitioners to codevelop software tools and pipelines for analyzing 3D data sets.

Recognize the diversity of user goals

Every organization has different goals for LAI; some intend to use it primarily as a visualization tool, others focus on extracting ecological data, and still others seek to document environmental impacts (e.g., for litigation purposes). Creative users will come up with new, unforeseen uses. These users will have different training, equipment, and staffing needs. Early adopters of LAI who provide training to their peers should recognize that LAI is a tool with diverse applications and that there are technological and social barriers to adopting LAI. Thus, it will be important to design software and research pipelines that accommodate potential users from a range of backgrounds and varied applications.

Publish research pipelines

Researchers should continue to publish open-access analytical pipelines, standard operating procedures, and supplementary methods as LAI technology progresses. These pipelines should be thorough and easy to follow and should cover a range of data types, from traditional metrics (e.g., percent cover, linear rugosity) to more advanced LAI metrics (e.g., volumetric change, survivorship, etc.). Users should be encouraged to recognize the common features of these pipelines rather than considering them as competing, mutually exclusive standards.

Develop standardized methods

Multiple different LAI pipelines exist (Bayley & Mogg, 2020; Gutierrez-Heredia et al., 2016; Lange & Perry, 2020; Raoult et al., 2016; Rodriguez et al., 2021; Suka et al., 2019). An effort to collate these pipelines and develop overarching guidance of LAI best practices would make the technology more accessible for new users. Furthermore, developing a standard set of metrics to quantify the accuracy and precision of LAI products would help new and existing LAI users, peer reviewers, and the broader research community interpret findings from LAI-based research.

Improve LAI software

Developing open-access software that is fast and user friendly will be critical if LAI is to become a viable option for practitioners in the Global South. TagLab (Pavoni et al., 2021) was suggested by interviewees as a model of accessible LAI freeware. While freeware is being developed, universities should explore partnerships with small NGOs and community groups to facilitate access to LAI software and computing power.

Develop machine learning tools to efficiently collect data from LAI products

Extracting information from LAI products can be time-consuming, but researchers have made considerable strides in developing machine learning approaches to expedite this process (Parsons et al., 2018; Pavoni et al., 2021; Runyan et al., 2022; Yuval et al., 2021). Collecting additional training data and innovating machine learning methods are important contributions that the academic community can make to improve the accessibility of LAI to conservation practitioners because it would reduce the time lag associated with extracting usable ecological data.

Conduct conservation-relevant research using LAI

More work is needed to bridge the gap between the metrics and approaches used in academia and those that are relevant to conservation practitioners. This includes collecting and calibrating LAI data that can serve as a direct analogue to in situ metrics that conservation practitioners have used for decades so that long-term monitoring data sets can be compatible with LAI (Couch et al., 2021; Palma et al., 2017). Furthermore, researchers should seek to fill gaps in the LAI-based literature enumerated here (Figure 3) because those gaps were identified as priorities by conservation practitioners. Studies that use LAI to evaluate the efficacy of marine management (Bayley et al., 2019; Palma et al., 2019) or test different conservation interventions (Voss et al., 2019) will help demonstrate the potential of this technology for conservation. Visuals of LAI should also be utilized to convey scientific findings, restoration progress, and conservation needs to decision makers and involve members of the public (van den Bergh et al., 2021).

CONCLUSIONS

If properly used, LAI has the potential to be an impactful form of conservation technology. The ability to archive visual ecological baselines, track change over time, develop novel metrics, and scale up ecosystem monitoring will be invaluable for resource managers as marine ecosystems continue to change rapidly. Researchers at well-resourced institutions have served as the pioneers of LAI method development and application. These same researchers now have an ethical responsibility to make LAI more accessible by facilitating the transfer of technology from the ivory tower to the hands of conservation practitioners. Academic researchers in particular have an opportunity as educators to train their colleagues outside academia. This includes developing training materials, hosting workshops, fostering partnerships for data processing and analyses, establishing clear communications with partners, publishing clear pipelines and standardized methods, working with developers to improve software related to all stages of the LAI pipeline, and conducting LAI-based research that is relevant to conservation practitioners. These steps, among others, will help maximize the positive impact of LAI for conservation. More broadly, similar actions can be taken to improve the accessibility of other technologies with relevance to conservation.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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