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•论坛•

中国的野生动物红外相机监测需要统一的标准

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摘要: 采用及时、可靠的方法对物种开展有效监测是生物多样性保护的基础。红外相机技术可以获得兽类物种的影像、元数据和分布信息，是监测生物多样性的有效途径。这项技术在野外便于部署，规程易于标准化，可提供野生动物凭证标本(影像)以及物种拍摄位置、拍摄日期与时间、拍摄细节(相机型号等)等附属信息。这些特性使得我们可以积累数以百万计的影像资料和野生动物监测数据。在中国，红外相机技术已得到广泛应用，众多机构正在使用红外相机采集并存储野生动物影像以及相关联的元数据。目前，亟需对红外相机元数据结构进行标准化，以促进不同机构之间以及与外部保护团体之间的数据共享。迄今全球已建立有数个国际数据共享平台，例如Wildlife Insights，但他们离不开与中国的合作，以有效追踪全球可持续发展的进程。达成这样的合作需要3个基础：共同的数据标准、数据共享协议和数据禁用政策。我们倡议，中国保护领域的政府主管部门、机构团体一起合作，共同制定在国内单位之间以及与国际机构之间共享监测数据的政策、机制与途径。

关键词: 红外相机；元数据；爱知生物多样性目标；野生动物数据平台；数据禁用规则

China’s wildlife camera-trap monitoring needs a unified standard

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Abstract: Conserving biodiversity relies on the effective monitoring of species in a timely and credible way. Camera traps provide images and metadata for many mammal species and are now used widely enough that they can provide a viable method for biodiversity monitoring. Camera-trapping is rapidly deployable, allows standardization of protocols, and provides a voucher specimen (i.e. image) with relevant information about the species’ location, time and date of capture, and other capture details (camera model, etc.). This technique has resulted in millions of images being captured and stored for current and future examination of biodiversity. Camera-trapping has become particularly popular in China. Multiple institutions are running their own monitoring programs and collecting and storing wildlife images and associated metadata. There is an urgent need to standardize the metadata format in order to share data across institutions and with the larger conservation community. Global data sharing repositories, such as Wildlife Insights, exist but will need China’s data to effectively track global efforts for achieving sustainability. Three steps are needed for this to

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occur: common data standards, data sharing agreements and data embargo policies. We urge the Chinese conservation community to develop the policies and the mechanisms needed to share wildlife images within China and with the international community.

Key words: camera-trapping; metadata; Aichi Biodiversity Targets; wildlife data repositories; data embargos

1 背景

物种多样性及其状态已成为全球公认的评估可持续发展的关键指标(Mittermeier et al, 1998; Brooks et al, 2006; Tilman et al, 2017)。在人类活动日益成为全球环境变化的主导因素的背景下，生物多样性的全球指标使得国际各方机构可以追踪可持续发展的进程(Pereira & Cooper, 2006; Lohbeck et al, 2016; Proença et al, 2017)。在全球尺度，生物多样性的度量指标是评估爱知生物多样性目标(Aichi Biodiversity Targets)和联合国可持续发展目标(UN sustainable development goals)是否实现的主要指标(O'Connor et al, 2015)。在区域尺度，保护和维持物种多样性以提供人类生计与情感愉悦所需是保护地的重要实用功能(Naughton-Treves et al, 2005)。生物多样性监测是保护地用以评估其资源状况及其保护能力的手段。关键物种的变化动态是保护地评估其管理行动，尤其是保护行动，是否有效的重要衡量标准(Li et al, 2012; Wetzel et al, 2015)。

传统的调查物种数量及其分布的方法以凭证标本(voucher specimen)为依据，记录下于何时、何地采集到某物种，以及其他的辅助信息，例如采集方式、采集人等。这些凭证标本和附属信息构成了全世界博物馆的核心数据，并提供了全球生物多样性的重要基准信息(Suarez & Tsutsui, 2004; Edwards, 2004)。然而，在全球气候变化和人类活动对生态系统影响快速扩张的当下，生物多样性的测量如何跟上环境变化的速度就至关重要，这样才能保证管理决策者能够依据当下最新的数据，及时快速地制定政策与管理对策(Visconti et al, 2016; Santini et al, 2017; Kays et al, 2020)。科学技术的发展正在日益满足这个领域的需求。比如，遥感技术的发展已经为追踪土地利用变化、监测火灾、评估森林破碎化和植物生产力变化提供了极好的工具(O'Connor et al, 2015; Skidmore et al, 2015)。但是，对于那些分布和生存依赖于具体栖息地特征(而不仅仅是栖息地类型)的物种，卫星或机载传感器通常难以监测到此类动物群落的变化；栖息地的变化(或稳定)并不能够反映出由疾病、偷猎或外来物种入侵等原因引起的野生动物种群的变化(Pereira & Cooper, 2006; Steenweg et al, 2017)。对于重要的野生动物物种，需要建立快速收集和处理数据的同时对被监测物种干扰小、能准确反映其多度和分布变化的监测体系(Rowcliffe & Carbone, 2008)。如果建立起社会公众可以通过数据收集而参与其中的机制，生物多样性监测也可以从中受益(McShea et al, 2016; Forrester et al, 2017)。

