

蝗虫遥感监测预警研究现状与展望

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摘要: 气候变化背景下全球蝗灾日益肆虐, 为支撑虫害及时精准防控, 迫切需要开展大面积蝗虫动态监测预警研究。本文从蝗虫生境遥感监测、蝗虫发生动态遥感预警, 以及蝗灾遥感损失评估3个方面介绍了当前研究现状, 并指出当前存在的问题主要包括3个方面: 蝗虫监测预警的时空分辨率较粗, 无法精准定位虫害热点发生区和重点危害区; 遥感虫害响应机制与虫害生物学扩散模型耦合度较低, 导致模型时空普适性较差; 缺乏高时空精度的虫害监测预警空间信息服务产品。因此, 当前急需发展面向全球、洲际、全国、区域的多尺度、长时序、高精度虫害精准监测预警平台。通过建立时空精细尺度的虫害监测预警指标体系, 研制遥感机制与虫害生物学机理深度耦合的高精度预测预报模型, 发布多尺度高时频的虫害监测预警空间信息产品和服务, 以实现海量数据的自动入库和智能存储、多层次模型的快速调用和高性能计算、虫害测报产品的在线生产和可视化服务。建立从数据到模型到产品服务的全链路, 从而切实提升全球应对重大迁飞性虫害的智能化水平, 为保障粮食安全、维护区域稳定和可持续发展提供科技支撑。

关键词: 蝗虫, 遥感, 监测, 预警, 平台

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1 引言

蝗虫是世界范围内的重大迁飞性害虫, 对农田、草地、森林等植被生态系统带来巨大威胁, 蝗灾暴发严重影响粮食安全、生态安全和社会稳定(马世骏, 1958; Krall等, 1997; 倪绍祥, 2002; 朱恩林, 1999; Cease等, 2012; Le Gall等, 2019; Shroder和Sivanpillai, 2016)。全世界约有1/3的大陆包括100多个国家和地区受到不同程度的蝗灾威胁, 每年受灾面积约5000万ha, 约1/8的人口受到蝗虫入侵影响(Latchininsky, 2013; Wang等, 2017)。沙漠蝗(*Schistocerca gregaria*)

为世界上发生危害最严重的蝗虫, 影响非洲和亚洲60多个国家和地区, 覆盖面积约为全球陆表面积的20% (Gómez等, 2019; Murali Sankar和Shreedevasena, 2020; Shroder和Sivanpillai, 2016)。2019年, 沙漠蝗虫在非洲角和西南亚各国不断蔓延并持续肆虐, 至今已严重危害亚非多国农牧业生产和粮食安全(FAO, 2019, 2020; Roychoudhury, 2020; Joshi等, 2020; Stokstad, 2020)。中国主要受飞蝗、草地蝗虫和土蝗等蝗虫危害, 其中为害最严重的为东亚飞蝗(*Locusta migratoria manilensis*)。据全国农业技术推广服务中心公布的数据, 中国东亚飞蝗年均发生面积高

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达150万ha,严重影响粮食产量和质量安全(任彬元等,2017)。近年来,随着气候变化和极端天气影响,蝗虫的发生范围和流行程度有明显的扩大和增强趋势(Cressman,2013a;Tu等,2020;Meynard等,2020)。实现蝗虫灾害的早期监测预警和科学防控对于减少化学农药施用、保障粮食安全和生态环境安全、实现农业可持续发展具有重要战略意义。

传统的蝗虫灾害监测预警方法大多基于地面调查、生物学模型、流行学机制融合专家知识等技术手段进行。此类在“点”上开展工作的方法虽然具有较高的局地精度,但无法准确获取大范围蝗虫孳生地及扩散区;且较粗的时空分辨率不能满足科学防控需求,尤其是对于突然爆发的蝗灾,难以合理有效的实施精准防控特别是生物防控,导致农药浪费及施用效率低。

