综述

联合国
环境规划署

50
1972-2022

从污染到解决

全球海洋垃圾和塑料污染评估

开展本项评估的理由和背景见附件一。

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环境署在全球和自身活动中推广无害环境做法。我们的发行政策旨在减少环境署的碳足迹。

主要结论

1 海洋垃圾和塑料污染的数量一直在迅速增长。如果不采取有意义的行动，到2040年时，向水生态系统排放的塑料废物预计将增加近两倍。

海洋垃圾和塑料污染的规模和数量迅速增加，正在危及世界上所有海洋的健康。包括微塑料在内的塑料现已无处不在。它们是当前地质时代“人类世”的标志，正成为地球化石记录的一部分。塑料让一种新的海洋微生物栖息地被命名为“塑料圈”。

尽管目前有各种举措和努力，但海洋中大约有7 500万吨至1.9亿吨塑料。 每年全球陆源塑料垃圾排放量的估算值因所用方法而异。在一切照旧的情况下，不进行必要的干预，到2030年时，进入水生态系统的塑料数量预计可能比2016年每年约900万至1 400万吨增加近两倍，到2040年预计将达到每年2 300万至3 700万吨。用另一种方法计算，则这一数量到2030年时预计将翻番，，从2016年的每年估计1 900万至2 300万吨增加到每年5 300万吨左右。

2 海洋垃圾和塑料严重威胁所有海洋生物，同时也影响气候。

塑料在海洋垃圾中数量最多、危害最大和最为持久，至少占海洋废物总量的85%。它们对鲸、海豹、海龟、鸟类和鱼类以及双壳类、浮游生物、蠕虫和珊瑚等无脊椎动物产生致命和亚致命的影响。其影响包括缠绕、饥饿、溺水、内部组织撕裂、窒息和剥夺氧气和光线、生理压力和毒性伤害。

塑料还可以通过对海洋、淡水和陆地系统中的浮游生物和初级生产量的影响来改变全球碳循环。海洋生态系统，特别是红树林、海草、珊瑚和盐沼，在封存碳方面发挥着重要作用。 我们对海洋和沿海地区造成的破坏越大，这些生态系统就越难抵消并保持对气候变化的适应能力。

当塑料在海洋环境中分解时，它们将微塑料、合成微纤维和纤维素微纤维、有毒化学品、金属和微污染物带到水域和沉积物中，最终进入海洋食物链。

微塑料充当了对人类、鱼类和水产养殖种群有害的病原体的媒介。微塑料被摄入时，会导致基因和蛋白质表达的改变、炎症、摄食行为中断、生长放慢、大脑发育发生变化以及过滤和呼吸速率降低。它们可以改变海洋生物的繁殖成功率和生存状况，损害关键物种和生态“工程师”建造珊瑚礁或生物扰动沉积物的能力。

3 人类健康和福祉面临危险。

人类健康和福祉面临的危险来自露天焚烧塑料废物、摄入被塑料污染的海产品、接触塑料携带的致病细菌以及令人关切的物质滤出到沿海水域。与塑料有关的化学物质通过沥滤释放到海洋环境中的问题正受到越来越多的关注，因为其中一些化学物质令人关切或具有干扰内分泌的特性。

微塑料可以通过吸入和皮肤吸收进入人体，在包括胎盘在内的器官中蓄积。人类通过海鲜摄入微塑料可能会对沿海和土著社区构成严重威胁，因为在这些社区中，海洋物种是主要食物来源。目前尚不清楚接触海洋环境中的塑料中的化学品与人类健康之间的联系。然而，其中一些化学物质会严重影响健康，特别是女性的健康。

海洋塑料对社会和人类福祉产生广泛的影响。它们可能会使人们不愿前往海滩和海岸，享受体育活动、社交和全面改善身心健康带来的好处。精神健康可能会受到影响，因为人们知道，海龟、鲸、海豚和许多海鸟等富有魅力的海洋动物正面临危险。。这些动物对某些社区具有重要的文化意义。主流媒体上经常见到的鲸和海鸟肚子里满是塑料碎片的图片和描述可能会引发强烈的情感冲击。