红外相机技术是可以有效探测许多大中型野生动物(例如有蹄类、食肉类、部分灵长类)的技术体系，已经过广泛的测试和应用；对于准确监测不同目标物种类群所需的取样方法和取样量，以及在做数据对比时需要哪些元数据作为基础，已经有研究者进行了系统的了解与评估(O'Connell et al, 2010; Meek et al, 2014; Kays et al, 2020)。红外相机照片所附属的信息是至关重要的；一份影像(image, 照片或视频)只有在包含诸如物种名称、拍摄地点、拍摄日期(和时间)、相机型号和采集人等信息时，才算成为有效的记录(数字化标本) (Forrester et al, 2016)；这些信息就是红外相机照片的元数据，必须在数据库中通过唯一编号(unique ID)与照片相关联。同时还有其他与相机设置位点有关的协变量(比如探测距离、植被特征、天气状况等)，这些变量可以用来解释调查位点之间的差异(O'Connell et al, 2010; Meek et al, 2014)。单个调查位点上的所有记录都与这样一组协变量对应，从而可以解释为什么在某些位点和时间段里记录了更多物种，以及为什么同一物种在不同位点上的探测率和多度会有所不同。如果在一个数据库中整合多个调查项目，就会需要更多的字段信息，比如，调查是否使用了诱饵或气味剂、相机阵列的空间布设方案等。因此，我们需要对红外相机布设所用的规程进行规范，同时严格规定对照片关联信息设定统一的数据格式标准，即元数据结构(Forrester et al, 2016; McShea et al, 2016; Ahumada et al, 2020)。这样标准化的元数据结

构不仅对于单个项目或研究组来说是重要的，同时也是不同机构、部门和国家之间共享数据的必需基础(Ahumada et al, 2020)。我们认为，对许多物种来说，红外相机影像是一套更为有效的凭证系统，而这一系统的推广应用，需要建立起标准化的元数据结构和管理框架。

2 中国红外相机发展现状

红外相机技术在20世纪90年代被引入中国，随着方法的日渐成熟，在过去25年里被大规模地用于野生动物的监测和研究(李晟等，2014; 朱淑怡等，2017; 肖治术，2019)。中国大多数的国家级自然保护区内均布设了红外相机用于野生动物调查和评估。中国的科研院所和高校建立了一系列以红外相机技术为核心的监测网络，其中调查规模较大和调查持续时间较长的平台包括: 生态环境部南京环境科学研究所组织建立的全国哺乳动物多样性观测网络(China BON-Mammal; 李佳琦等, 2018)、中国科学院动物研究所牵头建立的中国生物多样性监测与研究网络中的兽类监测网(Sino BON-Mammal; 肖治术等，2014，2017，http://www.cameradata.ioz.ac.cn/)、北京大学在西南山地生物多样性热点区建立的红外相机监测网络(Li et al, 2010, 2012)、北京师范大学建立的东北虎豹监测网络(Tiger-Leopard Observation Network, TLON) (Wang et al, 2016)、国家林业与草原局红外相机处理平台(http://139.159.240.228:8041/cameramath/loginController.do?login#/)、中国林业科学研究院建立的中国自然保护区标本资源共享平台中的红外相机数据库(http://www.papc.cn/)等。

中国现有的红外相机监测项目极大地促进了大型兽类的调查研究以及对其种群趋势的监测，从而为保护行动提供了有效支持。研究人员也正在开发基于红外相机影像自动识别、鉴定物种的工具，并将这些工具整合入红外相机影像数据库，以快速处理野外拍摄的大量影像。部分数据库还包括数据分析(例如计算物种相对多度指数、分析物种日活动节律、绘制物种累积曲线等)与生成报表的工具。中国大部分的红外相机调查采用了网格化的布设方案(例如1 km × 1 km, 2 km × 2 km, 3.6 km × 3.6 km等)，数据库的基本数据格式相似，这使得将来不同监测平台之间开展数据共享在技术上是可行的。

