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The current state of odonatology in India

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Abstract. In the past 50 years, odonatology has advanced on a global scale in phylogenetics, diversity, organismal and population ecology, and conservation biology. This study explored if such knowledge gains are perceived to have occurred in India, as they did worldwide, and identified knowledge gaps and challenges that might be hindering progress in Indian odonatology. Responses to an online questionnaire and semi-structured interviews with researchers in the country indicated that the majority of Odonata research had occurred regionally in the Western Ghats and in the areas of taxonomy and species distribution. Knowledge gaps included Odonata research in northeast India, known for its rich biodiversity, and conservation studies to ensure evidence-based ecosystem management. Respondents also identified a lack of studies on Odonata larvae despite this being the longest stage in the taxa's life cycle. Key challenges faced by Indian odonatologists were reported to be lack of funding and laboratory and field resources and poor access to research papers published in journals. Social media platforms could aid in addressing some knowledge gaps and challenges to researchers through engaging citizen scientists and facilitating skill-building and knowledge-sharing among odonatology researchers in the country.

Keywords. Odonata, dragonfly, citizen science, India, knowledge gains, knowledge gaps, research challenges

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All relevant data are within the paper and its Supporting Information files.

Introduction

The field of odonatology has been instrumental in understanding insect evolution (Córdoba-Aguilar, 2008). Odonates were one of the first winged insects, which makes them of utmost importance for comparative studies with other insect species. Fortunately, odonates have the most complete and well-preserved fossil records among all insects (Kukalová-Peck, 2009). Combined with plentiful information on their relative ages from genomic data, this offers the prospect of answering many evolutionary questions.

Odonates also make an excellent group to understand the evolutionary causes and consequences of complex life cycles as they possess aquatic or semi-aquatic larvae and terrestrial adult stages of development, which also links terrestrial and aquatic systems (Stoks & Córdoba-Aguilar, 2012). Odonates share many features with butterflies, which makes their study important for future integrative research in movement dynamics along with comparative studies of their larval life history traits (Bybee et al., 2016). Traditionally, odonates have been used for studying sexual conflict, character displacement and sexual selection on the basis of color polymorphism and sperm competition (Fincke, 1997; Khan & Herberstein, 2021; Sánchez-Guillén et al., 2020). The species' constancy to reproductive areas (espe-

cially males), diverse reproductive behavior and cooperation with phenotypic manipulation makes them excellent systems for field studies, experiments, and behavioral observations (Cordero-Rivera & Stoks, 2008). Flight-based species develop high body temperatures at the time of flight. Being one of the earliest fliers, Odonata may have developed the earliest thermoregulation strategies to mitigate the overheating problem (Heinrich, 1993). Odonates offer an ideal system for understanding gene evolution involved in vision due to their complex color vision and many Odonata behaviors for distinguishing color (Bybee et al., 2016).

Odonatology in the Global North can be divided into four successive eras of research: the Selys era (systematics), Tillyard era (biology), Corbet era (behavior and ecology), and the blossoming era (citizen scientists, phylogenetics and climate change). These eras are characterized by the focus of scientific publications and provide a knowledge base referred to in subsequent eras. The first three eras were named after scientists (Selys Longchamps, Robert John Tillyard, and Philip Steven Corbet), but the fourth was named so due to the sudden increased popularity in Odonata studies, both in terms of scientific research and citizen science engagement (reviewed in Khelifa et al., 2017).

In the past 50 years, these eras of odonatology have resulted in major advancements in knowledge, including phylogenetics and the crucial role in understanding evolutionary relationships among odonate species (Artiss et al., 2001; Dijkstra et al., 2014; Fleck et al., 2008; Kambhampati & Charlton, 1999; Ware et al., 2007), diversity (60 new species were discovered in Africa, often by western researchers, making it the largest number of species to be named at once in 130 years), reproductive behavior and sexual selection (e.g., sperm displacement), seasonal regulation (adjustment of life history of species based on local environmental conditions), thermoregulation strategies (based on climate, body size and behavior), and conservation biology (due to cosmopolitan distribution, trophic position in the food web and being a bioindicator) (reviewed in Khelifa et al., 2017). Moreover, studies have determined that the distribution and abundance of many damselfly species have changed over the past few decades as a result of rising global temperatures (Hassall et al., 2007; Hickling et al., 2005; Sanchez-Guillén et al., 2013). Distributional data indicates that odonates have shown a strong poleward movement, making them excellent model animals for studying the poorly documented microevolutionary changes associated with range expansions (Merila & Hendry, 2014). Such range expansions have led to the creation of new, overlapping geographic areas that can lead to modifications in species interactions and a breakdown of species barriers and rapid hybridization (Sanchez-Guillén et al., 2016). These scenarios act as warning signs for the possible outcomes of global climate change. Lastly, studies of damselfly larvae have been instrumental in the understanding of physiological stress responses and will help in further research on how physiological stress is affected by predation risk, environmental contaminants, and responses to combinations of stressors (Bybee et al., 2016).