近年来,遥感技术作为一种大范围快速获取农田时空连续信息的途径,被广泛用于虫害监测预警和损失评估。国内外先后发射了多颗高时空分辨率遥感卫星,包括国产高分系列、美国Landsat系列、欧盟Sentinel系列等,综合多源数据可以实现高达米级的空间分辨率和约5 d的全球重访周期。加之基础地理数据、土地利用/土地覆盖数据,不断加密的气象站点数据和长时间序列的气象再分析资料,以及覆盖全球的虫害测报站点获取的地面植保调查资料等,为虫害动态监测预警和损失评估提供了时空连续、类型丰富的海量数据资源。遥感技术在蝗虫生境监测、蝗虫发生等级监测、蝗灾预警、蝗灾危害损失评估等方面都有着不同程度的应用(倪绍祥,2002;Cressman,2013b;Waldner等,2015;Löw等,2016;Cissé等,2016;Shi等,2018;Stefan等,2018;Piou等,2019;Gómez等,2019)。此外,近年来数据融合算法、深度学习模式、大数据技术发展迅猛,为虫害遥感监测预警大数据分析和信息挖掘提供了强有力的智能化自动化手段(Guo,2017;Gómez等,2018;Zhang等,2019;Lu和Ye,2020)。应用遥感技术对蝗虫生境进行实时、动态大范围监测,以及对蝗虫潜在繁殖区和扩散危害区进行预警成为近年来的研究热点。

本文介绍了当前国内外蝗虫生境及蝗灾遥感监测预警和损失评估的方法和技术,分析了当前蝗虫遥感监测预警研究中存在的问题及面临的挑战,在此基础上阐述了未来蝗虫遥感监测预警的研究趋势,并对蝗虫遥感监测预警在科学、行业应用及社会经济等方面的应用前景进行了展望。

2 蝗虫遥感监测预警研究现状

随着遥感卫星数据源的不断丰富,以及近年不断发展的无人机遥感技术,使得遥感对地观测数据的空间、时间和光谱分辨率都得到极大提升。国内外学者利用多光谱、高光谱、雷达等多源遥感数据,研究蝗虫各生境因子与蝗虫发生发展的响应机理,在蝗虫生境监测、蝗虫发生动态预警及蝗灾损失评估等方面进行了大量卓有成效的研究,实现了蝗虫大尺度监测预警,为蝗虫的早期防控及蝗虫生境的有效治理提供了科学依据。

2.1 国内外主要研究机构

全球造成重大灾害的蝗虫主要包括沙漠蝗、澳洲疫蝗(*Chortoicetes terminifera*)和东亚飞蝗等。国外蝗虫遥感监测研究起步较早,其中联合国粮食及农业组织FAO(Food and Agriculture Organization of the United Nations)、澳大利亚疫蝗委员会APLC(Australian Plague Locust Commission)为较为成熟的研究机构,分别对沙漠蝗及澳洲疫蝗进行监测预警。国内从事蝗虫遥感监测预警的研究机构主要有南京师范大学、中国科学院空天信息创新研究院等机构,重点对东亚飞蝗、草地蝗虫及沙漠蝗的监测预警及灾后评估开展了研究。各机构主要研究内容及研究成果见表1。

2.2 蝗虫生境遥感监测研究现状

生境是蝗虫赖以生存的生态环境,由于蝗虫个体较小,无法直接对其进行监测,现有研究多是通过获取与蝗虫密切相关的重要生境因子,研究其对蝗虫产卵、孵化、成虫等关键生育周期的影响机理,从而实现对蝗虫的生境监测(Scanlan等,2001;倪绍祥,2002;韩秀珍,2003;Ma等,2005;Latchininsky等,2007;Deveson,2013;Renier等,2015)。