剩下的问题是如何调动大家在不同平台之间开展数据共享的意愿，同时确保数据共享中的公平。根据监测目标的不同，不同监测项目的取样样本量大小与调查时长之间可能存在差别，但都需要达到最基本的要求(如，采用网格化的布设方案，调查时长不少于30天)。数据共享的关键在于野生动物影像与关联数据的数据格式标准。这些数据可以用于两个目的: (1)为完成单个研究区域内的研究或监测提供所需的数据; (2)为大尺度(比如国家、洲或全球)评估提供生物多样性度量指标(Ahumada et al, 2020)。后者并不是大多数使用红外相机的研究者或管理者所考虑的首要目标，但对监测大尺度生物多样性的研究人员而言却很重要(Jetz et al, 2012)。所以数据共享的挑战在于如何兼顾局域和大尺度的监测需求，既能满足局域的研究和管理人员调查的需求，也可以为大尺度的研究提供可访问的数据。由于中国幅员辽阔，任何一个单位和组织的工作都不足以描述中国大中型兽类多样性的全貌，因此，面向国家层级未来的保护规划需求，开展数据分享将是大势所趋。

3 数据共享的标准与政策

目前，有多种软件可以用于标记图片和管理各个层级的信息，比如Digikam、Adobe Bridge和Adobe Lightroom。机构或个人可以使用这些软件来对他们的野生动物照片进行归类与管理。近年来快速发展的人工智能(AI)技术将具备自动识别空拍照片并最终自动鉴定物种的能力，加快数据处理的速度(Norouzzadeh et al, 2018; Thau et al, 2019)。但是，在提供信息下载和数据格式转化等简单的功能之外，对于用户来说，这些软件现有的功能并不能满足跨平台数据共享的需求。这些软件现有的简单数据格式转换功能不能在统一数据格式的过程中实现不同数据集间的数据语言和格式的匹配。数据共享首先需要建立在共同的语言和数据标准之上，我们推荐参考Forrester等(2016)提出的可共享的红外相机数据标准。在该标准中，每份影像都需要被赋予一个独立的编号，单次触发连续拍摄的一组影像合并为一个序列(sequence)；当不同动物物种或个体在相机传感器前移动时，单台相机在一次布设(deployment)中就拍摄到一系列的影像序列；这些布设组合起来就构成了子项目(sub-project)或者项

目(project)。由此构建出一个多级管理结构的数据库(图1), 其中每一个层级的数据都建立有相应的标准化元数据结构, 便于数据管理者和使用者对数据进行检索和分类管理(McShea et al, 2016; Ahumada et al, 2020)。这样的数据标准包含必需的字段, 例如项目编号、相机位点编号、鉴定人、相机布设日期、相机收回日期、影像拍摄日期与时间、拍摄物种、个体数量、相机型号等。其他的附属数据(例如温度、是否使用诱饵/引诱剂、栖息地类型等)也是很有价值的信息, 但并非必需。我们强烈建议中国目前正在使用红外相机的机构和组织, 在数据存储过程中采用最基本的数据标准, 为将来的数据共享做好前期准备。

目前, 有一些包含数据共享与禁用(embargo)政策的国际红外相机数据平台已经建成。这些国际数据平台的构建与运行基于如下的假设, 即数据共享可以增加样本量, 拓宽每个野生动物物种数据的时空范围, 进而可以优化这些物种的分析模型和度量指标(Jetz et al, 2012)。单项研究所能获得的目标物种的数据往往十分有限, 不足以构建可靠的模型, 但不同研究者开展的同类项目的整合就可以让这样的分析成为可能。例如, 一个专注于评估某种大型食肉动物种群密度的项目可能获得充足的资金支持, 这样的项目同时也能收集到大量非目标物种的“兼捕(by-catch)”数据, 类似这样的附加产出能够为那些研究不受关注物种的研究人员提供宝贵的数据。这类国际数据共享平台的例子包括: 由史密森学会(Smithsonian Institution)牵头建立的eMammal红外相机数据平台(http://www.emammal.si.edu), 以及由多个科研与保护组织共同组成联盟而正在建立的Wildlife Insights数据平台(http://www.wildlifeinsights.org/), 发起方包括保护国际(Conservation International)、世界野生动物基金会(World Wildlife Fund)、国际野生生物保护学会(Wildlife Conservation Society)、伦敦动物学会(Zoological Society of London)、北卡罗来纳州自然博物馆(North Carolina Museum of Nature)和史密森学会。这两个国际数据平台在数据共享方面提供了一种平台架构的模式。不同来源的数据可以基于共有的元数据结构和通用界面(eMammal采用桌面应用程序, Wildlife Insights采用基于Web的应用程序)输入数据库(McShea et al, 2016; Ahumada et al, 2020)。通过在数据录入的网页界面上采用下拉菜单进行选择录入的方式, 公众参与者就可以把数据添加进数据库, 而无需担心复杂的数据格式问题。然后, 通过一个面向公众的网站, 这些数据就可以供全球使用者访问。对于敏感信息(比如濒危物种和受关注物种的分布位点), 平台可以设置数据禁用(data