4 给全球经济带来隐性成本。

海洋垃圾和塑料严重威胁沿海社区的生计以及航运和港口作业。2018年海洋塑料污染对全球旅游业、渔业和水产养殖业的影响的相关经济成本，以及清理等其他成本，估计至少为60-190亿美元。据预测，到2040年，如果政府要求企业按预期数量和可回收性支付废物管理费用，那么企业可能每年要为泄漏到海洋中的塑料承担1 000亿美元的财务风险。相比之下，2020年全球塑料市场估计约为5 800亿美元，而海洋自然资本损失的货币价值估计高达每年 25 000亿美元。

5 海洋垃圾和塑料使威胁成倍增加。

海洋垃圾和塑料的多重和连锁风险使它们产生的威胁成倍增加。它们可以同气候变化和过度开发海洋资源等其他压力因素一起产生作用，造成比单独因素更大的破坏。海洋垃圾和塑料的直接影响引发重要沿海生态系统栖息地的改变，影响当地粮食生产并破坏沿海结构，导致广泛和不可预测的后果，包括沿海社区丧失抵御极端事件和气候变化的能力。因此，需要根据更广泛的累积风险来评估海洋垃圾和塑料的风险。

6 海洋垃圾和塑料污染主要来自陆地。

在1950年至2017年累计生产的估计为92亿吨的塑料中，约有7亿吨变成了塑料垃圾，其中四分之三被丢弃和放置在垃圾填埋场，成为不受控制和管理不善的废物流的一部分，或者被倾倒或丢弃在环境中，包括海洋。微塑料可通过较大塑料物品的分解、垃圾填埋场的沥出物、废水处理系统的污泥、空气悬浮颗粒（如由轮胎和其他含塑料物品的磨损产生）、农业径流、拆船和海上货物的意外损失进入海洋。洪水、暴风雨雪和海啸等极端事件可能会将沿海地区的大量废弃物带入海洋，并使垃圾堆积在河岸、河口和海岸线。由于1950年至2050年期间全球塑料累计产量预计将达到340亿吨，因此迫切需要减少全球塑料产量和流入环境的塑料垃圾。

7 海洋垃圾和塑料的移动和积累已有几十年之久。

海洋垃圾和塑料在岸上和近海的移动受海洋潮汐、水流、波浪和风的控制，漂浮的塑料聚集在海洋环流中，下沉的物体集中在深海、河流三角洲、泥带和红树林中。从陆地流失到在近海水域和深海中沉积，中间可能会间隔很长的时间。在一些环流中发现的漂浮塑料有一半以上是在20世纪90年代和更早的时候生产的。

生态系统功能和人类健康可能面临长期大范围风险的热点地区数量目前越来越多。主要问题来源包括：地中海，其封闭性造成大量海洋垃圾和塑料积聚在这里，给数百万人带来风险；北冰洋，因为其原始自然状况可能受到损害，且海洋食物链上的生物摄入塑料会伤害土著人民和标志性物种；东亚和东南亚地区，因为在高度依赖海洋的众多居民附近有大量未经管控的废物。

8 技术进步和公民科学活动的增加让人们更容易发现海洋垃圾和塑料污染，但测量的统一仍是挑战。

在建立有效和负担得起的全球观测和测量系统以及确立用于检测和量化物理和生物样本中的垃圾和微塑料的规程方面取得了重大进步。然而，由于物理和化学特性差异很大，以及需要加强不同的采样和观察平台和仪器之间的一致性，科学家们仍然对在确定不同生境中发现的微塑料的绝对数量时仍有采样偏差感到关切。目前有15个正在运行的主要监测方案，涉及海洋垃 圾行动的协调、数据收集框架以及大型数据储存库和门户举措，但它们的数据和信息在很大程度上是互不相关的。除这些方案外，还有指标工作和基线数据收集活动，这些活动得到了世界各地越来越多的网络、公民科学项目和参与进程的支持。

9 塑料回收利用率不到10%，与塑料有关的温室气体排放量很大，但一些解决方案正在显现。

在过去四十年中，全球塑料产量翻了两番多，2020年全球塑料市场价值约为5 800亿美元。与此同时，如果一切照旧，全球城市固体废物管理的估计费用将从2019年的380亿美元增长到2040年的610亿美元。生产、使用和处置传统化石燃料塑料产生的温室气体排放量预计到2040年将增长到大约21亿吨二氧化碳当量，占全球碳预算的19%。用另一种方法计算，2015年塑料温室气体排放量估计为17亿吨二氧化碳当量，预计到2050年将增加到大约65亿吨二氧化碳当量，占全球碳预算的15%。