表1 国内外从事蝗虫遥感监测预警的主要机构

Table 1 Major institutions of locust remote sensing monitoring and early warning

序号	机构名称	相关研究内容	成果应用情况
1	联合国粮食及农业组织 FAO(Food and Agriculture Organization of the United Nations)	(1)研制了沙漠蝗预警管理系统 WARMS(Schistocerca Warning and Management System),用于管理和分析环境和蝗虫数据,对大区域尺度的沙漠蝗发生动态进行预测(Healey等,1996) (2)开发了eLocust3工具,提供遥感、绿度、降雨数据,提高实地调查效率,收集、整理、分析实地调查数据并将其传送至FAO总部的沙漠蝗虫信息处 DLIS(Desert Locust Information Service)(http://www.fao.org/faostories/article/en/c/1244192/ [2020-07-01]) (3)沙漠蝗繁殖区时序监测(Cressman,2008;Pekel等,2011;Waldner等,2015;Renier等,2015;Shroder 和 Sivanpillai,2016;Escorihuela等,2018) (4)沙漠蝗发生动态预警(Cressman,2001;Cressman,2013b;Piou等,2019) (5)开发了蝗虫网站 LocustWatch 提供沙漠蝗监测预警及防控相关信息(http://www.fao.org/ag/locusts/en/info/info/index.html [2020-07-01])	相关信息及网站已经广泛应用于亚非区域沙漠蝗监测预警,指导虫害防控
2	澳大利亚疫蝗委员会 APLC(Australian Plague Locust Commission)	(1)蝗虫生境地图概况和详细的区域视图绘制(McCulloch 和 Hunter,1983;Deveson,2013) (2)蝗虫动态监测预警(Deveson 和 Hunter,2002;Hunter 和 Deveson,2002;Weiss,2016) (3)研发决策支持系统 Decision Support System 实现蝗虫自动化监测预警(Deveson,2001;Deveson 和 Hunter,2002)	产品及网站为澳大利亚动态实时蝗虫监测预警提供支撑
3	印度空间研究组织 ISRO (Indian Space Research Organisation)	(1)基于生物气象因素评估蝗虫生境适宜性(Dutta 等,2004) (2)基于VEDAS & Google Earth Engine 实现作物损失自动检测 (3)蝗虫迁飞的启发式预警(Hunter 和 Deveson,2002)	基于该研究内容对印度蝗灾导致的作物损失进行评估,并对蝗虫迁飞路线进行预警,为印度沙漠蝗防控提供数据支持
4	南京师范大学	(1)草地蝗虫生境分类及蝗虫发生预警模型构建(蒋建军 等,2002;倪绍祥,2002) (2)构建草地蝗虫实地自动化监测技术系统(倪绍祥,2002;张洪亮和倪绍祥,2003) (3)东亚飞蝗生境遥感分类、发生遥感监测及综合预警(Zha 等,2005;李开丽和倪绍祥,2006;吴彤 等,2006;Zha 等,2008)	应用于青海湖地区草地蝗虫及河北黄骅地区东亚飞蝗监测预警,为草地蝗虫和东亚飞蝗防治提供了科学依据和技术支撑
5	中国科学院空天信息创新研究院(原遥感与数字地球研究所)	(1)基于全生育周期(孵化期、发育期及成虫期)的东亚飞蝗灾害遥感监测(马建文 等,2003;马建文 等,2004;Ma 等,2005) (2)全国东亚飞蝗蝗区遥感监测及虫害发生动态预警(http://rscrop.locust.imagepy.org/hc/ [2020-07-01]) (3)亚非地区沙漠蝗虫迁飞路径研究及重点区域损失评估(http://data.casearth.cn/ [2020-07-01])	生成多期报告及科学数据为国内东亚飞蝗监测预警、防控,及亚非沙漠蝗灾监测预警提供了科技支撑

当前研究对于蝗虫生境的遥感监测主要基于植被(植被类型和植被覆盖度)、土壤(土壤湿度和土壤盐分)及气候(温度等)3类因子开展。蝗虫喜食的植被类型分布严格影响着蝗虫的分布(Anderson, 1964; 康乐等, 1989), 大量学者通过对研究区域植被类型进行遥感识别对蝗虫分布区进行监测(Sivanpillai等, 2007; Latchininsky, 2013; Löw等, 2016)。植被覆盖度通过影响蝗虫的栖息环境来影响蝗虫分布, 覆盖度过高或者过低都不利于蝗虫生存(Cherlet等, 2000), 部分学

者通过植被指数获取植被覆盖度来监测蝗虫分布(Gutman, 1999; Despland 等, 2004; Pekel 等, 2011; Zhao 等, 2020)。土壤湿度及土壤盐分对蝗卵的分布、存活及孵化具有重要影响(Qi 等, 2007)。通过土壤湿度及盐分的遥感反演可以实现蝗虫分布监测及潜在繁殖区提取, 如 Gómez 等(2018)基于欧空局的土壤湿度产品, 应用机器学习方法对沙漠蝗的繁殖区进行定位; Crooks 和 Archer (2002) 及 Crooks 和 Cheke (2014) 应用 SAR 数据反演土壤湿度评估其对褐蝗