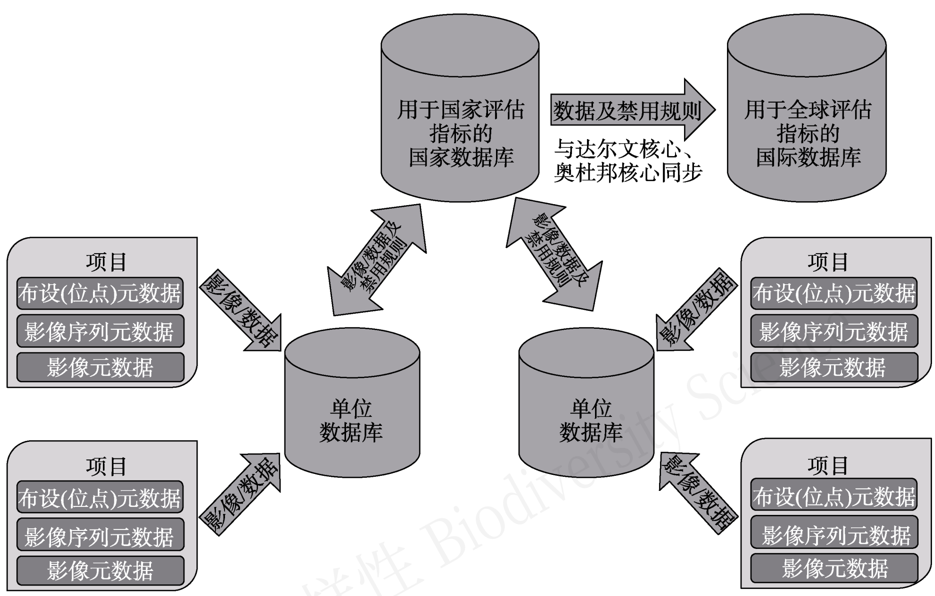

图1 红外相机元数据结构及单位数据库与国家、国际数据库间数据交换的数据流架构示意图

Fig. 1 A common camera-trapping metadata structure and schema for data flow between institutional repositories and national and international repositories embargos), 禁止公开; 同时, 平台也建立有许可制度, 每个项目可以设定数据公开之前的禁用时限, 以便于数据所有者在数据公开前有时间完成所需的分析、发表等。这两个数据平台都具有便捷的数据上传方式, 并提供有其他数据管理平台所缺乏的数据分析(例如自动计算野生动物图片指数wildlife picture index)和报表功能, 以此鼓励数据所有者加入平台和提交数据。对于Wildlife Insights平台来说, 这些功能包括使用人工智能(AI)自动进行物种鉴定, 以及提供详细的统计分析结果(Thau et al, 2019)。对于eMammal平台来说, 则重点加强了公众科学调查参与者的管理, 以及由志愿者完成的物种鉴定结果的专家审核(McShea et al, 2016; Forrester et al, 2017)。数据平台必须向用户提供有用的工具, 否则将难以得到用户的支持。除了濒危物种的数据之外, 这两个国际数据平台上的所有其他数据最终将全部公开。

在中国, 研究者与政府部门普遍关心数据共享后是否会出现在共享协议规定范围之外被不当使用的问题; 这也是其他各类数据库共同关心的问题。ForestGEO森林动态样地网络(https://forestgeo.si.edu/)所采用的另一种数据共享模式可以作为参考。在该网络内, 单个森林样地遵循统一的野外调查规程和元数据结构开展样地调查, 获得的样地清查数据集汇总为一个总体数据库; 该数据库建有一个面向公众的网站, 集中展示每个样地数据集的概要描述。但是, 如果要获取具体某个数据集, 必须首先获得相应项目负责人的许可, 然后通过电子邮件链接进行数据分享。ForestGEO数据库中包括了多个中国样地的数据集, 在保证了数据标准与质量的同时也使得合作者之间可以进行数据共享。中国森林生物多样性监测网络(CForBio, www.cfbiodiv.org/)内发展出了一套独立的数据共享机制。在该网络内, 寻求合作与数据共享的研究者需要把研究方案发送给其他样地的负责人, 对拟议的研究问题、作者署名、数据需求等进行说明。同意参与的数据所有者将会从申请人那里获得用于数据分析的R代码, 对自己的数据进行分析, 然后把分析结果发送给申请人, 从而无需共享其原始数据。以上两个案例的实践均表明, 对数据发表公平性或敏感数据分享风险的担心, 并不妨碍大家建立起一套通用的数据标准。