The contribution of countries in the Global South, such as India, to this knowledge is not widely known. The first scientific description of Odonata in India dates back to 1758, when five species (*Neurobasis chinensis*, *Aeshna juncea*, *Libellula quadrimaculata*, *Orthetrum cancellatum* and *Sympetrum vulgatum*) were described (Linnaeus, 1758). However, the species were named and described by non-Indian scientists. The first odonate specimen described by an Indian scientist was the dragonfly *Rhyothemis variegata* (Linnaeus, 1763). The earliest records of larval study of odonates in India was around 1890 (Cabot, 1890). Later, the larvae of *Pseudagrion microcephalum* from Chilika and Kolkata were identified by F. F. Laidlaw (Laidlaw, 1920). Between the period of 1918 and 1935, Fraser (1933a, b) published several Odonata papers in the Memoirs of Indian Museum and Journal of Bombay Natural History Society which were eventually compiled into three volumes of Fauna of British India-Odonata (Fraser, 1933c, 1934, 1936). To this day, this remains a basic reference source for Odonata identification in India. Post-independence, after 1947, researchers explored different locations in search of new Odonata species (Subramanian & Babu, 2017). The Zoological Survey of India started in 1916, and many trained taxonomists became involved in collecting data and publishing lists of Odonata of various regions. Introduction of field guides (such as Andrew et al., 2008; Dawn & Basu Roy, 2016; Emiliyamma et al., 2005; Kiran & Raju, 2013; Nair, 2011; Nazneen, 2019; Raju & Ramachandran, 2021; Subramanian, 2005, 2017) further accelerated Odonata data collection. Wider accessibility of information about odonates with information in the public domain began with the introduction of open-access public forums and websites (e.g., Asia-Dragonfly, 2014; DragonflyIndia, 2014; India Biodiversity Portal, 2014).

Most of the initial odonatology research in India was limited to taxonomy and some studies of larvae (Dawn, 2016). It is only in the last decade that more importance has been given to physiological and morphological studies. The availability of pictorial field guides (referenced above) and global internet resources (including India Biodiversity Portal, https://indiabiodiversity.org/; Odonata of India https://www.indianodonata.org/; DragonflySouthAsia, https://dragonflysouthasia.wordpress.com/; Blog of Thai Odonata, http://thaiodonata.blogspot.com/) has led to open access species data and an upsurge in scientific research. The spread of the new generation citizen science projects such as DragonflySouthAsia (http://dragonflysouthasia.wordpress.com/) has inspired the public's growing interest and contribution to odonate research.

To better understand odonatology in India, this study identified major knowledge gains and gaps along with challenges to further progress in the research area. The current and potential future role of citizen science in

Table 1. Demographics of respondents to a questionnaire about odonatology in India.

Age (years)	%	Odonata experience (years)	%	Gender	%	Affiliation	%
18–30	52.4	< 5	57.1	Male	69.8	Academic institution	58.7
31–45	33.3	6–10	31.7	Female	27.0	NGO	27.0
46–60	7.9	11–15	3.2	Non-binary	3.2	Government agency	4.8
> 60	6.3	16–20	1.6			Other	9.5
		> 20	6.3				

the field was also examined. These findings can act as a reference for current and future researchers and citizen scientists engaged in odonatology in India.

Materials and methods

A multi-methods approach was used to collect information. Approval from the FLAME University Institutional Review Board (IRB Approval number: 2020/09/01/EXP) was obtained and all respondents gave voluntary, informed consent before collection of any data. Incentives to participate were not offered, and respondents could decline to participate, decline to answer specific questions, or cease responding to questions at any time.

Information about knowledge gains, gaps and challenges was collected from Indian odonatology researchers and citizen scientists. Respondents were recruited through Odonata-focused WhatsApp and social media groups, Twitter, and national mailing lists. An online questionnaire created in Google Forms, comprising 28 questions in English (Supplementary Info 1), was open for responses from 8th October 2020 to 8th January 2021. The questionnaire took up to 30 minutes to complete. Responses to questions were categorized, using emergent coding where relevant, and descriptive statistics were calculated. Illustrative quotations which provide deeper context to findings were extracted and are presented in the Results, attributed to specific de-identified respondents by number.