(*Locustanapardalina*) 的繁殖潜力; 扶卿华(2005)应用ASTER高分辨率遥感影像通过BP神经网络模型对土壤盐分进行反演,分析其对东亚飞蝗发生、成灾的影响。温度对蝗卵的孵化及蝗蝻的活动性具有重要影响,如张灿龙(2006)利用东亚飞蝗关键生育期的TM、MODIS遥感数据对黄骅地区进行地表温度反演,发现飞蝗分布与地表温度关系密切; 张洪亮和倪绍祥(2003)应用Landsat和MODIS影像获取地表温度LST(Land Surface Temperature)并将其应用于蝗虫生境的绘制和监测。除应用单因子对生境与蝗虫发生机理进行研究外,部分学者综合多生境因子对蝗虫生境进行监测,如Shi等(2018)基于多源遥感数据结合植被指数、地表温度及土地覆盖类型对东亚飞蝗生境进行分类,将其分为常发蝗区及偶发蝗区。中国科学院空天信息创新研究院研究团队综合土壤、植被、温度、土地利用类型等多生境因子,结合蝗虫发生地面调查数据,构建了东亚飞蝗蝗区遥感监测模型,实现了全国尺度东亚飞蝗蝗区的提取,并形成多套科学报告,为农业农村部虫害防控决策制定提供科技支撑。

2.3 蝗虫发生动态预警研究现状

蝗虫发生动态预警研究可为蝗虫发生区及时准确地开展蝗虫防控行动提供科学依据,以避免蝗灾大规模爆发导致粮食减损。当前,蝗虫的发生动态预警研究主要通过多源遥感数据获取植被、气候或土壤等生境因子对蝗虫潜在繁殖区、蝗卵孵化动态、蝗虫发生风险及等级、发生面积及迁飞路径等进行预警。

当前蝗虫潜在繁殖区预警主要通过研究多生境因子对蝗虫发生的适宜性来确定,如Gómez等(2019)应用SMAP卫星的表面温度、叶面积指数LAI(Leaf Area Index)和土壤湿度等变量来识别沙漠蝗的存在,进而确定其潜在繁殖区; Boltart等(2016)应用MODIS和Landsat多时相遥感数据,通过随机森林方法对咸海南部地区亚洲飞蝗生境类型进行分类,从而得出蝗虫潜在繁殖区。在蝗卵孵化动态预警研究方面,部分学者利用遥感影像数据对土壤水分、温度等生境条件进行反演,分析虫卵孵化与土壤水热的关系,对蝗卵孵化动态进行预警(马建文和韩秀珍,2004; Escorihuela等,2018; Piou等,2019)。对于蝗虫

发生风险及等级预警研究,主要通过蝗虫生境适宜度评价来实现,如Löw等(2016)应用Landsat和MODIS数据反演植被指数并对研究区植被进行分类,进而对蝗虫发生风险及等级进行预警; 张显峰等(2015)利用MODIS定量反演蝗虫种群发育的关键生境因子,提出一种渐进式草原蝗灾风险评估模型,对蝗虫发生风险进行预警。国内黄文江研究员带领的植被遥感机理与病虫害应用团体,依据东亚飞蝗发生发展特点,应用多源遥感数据定量提取蝗虫关键生境因子,构建了蝗虫发生动态预警模型,并结合测报指标定量划分蝗虫发生风险等级,实现了全国东亚飞蝗发生动态预警,已形成多期遥感科学报告被农业农村部采纳。在蝗虫发生面积预警方面,吴彤等(2006)应用Landsat数据反演LAI,发现LAI与飞蝗发生面积呈负相关,并在此基础上构建了基于LAI的东亚飞蝗发生面积预警模型。在蝗虫迁飞动态预警研究方面,部分学者通过遥感反演植被指数或提取植被类型监测植被变化,对蝗虫迁飞动态进行预警(Cherlet等,2000; Piou等,2013; Deveson,2013); 部分学者基于SMAP、MODIS数据提取降雨、温度、植被等数据,借助地理信息技术实现蝗虫迁飞动态预警(Deveson和Hunter,2002; Cressman,2008; Shroder和Sivanpillai,2016); 中国科学院空天信息创新研究院协同遥感、气象、植保等多源异构数据,结合FAO蝗虫调查信息,基于地球大数据平台实现了洲际沙漠蝗的迁飞及危害的时空动态监测及预警。