4　对下一步工作的建议

保护生物多样性已成为全球共识与责任, 而这离不开国际合作(Proença et al, 2017; Steenweg et al, 2017; Kissling et al, 2018)。许多受关注的物种的分布范围跨越多个区域、国家或地区, 这些物种动态的任何度量指标的评估, 都依赖不同国家间及同一国家内不同机构和研究人员之间的合作(Ahumada et al, 2020)。我们需要建立跨越政治和行政边界的合作途径, 而这始于数据采集者之间的交流。我们建议分步骤地推进红外相机研究者之间的合作。首先, 创建论坛, 探讨全球尺度和国家内的监测需求。其次, 协调各方共同确定共享的元数据结构, 或至少确定每个独立数据集中必须包含的组成部分, 以及相应的数据字段, 共同建立各方均认可的监测标准与数据标准, 开发数据库之间的通用接口(APIs)。第三, 通过提供便利的数据上传和分析工具作为激励, 确保有更多数据加入这些大的数据平台。第四, 制定国内和合作国家之间数据共享的规则。每个国家都需要制定适用于其国内参与者的规则, 可以共享原始的或者处理后的数据, 可以将数据上传至全球数据库, 也可以在国家或者区域内建立独立的数据共享平台, 但最终的目标应该是确保不同的监测项目采用相同的元数据结构, 进而可以采用统一的方法和指标计算全球的度量指标, 以汇总评估全球可持续发展的进程, 以及监测跨界分布的物种。

全球自然保护的共同体需要中国的参与以准确评估全球可持续发展进程。作为参与的第一步, 中国的野生动物研究人员、机构之间需要首先实现数据共享, 然后再作为一个整体来决定如何与国际社会的保护工作者之间共享数据。只有通过这样的途径, 中国才能建立起定量评估其保护进展的指标体系, 使国际社会对中国丰富的生物多样性有更充分的认识。近20年来, 中国积极参与生物多样性监测与保护的国际事务, 在其中所发挥的作用和影响力日益增加。中国已经发起或开始主导建立数个国际生物多样性大数据平台, 例如, 中国政府近期刚刚宣布, 将设立“可持续发展大数据国际研究中心”, 为落实《联合国2030年可持续发展议程》提供新助力。统一的数据标准与共同的数据分享机制的建立, 将

为这些国际数据平台的开发、建设提供必要的基础。

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附录　Supplementary Material

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China's wildlife camera-trap monitoring needs a unified standard

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Abstract: Conserving biodiversity relies on the effective monitoring of species in a timely and credible way. Camera traps provide images and metadata for many mammal species and are now used widely enough that they can provide a viable method for biodiversity monitoring. Camera-trapping is rapidly deployable, allows standardization of protocols, and provides a voucher specimen (i.e. image) with relevant information about the species' location, time and date of capture, and other capture details (camera model, etc.). This technique has resulted in millions of images being captured and stored for current and future examination of biodiversity. Camera-trapping has become particularly popular in China. Multiple institutions are running their own monitoring programs and collecting and storing wildlife images and associated metadata. There is an urgent need to standardize the metadata format in order to share data across institutions and with the larger conservation community. Global data sharing repositories, such as Wildlife Insights, exist but will need China's data to effectively track global efforts for achieving sustainability. Three steps are needed for this to occur: common data standards, data sharing agreements and data embargo policies. We urge the Chinese conservation community to develop the policies and the mechanisms needed to share wildlife images within China and with the international community.

Key words: camera-trapping; metadata; Aichi Biodiversity Targets; wildlife data repositories; data embargos

1 Introduction

The world conservation community has identified the biodiversity of species and their status as critical measures of sustainability (Mittermeier et al, 1998; Brooks et al, 2006; Tilman et al, 2017). In an increasingly human-dominated landscape, global metrics of biodiversity allow international entities to track progress toward sustainability (Pereira & Cooper, 2006; Lohbeck et al, 2016; Proença et al, 2017). At the global scale, biodiversity metrics will be major indicators toward reaching the Aichi Biodiversity Targets (O'Connor et al, 2015) and the UN sustainable development goals. At the regional scale, the practical function of protected areas is to protect and sustain a diversity of species for the enjoyment and support of human livelihoods (Naughton-Treves et al, 2005). Monitoring biodiversity is the means by which protected areas measure their resources and their ability to protect them. Trends in critical species become the metric by which a reserve judges its management actions especially protection (Li et al, 2012; Wetzel et al, 2015).