Administrators of social media groups/pages dedicated to Indian odonatology were invited via Email, Facebook and WhatsApp to participate in semi-structured group interviews about citizen science which were conducted using Google Meet. Up to 15 questions (Supplementary Info 1) about the purpose, activities and moderation of the group were asked. One to three representatives from six groups (eight respondents in total) contributed responses, with the interview duration from 30 to 60 minutes. Interviews were recorded using the Google Meet recording feature and then transcribed manually. Emergent coding was used to identify and summarize common themes among responses. Illustrative quotations which provide deeper context to findings were extracted and are presented in the Results, attributed to the six groups of de-identified respondents by letter A through F.

Results

Demographics of respondents

The questionnaire received 65 responses. The majority of the respondents were early (18–30 years; 52.4%) to mid-career (31–45 years; 33.3%) and identified as male (69.8%). Most respondents were affiliated with academic institutions (58.7%); the remainder were either associated with NGOs, or government agencies or were independent researchers or students and professionals from outside the natural sciences. Respondents most frequently worked specifically with odonates (76.6%) and had less than 10 years of experience (88.8%) working with the taxa (Table 1). On average, respondents had recorded 64.3 ± 56 SD (0–230 range) Odonata species each. Collectively, their research on odonates spanned the majority of States and Territories in India, but most had occurred in Kerala (13.3%) and Maharashtra (12.6%) (Figure 1). Odonate diversity and distribution was a common research area (Figure 2), and adult Odonata was a more common research subject than larval stages (Supplementary Info 1).

Semi-structured interviews were conducted with the administrators of six Facebook groups dedicated to Indian odonatology. One was a national-based group, while the others catered to interested members in a single state of India. Odonatology is a relatively new field in India, and most (56.6%) of the administrators had less than 5 years of experience through field observations, photography, research work, seminars, and other citizen science-based programs.

Knowledge gains and gaps in Indian odonatology

The discovery and description of new Odonata species were regarded by the largest group of respondents (30.8%) as an important knowledge gain in Indian odonatology, followed by the understanding of distribution, taxonomy and odonates as environmental indicators (7.7% each; Figure 2). Research areas that respondents considered to need greater attention included conservation studies (12.1%), taxonomy (11.4%), distribution and abundance (10.6%) and behavioral biology (10.6%) (Figure 2). Geographic areas that were under-studied included states in northeast India (Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Tripura; 9.6%) the Himalayas

Table 2. Respondent's perceptions of challenges to odonatology in India and sources of their funding.

Limitation	%	Sources of respondent's funding	%
Funding	22.3	Other (e.g. self-funding)	26.8
Resources (e.g., laboratory or field equipment)	19.7	Individual Donations	23.2
Specialized skills (e.g., identification, data analysis)	16.6	Government funding	17.1
Access to information such as published literature or specimens	14.6	Volunteer fees	12.2
Skilled Human Resources (Experts)	12.1	Corporate sponsors	11.0
Permits	9.6	Grants from other countries	7.3
Other (e.g., lack of formal training)	2.5	Tourism revenues	2.4
None	2.5		

and the states of Gujarat and Bihar (5.9% each) (Figure 1):

> "North East India is a vastly under-studied region when it comes to odonates because big cities such as Pune, Mumbai, Bangalore, Chennai etc. are closer to the Western Ghats" (group A).

Challenges to Odonata research in India

Funding (22.3%), resources (19.7%), and lack of specialized skills (6.6%) were among the greatest challenges faced by respondents while conducting Odonata research in India (Table 2). The greatest challenge to research—availability of funding—resulted in most respondents self-funding their research.

> "I have been using my family earning for all the various research... If I am supported with some funds, I would be able to document more species…" (respondent 19).

Others acquired Government funding and corporate sponsorships (Table 2); however, respondent 52 stated that

> "Odonates being a 'lesser important' group of animals is not considered important enough to funding agencies".

Limited accessibility to field guides and published research that provide detailed information about odonates in India and appropriate research methods was also perceived as a challenge to research (Table 2). Respondent 27 commented,

> "If I cannot have information on habitat preference or rather dependence of particular species, then especially for EIAs I find it very difficult to predict the impact of the proposed project activities." (EIAs: environmental impact assessments.)