2.4 蝗灾遥感损失评估研究现状

蝗灾遥感损失评估可为蝗虫重点危害区的防控策略制定提供科学依据。大面积蝗虫灾害遥感损失评估研究多是基于多源遥感影像数据,提取蝗灾前后植被光谱信息及植被指数变化信息,主要包括蝗虫发生程度监测、蝗虫危害范围监测及蝗灾损失评估等。

蝗灾遥感损失评估目前常用的方法是基于LAI或归一化植被指数NDVI(Normalized Difference Vegetation Index)等植被指数,通过对比受灾前后植被变化情况,来判断蝗虫的发生程度、发生范围及等级,将植被指数下降的区域确定为受灾区域,并根据下降程度划分危害等级(Bryceson,

1990; Ji 等, 2004; Deveson, 2013; Eltoum 等, 2014; 陈健等, 2008)。如季荣等(2003)应用东亚飞蝗大发生年芦苇受灾前后的多时相MODIS遥感数据, 反演和比较了芦苇的NDVI, 得出受蝗虫危害程度不同的NDVI临界值, 并据此确定蝗虫的严重受灾区和中等受灾区; Zha等(2005)提出了基于连续MODIS遥感影像数据的时间滤波法, 实现了东亚飞蝗灾害随时间变化的严重程度监测; Zha等(2008)基于多时相Landsat TM数据, 构建了基于NDVI差值的东亚飞蝗密度指数LDI(Locust Density Index)模型, 并据此辨别和划分出了东亚飞蝗的发生等级。在蝗灾损失评估中, 部分学者基于地面高光谱遥感数据, 构建了蝗虫灾害导致的植被损失评估模型(赵凤杰, 2014; 郑晓梅, 2019)。随着遥感技术的发展, 学者们将无人机高光谱数据应用到蝗灾损失评估中, 如Song等(2020)和郑晓梅(2019)应用无人机高光谱成像仪采集蝗虫危害的芦苇冠层光谱, 对芦苇损失进行评估, 从而实现蝗虫危害等级监测和损失评估。随着遥感大数据技术的发展, 中国科学院空天信息创新研究院基于沙漠蝗虫危害区过去二十年的MODIS、Landsat等多源遥感大数据, 开展了2019年—2020年洲际尺度沙漠蝗危害区的监测及农牧业损失评估。相关研究成果为沙漠蝗的多国联合防控提供了科学数据基础。

3 蝗虫遥感监测预警未来研究趋势

如前所述, 随着遥感技术的不断发展, 气象、农业、遥感、计算机等不同专业背景的学者们应用遥感技术在蝗虫生境监测、蝗虫发生动态预警及灾情评估等方面进行了具有学术价值和现实意义的探索, 为蝗虫防控做出了重要贡献。虽然上述研究在各自领域取得了重大进展, 但是, 在气候变化背景下的蝗虫在世界范围内的迁飞危害复杂化, 对全球、洲际、全国及重点区域蝗虫发生动态快速监测预警和应急响应研究提出了更高要求。近年来, 遥感大数据技术、深度学习模式及人工智能技术迅猛发展, 基于多学科领域协同与集成的大尺度、高精度蝗虫监测预警研究成为必然趋势。本研究通过分析当前研究存在的问题, 认为蝗虫遥感监测预警研究未来发展趋势主要包括以下3个方面:

3.1 时空精细尺度蝗虫遥感监测预警指标体系构建

当前对于蝗虫热点发生区和生境的监测, 以及对其迁飞路径和潜在繁殖区的预警使用的指标体系主要包括气象(温度、湿度、风速等)、土壤(土壤温湿度、盐碱度等)和植被(植被空间分布和植被指数等)。其中, 植被指标可基于多源多尺度遥感数据高精度反演获取, 而气象和土壤指标多来自地面站点观测数据或空间分辨率较粗的遥感产品(分辨率约250 m到0.25°)。较粗的空间分辨率虽适用于大尺度蝗虫动态演进趋势监测预警, 但却无法满足地面虫害防控所需的核心繁殖区和重点危害区的精准定位。同时, 蝗虫的发生、扩散及迁飞是一个复杂的过程, 除考虑其生境条件外, 还需考虑不同蝗虫类型的生物学特性并将其包括在蝗虫监测预警指标体系内。目前, 随着遥感对地观测手段的多样化, 不同时间、空间和光谱分辨率的遥感影像为蝗虫遥感监测预警提供了多尺度时空连续的面状数据源。但是与遥感数据获取能力的大幅度提升相比, 当前多源、多尺度数据的数据融合与挖掘技术仍存在诸多瓶颈问题, 迫切需要发展海量时空异构数据的融合及信息挖掘系列关键技术。如何将时空尺度粗放的点状信息与时空连续的面状信息进行有机结合, 以解决跨地域、跨平台、跨类型、跨机构的多源观测数据高效融合和汇聚; 并深入挖掘蝗虫生境变化及蝗虫发生发展动态的有效信息; 进而构建时空精细尺度的蝗虫遥感监测预警指标体系是关键所在。

3.2 耦合虫害生物学机制与遥感技术的大尺度虫害监测预警建模

现有的蝗虫遥感监测预警模型多是基于单生境因子或多生境因子分析生境条件对蝗虫发生的适宜性进而对蝗虫的发生动态进行测报。此类研究或监测指标单一, 或研究区较小, 模型普适性较差, 难以满足大尺度下蝗虫的高时效高精度监测预警需求。此外, 当前蝗虫遥感测报研究中较少将蝗虫的生物学模型, 如蝗虫孵化、迁飞路径模型等, 囊括在遥感监测预警建模中。而虫害监测预警模型效力的优劣有赖于信息的有效性和模型结构的合理性。当前, 人工智能技术因其呈现出的深度学习、跨界融合、人机协同、群智开放和自主智能等特点以及大数据处理能力被广泛应

用于众多领域。针对蝗虫发生动态预警所需信息的复杂性及数据量大等问题,如何基于农学、生态、气象、遥感、专家知识及植保调查等多源信息,从不同角度为虫害监测预警提供关键输入指标,将虫害发生扩散生物学模型与遥感监测虫害热点发生区和生境适宜性评价机制进行有效链接是亟待解决的关键问题。此外,如何结合预警指标初始态和扩散状态实现基于深度学习框架的多模型耦合参数在线训练和时空动态更新;以及将生物学模型、遥感反演因子、专家知识等通过深度学习、人工智能等技术进行汇聚和整合,构建耦合虫害生物学机制与遥感技术的空间普适性强、时间稳定性高的虫害监测预警模型是未来蝗虫遥感监测预警研究的重要趋势。

3.3 基于大数据的量化蝗虫监测预警平台

国内外学者在蝗虫遥感监测预警方面开展了系列研究,且开发了多个蝗虫监测预警系统,但是这些系统多是基于地面点状调查及专家知识的定性描述的结论,且观测区域较小,不能真正意义上实现大尺度、时间和空间连续的精准蝗虫灾情定量监测预警及展示。另一方面,与对地观测数据的实时海量获取能力相比,蝗虫灾害的动态监测预警与防控决策产品和信息能力远远滞后,缺乏全国、洲际、全球尺度的监测预警和应急响应空间信息系统平台。未来,应充分利用当前数字地球和数据发展提供的契机来提升蝗虫监测预警的信息化水平,从而实现全球范围内不同地域的虫害发生热点监测和扩散危害预警算法的集成,以及虫害测报量化产品生产,并建立数据—模型—产品的全链路。通过构建支持高分辨率、长时间序列海量数据处理与多线程并行计算,且涵盖数据库、模型库、产品库的综合云服务平台,以实现模型在线计算、监测预警产品生产、宏观防控决策技术方案制定等;从而提高蝗虫测报效率、监测预警精度、产品连续性等服务能力,并缩短虫害监测预警尤其是应急响应时的数据挖掘和信息解译周期,以提升全球应对重大迁飞性虫害的智能化水平。