The traditional system of counting species and their distribution is through the collection and curation of voucher specimens which document the species and their location at a specific time, as well as ancillary metadata such as collection technique and collector, etc. These voucher specimens and their data are the core of museums throughout the world and provide a critical baseline of the world's biodiversity (Suarez & Tsutsui, 2004; Edwards, 2004). In this time of global climate change and rapid human expansion, it is essential that biological diversity measures keep track with the rate of change and allow policy/management decisions to be made rapidly using current data (Visconti et al, 2016; Santini et al, 2017; Kays et al, 2020). Some scientific advances have provided the needed utility. For example, the advent and development of remote sensing technology provides an excellent tool for tracking changes in land use, fire monitoring, forest fragmentation, and changes in plant productivity (O'Connor et al, 2015; Skidmore et al, 2015). However, satellite or airborne sensors rarely detect changes in the animal communities that rely on habitat features and not all habitat changes (or lack of change) reflect changes in wildlife populations due to disease, poaching or the influx of exotic species (Pereira & Cooper, 2006; Steenweg et al, 2017). Critical wildlife species need a monitoring system that accurately reflects changes in abundance and distribution, without disrupting the species, and is capable of rapid acquisition and processing (Rowcliffe & Carbone, 2008). In addition, biodiversity monitoring would benefit from a metric that can engage the participation of citizen scientists through their contribution of data (McShea et al, 2016; Forrester et al, 2017).

Camera traps are a system that can reliably detect many large-bodied species (e.g., ungulates, carnivores and some primates) and has been tested extensively enough to identify the amount of sampling needed to accurately monitor guilds of species (O'Connell et al, 2010; Meek et al, 2014; Kays et al, 2020). The issue of data associated with the image is critical: an image only becomes a specimen if it contains the species' name, the location, the date (and time) collected, the collection device, and the collector (Forrester et al, 2016); and these details are called metadata and must be associated with the image through a unique ID. There are additional covariates associated with the camera placement itself (detection distance, amount of vegetation, and weather conditions) that help explain some of the variability between locations (O'Connell et al, 2010; Meek et al, 2014). All records at a single location are correlated with these associated data, as some locations and time periods record more specie and species differ in their detectability as well as their abundance. If multiple projects are to be added to the same database then the list of required information grows, such as use of bait or lure, and spatial array of cameras used in the project. All these details call for some limits on the protocols used to deploy the cameras, but also strict adherence to a standard format for the metadata associated with each image (Forrester et al, 2016; McShea et al, 2016; Ahumada et al, 2020). These metadata standards are not only important for a single project or research group but are required for sharing of data across institutions, agencies or countries (Ahumada et al, 2020). We advocate that a more efficient voucher system, camera trap images, exists for many species, and what this system lacks to be implemented is a standard metadata format and an administrative framework.

2 Current status of camera-trapping in China

Camera traps were introduced to China in the 1990s and have been widely used for wildlife monitoring and research in the past 25 years (Li et al, 2014; Zhu et al, 2017; Xiao, 2019). They are deployed in most of China's national nature reserves for wildlife surveys and assessments. Research institutes and universities have established a series of monitoring networks with camera traps. The platforms established across broad landscapes and for long durations include: the China BON Mammal Diversity Observation Network led by MEE's Nanjing Institute of Environmental Sciences (China BON-Mammal; Li et al, 2018), the Sino BON Mammal Diversity Monitoring Network led by the Chinese Academy of Sciences (Sino BON-mammal; Xiao et al, 2014, 2017, http://www.cameradata.ioz.ac.cn), the camera-trap monitoring network established by Peking University across the Mountains of Southwest China biodiversity hotspot (Li et al, 2010, 2012), the long-term Tiger-Leopard Observation Network (TLON) established by Beijing Normal University (Wang et al, 2016), the State Forestry and Grassland Bureau (http://139.159.240.228:8041/cameramath/loginController.do?login#) and the biodiversity monitoring system for China's protected areas established by the Chinese Academy of Forestry (http://www. papc.cn).

These current camera-trap monitoring programs are extremely helpful to survey China's large mammals and monitor their population trends to inform conservation activities. Tools for automatically identifying species from the images are being developed and included in the image database in order to quickly process the large amount of images collected from the field. Some database have tools for analysis and some capacity for report writing. Most of camera-trap surveys in China adopt a grid system of various sizes (e.g., 1 km × 1 km, 2 km × 2 km, 3.6 km × 3.6 km) for sampling, and the basic format of the image database are similar, which makes future data-sharing among different monitoring platforms technically possible.