Most (81.0%) respondents engaged with Odonata websites and blogs during their research, relying on

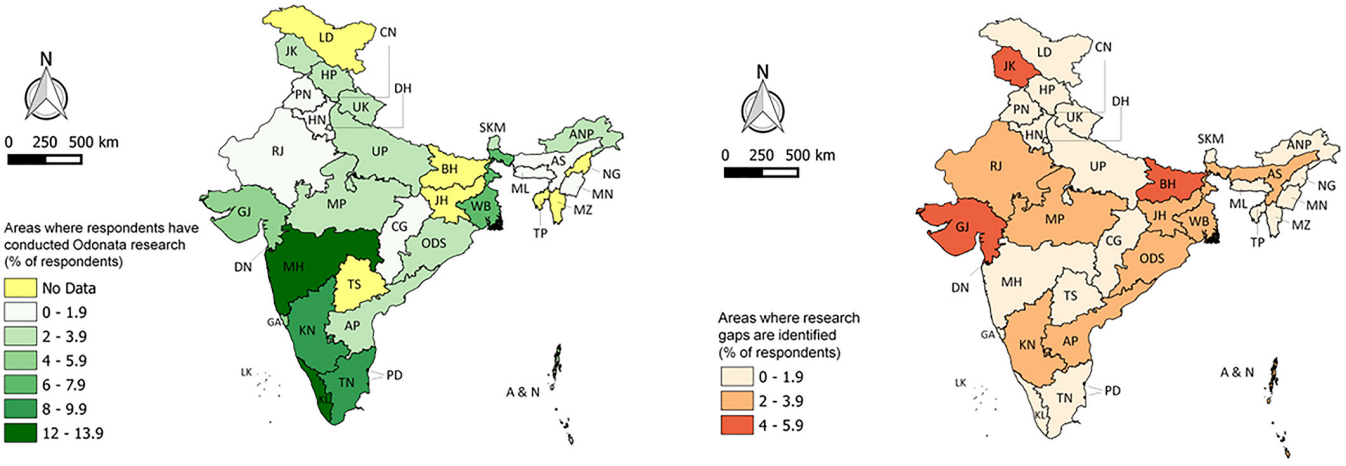

Figure 1. States and Territories of India where respondents have conducted Odonata research themselves (left) and consider Odonata to be under-studied (right). A & N = Andaman and Nicobar Islands; AP = Andhra Pradesh; ANP = Arunachal Pradesh; AS = Assam; BH = Bihar; CG = Chhattisgarh; CN = Chandigarh; DN = Dadra and Nagar Haveli and Daman & Diu; DH = Delhi; GA = Goa; GJ = Gujarat; HN = Haryana; HP = Himachal Pradesh; JK = Jammu and Kashmir; JH = Jharkhand; KN = Karnataka; KL = Kerala; LD = Ladakh; LK = Lakshadweep Islands; MP = Madhya Pradesh; MH = Maharashtra; MN = Manipur; ML= Meghalaya; MZ = Mizoram; NG = Nagaland; ODS = Odisha; PN = Punjab; PD = Pondicherry; RJ = Rajasthan; SKM = Sikkim; TN = Tamil Nadu; TP = Tripura; TS = Telangana; UK = Uttarakhand; UP = Uttar Pradesh; WB = West Bengal.

Table 3. Sources of information for respondents' research on odonates in India.

Identification/Taxonomy	%	Biology, Ecology, and Conservation	%
Website or Blogs (ThaiOdonata, AllOdonata, Odonata of India, etc.)	20.3	Social media groups (e.g., Facebook, Twitter, Instagram)	21.4
Pictorial field guidebooks	19.8	Private communication groups (e.g., WhatsApp, Telegram)	17.7
Social media groups (e.g., Facebook, WhatsApp)	16.8	Research journals- national and/or regional	16.9
Personal communication with experts through email or phone call	16.8	Research journals- international	15.7
Citizen science portals (e.g., iNaturalist)	14.7	Professional society news (e.g., World Dragonfly Association, International Dragonfly Fund, DragonflySouthAsia)	13.7
Taxonomy monographs (e.g., Fauna of British India)	13.4	Blogs (e.g., Thai Odonata, All Odonata)	9.7
		News media	4.4
		None	0.4

websites and blogs (20.3%), such as Odonata of India (https://www.indianodonata.org/), as well as pictorial field guides (19.8%) during identification of Odonata species. Social media sites were also a major source of information about Odonata biology and ecology for respondents (21.4%) in addition to research journals (32.6%) and professional societies (13.7%) (Table 3).