4 展望

科学研究方面:在大数据和人工智能等新兴学科的推动下,建立基于众源数据的海量样本采

集积累机制,以支撑多尺度大区域虫害监测预警建模和验证需求;将智能遥感与虫害机理深层次耦合,促进新的蝗虫监测预警模式的时空谱精细尺度信息挖掘模式的创新发展,以及虫害发生扩散时空联动范式的颠覆性变革;实现灾前预警—灾中监测—灾后损失评估智能化时空普适模型贯穿的虫害监测预警和损失评估科研链条构建,从机理层面推动蝗虫监测预警的原始创新与发展。

行业应用方面:将科学研究与防治需求相结合,构建蝗虫监测预警空间信息平台,提供虫害常规监测预警和应急响应等多层次服务模式;引入数据智能挖掘和高性能计算技术,缩短虫害测报信息解译周期,实现虫害监测预警产品的业务化生产;将虫害遥感监测预警产品与航空植保器械药物喷洒作业模式有机链接,搭建从蝗虫监测预警科研成果到行业虫害科学防治的桥梁;切实指导虫害科学防控,尤其是推进早期绿色防控措施的推广和实施,促进遥感空间信息产品的产业化进程。

社会经济方面:针对国际和国内政府部门、组织机构、商业团体、植保从业人员等群体的实际需求,通过互联网、移动终端的多媒体,推送多层次、立体化、可视化虫害监测预警和损失评估空间信息服务;培养建立稳定的国内国际客户市场,极大限度地缩短从产品服务到客户应用的响应周期,并构建信息互馈渠道,推动信息共享和遥感产品市场的健康蓬勃发展。

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Review of locust remote sensing monitoring and early warning

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Abstract: Vegetation systems worldwide are facing a growing challenge of locust threats, including Desert Locust (*Schistocerca gregaria*) invasion in African and Asian countries, Australian Plague Locust (*Chortoicetes terminifera*), and Oriental Migratory Locust (*Locusta migratoria manilensis*) in China. The traditional single-point hand-check monitoring method could obtain information on the occurrence and development of locust at the point level, which could not meet the needs of monitoring and timely prevention and control of locust at the area level. It is urgent to conduct large-scale locust remote sensing monitoring and early warning to support timely prevention and control of locust, to ensure the safety of agricultural production, and furthermore to promote the realization of the “Zero Hunger” goal. We reviewed the current research of locust from three aspects, i.e. pest habitat monitoring, pest occurrence early warning, and loss assessment. We found that, the locust monitoring and early warning normally has a coarse spatial and temporal resolution, which makes it impossible to accurately locate the hazard hotspots; and the loose coupling of remote sensing pest response mechanism and pest biological diffusion model leads to a poor temporal and spatial universality and prediction accuracy; also we lack of timely, quantitative and visualized remote sensing monitoring and early warning locust service products to promote effective pest prevention. Therefore, there is an urgent need to develop a multi-scale, long-term, high-precision locust monitoring and early warning platform in global, intercontinental, national, and regional levels, to establish spatial and temporal continuous pest monitoring and early warning indexes, to develop pest monitoring and early warning models by deeply coupling of remote sensing mechanism and pest biological mechanism, and to release multi-scale, high-time-frequency pest products and services. On the one hand, we need to bring together and produce cutting edge research to provide information for locust monitoring and early warning, by integrating multi-source data, such as Earth Observation-EO, meteorological, entomological and plant pathological, etc. On the other hand, multi-models, including vegetation radiation transfer model, vegetation parameter inversion model, pest diffusion model, loss assessment model, are needed to be coupled with each other to provide temporal and spatial continuously pest monitoring, forecasting and loss assessment results. Besides, an intelligent platform, including storage module, calculation module, product module, is needed to be constructed, to integrating big data intelligent analysis, conducting high-performance model computing, realizing online locust product production and service push. The future trend of pest remote sensing system is realizing automatic storage and intelligent storage of massive data, fast calling of multi-level models and high-performance computing, and online producing of pest products and visualization. It will fully open up the entire link from data to models to product services, to effectively improve the global level of intelligence to deal with migratory pests, and to provide scientific and technological support for ensuring food security and maintaining regional stability. Furthermore, with locust now a world migratory pest, China and other countries, together with each other to discuss joint monitoring, collaborative scientific research and development of new coordinated integrated pest management mechanisms to provide economic, effective and ecologically-friendly management solutions.

Key words: locust, remote sensing, monitoring, early warning, platform

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