The remaining issues are how to mobilize the willingness of data-share and at the same time guarantee the fairness of data-sharing among different platforms. The sampling size and sampling durations are allowed to vary according to the aim of different monitoring programs, as long as they meet the minimum requirements (i.e., a grid sampling system and a minimum sampling duration of 30 days). The focus for data-sharing will be the format standards for wildlife images and associated data, which serve two purposes: (1) to provide the needed structure to accomplish the research or monitor an individual landscape, and (2) to provide the broader biodiversity metric across a large landscape of country, continent or planet (Ahumada et al, 2020). This second, broader goal is not a first priority for most researchers or managers, but is critical for tracking biodiversity metrics that encompass regions broader than any single project can provide (Jetz et al, 2012). The challenge will be giving the individual researcher or manager the ability to produce their needed outputs and yet have the data accessible for the broader mission. Due to China's vast territory, the effort of any individual agency will not be enough for monitoring China's large- and medium-sized mammals, and data sharing is a necessity for the country's future conservation planning.

3 Standards and policies for data sharing

There are multiple software packages currently available for tagging images and assigning information at each level of organization. Examples are Digikam, Adobe Bridge, and Adobe Lightroom. These programs allow organizations or individuals to catalogue and track their wildlife detections. Rapid advances in Artificial Intelligence (AI) will streamline processing through the identification of empty sequences and eventually species identification (Norouzzadeh et al, 2018; Thau et al, 2019). The current features of these programs can not fulfill the user's need of sharing information across platforms beyond a simple download and reformatting of information. Even this reformatting process involves some cross-validation of data language and format to ensure information is properly transferred. Data sharing first needs a shared language and data standard, and here we recommend the shared data standard proposed by Forrester et al (2016). In this proposal, the images themselves are given a unique identifier and grouped into sequences and the deployment of a camera captures a series of image sequences as different species and individuals move in front of the sensor. These deployments are organized into sub-projects or projects, depending on the complexity of the effort. Each level of organization has metadata associated with it and the levels are placed in a relational database (Fig.1), such that routine searches and sorts can isolate the needed information (McShea et al, 2016; Ahumada et al, 2020). This standard has the required data fields of project ID, location of camera, image identifier, date camera out, date camera in, time and date of photograph, species ID, number of individuals, and camera model. Other metadata associated with the camera (i.e. temperature, use of lure, staff ID, habitat) are valuable, but optional. We strongly encourage the conservation community in China to adopt the practice of storing camera traps images using these minimal standards to set the stage for future data sharing.

There are camera trap repositories that currently have data sharing and embargo policies in place. The international data repositories work under the assumption that sharing data allows for improved models and metrics for wildlife as they increase sample size, as well as temporal and spatial extent of the data on each species (Jetz et al, 2012). Whereas individual species of concern might be too rarely detected for rigorous model creation in one study, the combination of similar studies by different partners makes analysis possi-

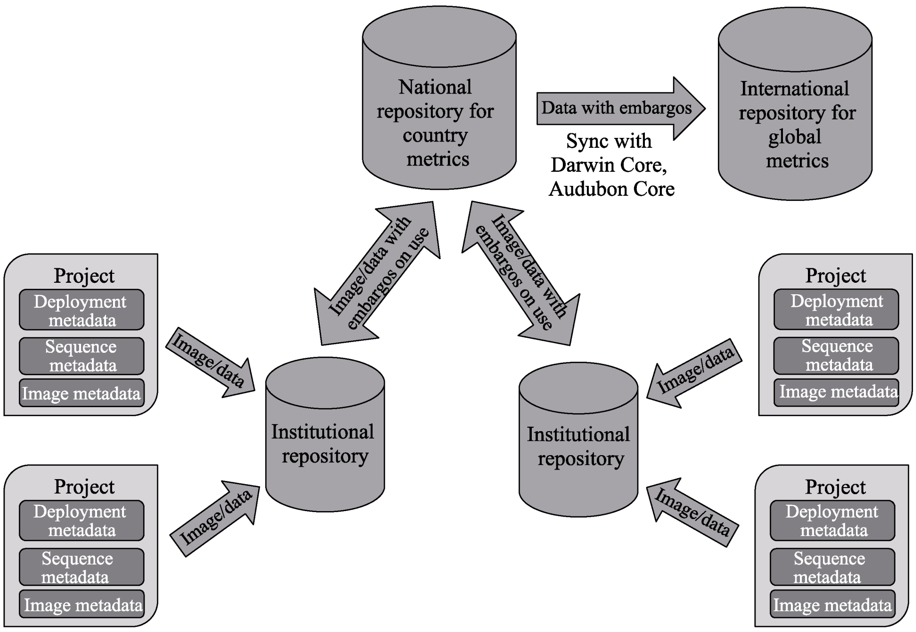

Fig. 1 A common camera-trapping metadata structure and schema for data flow between institutional repositories and national and international repositories