Preferred journals for accessing scientific papers about odonatology were the Journal of Threatened Taxa, Odonatologica, International Journal of Odonatology and Zootaxa, and 18.4% of the respondents had published their findings in such journals (Supplementary Info 2). Access to research papers and field guides in respondents' regional languages was high (93.5%), and many (88.9%) had also contributed towards such resources.

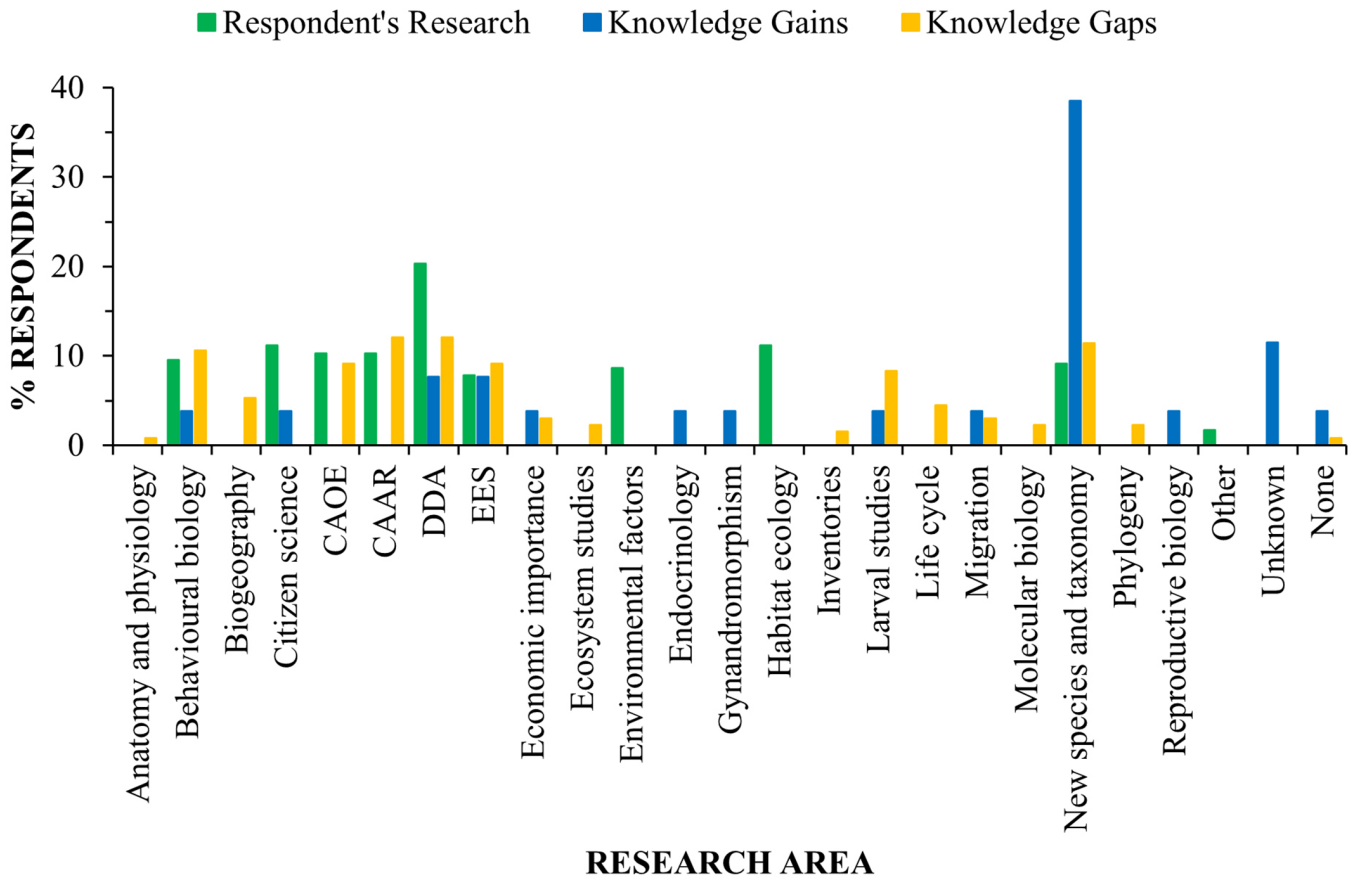

Figure 2. Areas of respondents' research and perceived knowledge gains and gaps in Indian odonatology. CAOE = Community awareness, outreach, and education; CAAR = Community action, assessment, and research; DDA = Diversity, distribution, and abundance; EES = Ecology and ecological services.