ble. Whereas a single project may have an emphasis on estimating density of a large carnivore, the "by-catch" from this well-funded project may be invaluable to those working on less charismatic species. Examples of international shared repositories are eMammal (http://www.emammal.si.edu), which is being coordinated by the Smithsonian Institution, and Wildlife Insights (http://www.wildlifeinsights.org) which is being developed by a consortium of NGOs including Conservation International, World Wildlife Fund, Wildlife Conservation Society, Zoological Society of London, North Carolina Museum of Nature, and Smithsonian Institution. The international repositories offer a model for data sharing. Data are input from multiple sources using a common platform (desktop application for eMammal and web-based for Wildlife Insights) and metadata structure (McShea et al, 2016; Ahumada et al, 2020). By creating web-based portals with drop-down options for data entry, citizen scientists can add data into these repositories without having to understand the complex data format. The data are then accessible to the global community through a public-facing website with reasonable embargos on sensitive information (location of endangered species and species of concern), as well as a permission structure that offers each project to set an embargo time prior to it becoming public. Both repositories encourage data submission by offering tools that make data uploads easier and provide analysis and report writing tools that might not otherwise be available to the data provider. For Wildlife Insights these include the use of AI to identify species and detailed summary statistics (Thau et al, 2019). For eMammal it is the emphasis on the management of citizen scientists and the expert review of data from volunteers (McShea et al, 2016; Forrester et al, 2017). Without access to valuable tools the repositories would not garner the support of individuals within the camera trap community. Both these platforms eventually make all data public (with the exception of endangered species).

One concern among Chinese researchers and government officials is the use of data outside any sharing agreements and there are other data repository which have similar concerns. ForestGEO (https://forestgeo.si.edu/) is a data repository where individual databases on forest demographics are curated at a single site (with a common field survey protocol and a standard metadata structure) with a public-facing information website on the size and parameters of each dataset. However, prior to access to any dataset the Project Manager for a dataset must release the dataset through an email link. This database contains multiple datasets from China and may provide the data control needed for important datasets, yet allow sharing between approved collaborators. A separate data sharing mechanism is developed within the Chinese Forest Biodiversity Monitoring Network in China (CForBio, www.cfbiodiv.org). Researchers who ask for collaboration and data sharing need to send proposals to PIs of other plots, with explanation on proposed research questions, authorship options and data required. The participant data owner will receive the R code from the applicant to run the analysis with their data, and send back results without sharing the raw data. Both of these examples highlight how concerns for publication fairness or sharing of sensitive data do not preclude establishing a common database.

4 Recommendations

The global mandate to sustain biodiversity demands international cooperation (Proença et al, 2017; Steenweg et al, 2017; Kissling et al, 2018). Many of the species of concern cross regional, and national, boundaries and any metrics to track these species will rely on cooperation between agencies and independent researchers within countries, as well as between countries that share the management of many species (Ahumada et al, 2020). We must develop the means to work across political and administrative boundaries, and this starts with communication between the entities generating the data. There are reasonable steps that will move the camera trap community toward cooperation. First, creating a forum to discuss issues both at the global scale and within each target country. Second, have these participants decide on a shared metadata structure or at least determine the commonalities of each independent dataset, "cross-walk" the data fields within each repository, create APIs to connect data repositories and established common monitoring protocols and data standards. Third, insure that more data goes into these large repositories by offering incentives through ease of upload and shared analysis tools. Fourth, set the rules for data sharing, both within the country and between cooperating countries. Each country will need to set rules that are appropriate for their participants, but the ultimate goal is sharing critical data. Ultimately the last step would be to contribute to the global repository via a portal that sends either raw or processed data for the use of global metrics and the examination of species with cross-boundary distributions.

The world conservation community needs China's participation to truly measure our shared progress toward a sustainable planet. The pathway of participation is first by sharing within the wildlife community of Chinese researchers and agencies, and then deciding as a group how to share with the wider community of conservationists. This is the way by which China's rich wealth of biodiversity will be evident to the world community and their progress on conservation measures will be quantifiable. During the past two decades, China actively participates in the international affairs of biodiversity monitoring and conservation, with increasing role and influence within the global conservation community. China has initiated or started to lead the establishment of several international biodiversity big data platforms. For example, the Chinese government recently announced that China will set up an International Research Center of Big Data for Sustainable Development Goals to facilitate the implementation of the 2030 Agenda for Sustainable Development. The establishment of a unified data standard and a common data sharing mechanism will provide the necessary foundation for the development and construction of these international data platforms.

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