Table 4. Characteristics of odonatology Facebook groups in India.

Group purpose	%	Target audience	%	Member's background	%
Recruit new citizen scientists	33.3	People interested in odonatology	33.3	Researcher	36.4
Species identification	33.3	Interested people from the region	33.3	Citizen Scientist	27.3
Share collected data	16.7	People interested in natural history	16.7	Student	18.2
Understand regional diversity and distribution	16.7	Youth	16.7	Environmentalist	9.1
				Entomologist	9.1

Current and future role of social media in Indian odonatology

Many individual interview respondents engaged with websites, blogs and social media sites for information during their research. When asked about the purpose behind starting their social media groups, the majority of social media group administrators mentioned that they wanted more citizen science engagement (33.3%) and species identification sources (33.3%) in Indian odonatology:

> "What we wanted as a group was to collect data not just for the sake of interest but for the greater good for their conservation. This change I hope did happen through the group activities and awareness efforts" (group B).

The primary target audience of each group were people interested in odonatology (33.3%), and preferably from their respective states (33.3%). Group D explained that

> "People normally observe different species but they don't know where to share the collected data. So these….. groups were started for the purpose of data collection and spreading the word about odonata species."

On being asked about the backgrounds of their group members, 36.4% of group administrators perceived their members to be already working as researchers on odonates or other taxa, while 27.3% were citizen scientists (Table 4). Many citizen scientists had prior experience with different taxa, such as birds and butterflies.

Common activities organized by Facebook groups included photography (posting photos on the platform for discussion regarding identification and behavior), educational and citizen science (25.0% each) initiatives. As described by group B

> "We ….. conducted a Dragonfly Festival in which we had around 80–90 participants….. we have tried to cover various aspects of odonata study during this festival such as behaviour study, larval study etc. We also tried to train people during the festival so that we can help in community conservation of these species."

(Note: a dragonfly festival is a citizen science campaign to showcase the importance and status of dragonflies.)

Group moderators perceived that the greatest member engagement occurred during identification (40.0%) and data collection (30.0%) initiatives (Table 5):

> "People tend to discuss more about new species descriptions, nomenclatures and during the backyard watch event, checklists also became popular. People also discuss photographs and identify them" (group B).
>
> "I know many people in my area who are interested in photographing species and even though they might not be keen on learning more about the species they do capture really good pictures. So it's an encouragement for them also to join the group and upload pictures so that on a later date we can assess the collected data. This is ensured by asking people to upload pictures with location and date" (group D).
>
> "Because people at first did not even know about these species but now they want to know more. Even though they do not know the ID of the species, they do take pictures and want to know more. In that way we do think it has been instrumental in the encouragement of saving micro habitats of every member's area by introducing them to more odonata information. For example, small ponds, ditches etc." (group E).

(Note: a backyard watch event asks citizen scientists to share photographs and/or identify dragonflies in their backyard.)

Some groups delivered research resources (22.2%) and webinars (22.2%) in regional languages. Group A explained

> "There still needs a lot of development in that area in India because we have various dialects under one regional area."

All events were predominantly promoted via word of mouth (26.1%), WhatsApp groups (26.1%), and Facebook group recommendations (21.7%) among others (Table 5).

> "We create a poster and post it on the group and till now the events have spread through word of mouth and through other local social media organizations. We also share the posters with other odonata and nature based groups on Facebook that garners the attention of a bigger audience. There are also many teachers and professors in the group who encourage their students to participate in the programmes" (group A).

All groups moderated posts made by members. Half (50.0%) had rules regarding the kind of material that could be posted on the group, but only 20.0% posted guidelines regarding spam posts (content not directly related to odonatology). Many groups (40.0%) directly removed such posts. To minimize spam, some groups analyzed individual profiles before accepting a joining

Table 5. Activities of odonatology Facebook groups in India.

All activities	%	Member engagement	%	Activity promotion	%
Photography	25.0	Identification	40.0	Word of mouth	26.1
Education	25.0	Data collection	30.0	WhatsApp	26.1
Citizen science	25.0	Workshops, webinars	20.0	Facebook	21.7
Research	12.5	Awareness programs	10.0	Twitter	13.0
Ecotourism	4.2			Other organizations	8.7
Journalism	4.2			Listserv	4.3
Creative writing	4.2				

request (20.0%) (Supplementary Info 2). To mitigate the posting of fake or inaccurate information, half (50.0%) of the groups required the location and date of Odonata photographs and sightings information to be shared. However, a large proportion (66.7%) of the groups had never seen any of the group members post information that was fake; other respondents (33.3%) were unsure if false information was shared on their Facebook page. One of the respondents believed that the relatively small Odonata community in India might currently limit the sharing of fake information, but the likelihood of it occurring could increase in the future once platforms become more popular.

Discussion

The present study was able to identify knowledge gains and gaps in Indian odonatology based on the perspectives of researchers and citizen scientists' responses to an online questionnaire. The majority of respondents were new to Odonata research (< 5 years' experience). The respondents' research had addressed diversity and distribution (species richness, abundance, diversity studies), habitat ecology (habitat use, preference, characterization studies), citizen science, community outreach and education, behavioral biology (reproductive behavior, color polymorphism), taxonomy (new species discovery, description), effects of environmental factors (pollution, climate), ecological services (ecological indicators, biocontrol, agroecology), conservation action (creative reserves, on-ground protection), conservation ecology (assessing threat status, IUCN reviews) among others.

Knowledge gains in Indian odonatology

Respondents indicated that the majority of Odonata research had been conducted in the South and West of India, including Maharashtra and Goa from the West, and Kerala, Karnataka and Tamil Nadu. Some of these states encompass a major biodiversity hotspot in India: the Western Ghats.

The discovery of new species was regarded as an integral accomplishment for Indian odonatology, followed by species distribution, taxonomy, and the study of dragonflies as environmental indicators. A knowledge base of taxonomy and species distribution in India, where landscapes vary from one state to another, in order to classify and understand the current distribution patterns can aid in creating predictive models. These models can act as a standard for explaining future distribution changes (Tremlová & Münzbergová, 2007). Various studies have mentioned that odonates indicate the environmental quality of aquatic ecosystems (de paiva Silva et al., 2010; Jacob et al., 2017; Koparde, 2016; Kutcher & Bried, 2014). The areas covered under Odonata research by the respondents included habitat ecology and citizen science. The collected data can be processed to curate various reports which will assist in the improvement of the quality of knowledge and enhance decision-making.

The basis of all Odonata research requires identifying the species, and the respondents relied on websites or blogs to gather information for the same. For additional information, the respondents also heavily refer to social media platforms (Facebook, Twitter etc.) and private communication groups (WhatsApp, Telegram etc.). Websites, blogs, social media platforms and communication groups offer free access to relevant information, mostly passed on by experts in odonatology. This removes the class hegemony and introduces inclusivity and a collaborative atmosphere to establish expertise in the field of odonatology in the country. The most preferred journals for publishing Odonata-related research for the respondents are the Journal of Threatened Taxa and Odonatologica. Many research papers have also been published or translated into regional languages. As India is a multilingual country, this initiative will help in spreading information about Indian odonates to various sections of Indian society.

Knowledge gaps in Indian odonatology

Overall, areas other than the South and West of India (the states of Maharashtra, Karnataka, Kerala, Tamil Nadu) need more attention. Most of the respondents specifically highlighted that studies of Odonata in Northeast India (states of Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Tripura) are lacking. This region is situated in the Indo-Burma biodiversity hotspot and hosts a diverse set of ecological, social,

and physiological landscapes that need conservation attention. Reasons for lesser research in northeast India potentially include differences in demography, government, and socio-political concerns (Chatterjee, 2008).

Conservation studies were identified as an area that required further attention, as knowledge in this area is necessary for evidence-based management of ecosystems that sustain threatened and endangered species; this research effort also needs to be strengthened across countries (Doi & Takahara, 2016). A need for more studies of Odonata larvae in India was also apparent, as most respondents had only worked on adult species despite odonates spending most of their time in the larval stage (Harabiš & Dolný, 2010).

Challenges to Indian odonatology

One of the key challenges for researchers in Indian odonatology is the lack of funding opportunities and resources such as laboratory and field equipment. This has limited the areas of study that respondents can explore as they tend to receive funding only to bridge specific knowledge gaps. For instance, the reason behind an asymmetrical distribution of research work in Indian odonatology wherein a few closely related themes dominate the rest can be due to funding issues. There is also an existing species bias that has impacted the funding opportunities. To give an example, in the context of India, large predator species receive more funding in comparison to smaller species (Habib et al., 2014). Responses to this study also established that only researchers in the middle to higher socioeconomic groups can afford research work, as much was self-funded due to a lack of funding options available in the country. We believe that funding agencies in India need to allocate specific funds for lesser-known taxa and that government departments should promote research on insects. The potential for Odonata as a model taxon in ecological or toxicological studies, an umbrella group in freshwater research and conservation projects, and a natural predator in studies examining the control of mosquitos in urban water bodies should also be recognized by researchers and funders alike.

Another limitation of Odonata research in India was the lack of access to published information. Institutions usually subscribe to journals for researchers and/or students to access, but prices are increasing such that even well-funded universities are finding it difficult to make such journals available (Brittain et al., 2020). Hence, the high costs of such journals prohibit researchers from being able to access the required information.

Current and future roles of social media in Indian odonatology

Most of the administrators of social media groups described citizen science engagement and species identification activities as the main purpose of starting their respective social media groups. Citizen science engagement is helpful towards the development of scientific and community knowledge, attitudes, and behaviors of a focal topic. This is established with the congruence of research, education, and community engagement (Roetman & Daniels, 2011), and studies that found individuals who were exposed to social media content (photos, videos, text) related to social responsibility and the environment were more positively influenced towards environmental awareness (Severo et al., 2019). A strong focus on species identification allows a better understanding of the ecology of a species (Hey, 2009). As Odonata-based social media platforms in India are relatively new, the administrators also felt that species identification was an appropriate approach to begin engaging their members.

The target audience of Indian odonatology social media groups were people interested in odonatology, preferably from a particular state/s. Most of the interviewees administrated social media groups that were state-based, with the need for members from the same area so that the understanding of local species was increased. Based on photographic submissions from members to groups, the species and information about sex, location, species diversity, and abundance can be determined. Half of the groups required the location, date, and sighting information to be included with every picture posted on the group to aid in this. This information is then accessible and can inform focused research (Sullivan et al., 2019). This might also be the reason why the greatest amount of member engagement occurred for photography and identification-related activities. Such activities were usually promoted using word of mouth, WhatsApp Groups, and Facebook group recommendations.

Even though English is one of the languages officially used in scientific communication in India, only 12% of the national population can speak and write it, so the availability of scientific content in regional languages makes the information inclusive (Barath, 2019). This also applies to odonatology, which is why social media groups contributed towards producing and spreading information about odonates in regional languages, through papers, books, and webinars. However, some groups were still planning the best way to go about this.

Administrators managed spam posts, i.e., information unrelated to odonates through rules regarding the kind of material that could be posted on the group page, but only 20.0% posted guidelines regarding posts on the group. Comprehensive guidelines should be normalized in such spaces for a better understanding of the kind of content that the group prefers to avoid mistakes. With regards to fake information regarding odonates, the majority of the groups had never seen any of the group members post any false or inaccurate information. Fake information causes difficulty in accessing genuine information and undermines the work of researchers. They can also be used as a mode of manipulation (Tandon, 2020). With the increase in the popularity of Indian odonatology platforms, administrators will have to be more alert and verify posts over time.

In summary, Indian odonatology is a fast-developing area of research. Respondents in this study identified the major knowledge gains in the field as having taken place in the Western Ghats wherein new species have been discovered. Taxonomy and species distribution have also been a focus over the past few years due to the importance of generating predictive models for future species diversity studies. Most of the aforementioned information has been made available on websites, blogs, social media platforms such as Facebook, and open-access journals. Major knowledge gaps noted by respondents were the lack of data from the biodiverse-rich northeastern region of India and conservation studies. Odonata larvae are also understudied. However, with the help of citizen science involvement, knowledge about odonates can transcend the academic space and engage other stakeholders. To achieve this, social media platforms can play an integral role by bridging the gap between citizen scientists and professionals when it comes to knowledge sharing and data collection. Information can also be retrieved from across the country as people from all regions become a part of such platforms. Moreover, the established knowledge gains and gaps can also act as a roadmap to understand the areas that need more attention, resulting in a conscious attempt by researchers and citizen scientists to work on a diverse range of topics. By considering the current challenges in Indian odonatology, stakeholders can draw attention to these issues to boost Odonata research and conservation efforts. Challenges can also be mitigated by using social media platforms where studies needed for advancement in the field can be discussed and applied under the guidance of experts. Finally, the enthusiasm of Indian researchers and citizen scientists to propagate information in regional languages can help establish a larger community of odonate enthusiasts and inspire conservation.

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Data Availability

Data are available from the authors upon reasonable request.

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Supplementary Material

Supplementary document 1. Online questionnaire for Odonata researchers and citizen scientists and interview questions for founders/administrators of social media groups.

Supplementary document 2. Supplementary Tables.