一个主要问题是塑料的回收率很低，目前还不到10%。数百万吨塑料垃圾被丢弃到环境中，或有时被运送到数千公里外，通常是进行焚烧或倾倒。据估计，每年仅分类和加工过程产生的塑料包装废物损失就价值800至1 200亿美元。另一个问题是标记为可生物降解的塑料，因为它们可能需要数年时间才能在海洋中降解掉，而且作为垃圾，它们可能会给个人、生物多样性和生态系统功能带来与传统塑料相同的风险。

单一解决办法战略不足以减少进入海洋的塑料数量。塑料生产与使用的上游和下游需要有多个系统的协同干预。这种干预措施已经出现。它们包括循环政策、逐步淘汰不必要、可避免和有问题的产品和聚合物、税收和收费等财政手段、押金退还制度、生产者责任延伸制度、可交易许可、取消有害补贴、开展绿色化学创新以生产更安全的替代聚合物和添加剂、改变消费者态度的举措，以及创建新的服务模式和进行生态设计促进产品的再利用，在原生塑料生产方面"关闭水龙头"。

10 各级都在取得进步，有望制定全球性文书。

全球、区域和各国都在开展越来越多的活动，有助于动员国际社会，以杜绝海洋垃圾和塑料污染。

城市、市政部门和大公司一直在减少流入垃圾填埋场的废物；在日益增加的公众压力下，监管进程在扩大范围；本地的大力行动和本地政府的举措掀起了热潮，其中包括街道垃圾收集、塑料回收和社区清扫。然而，当前的情况是，大相径庭的各种商业做法、国家监管措施和自愿安排混杂在一起。

国际上已经做出了一些承诺，要减少海洋垃圾和塑料污染（尤其是来自陆地的），还有几项涉及塑料贸易或减少对海洋生物影响的相关国际协定和软法文书。然而，自2000年以来商定的国际政策中，无一包含限制塑料污染的有约束力并可衡量的全球性具体目标。因此，多国政府以及商界和民间社会呼吁制定关于海洋垃圾和塑料污染的全球性文书。

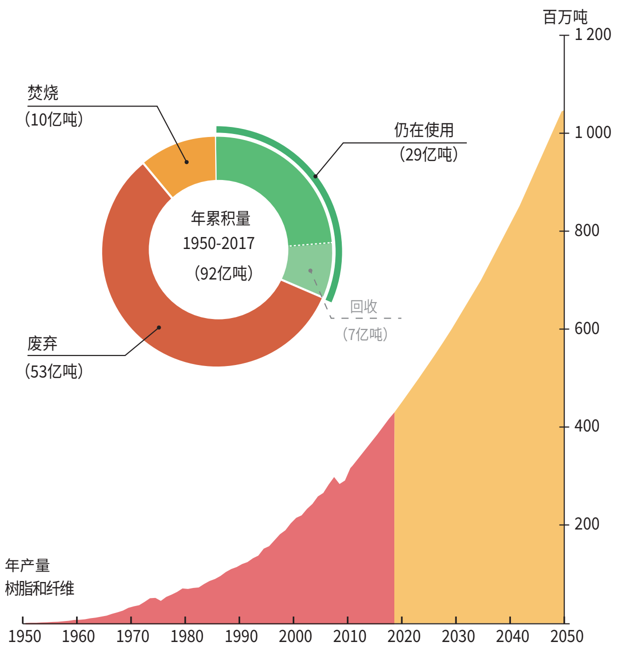
导言。

海洋垃圾和塑料污染正以前所未有的速度在世界海洋中积累起来。目前海洋中的塑料数量估计在7　500万至1.99亿吨3之间（Jang等人，2015；海洋保护协会和麦肯锡商业与环境中心，2015；Law，2017；国际资源委员会，2019；Lebreton等人，2019；Borrelle等人，2020；Lau等人，2020；皮尤慈善信托和SYSTEMIQ，2020）。在海底沉积物中、海滩上和全球许多其他地方都可以发现塑料垃圾。因此，塑料污染正在成为地球化石记录的一部分，也是当下地质时代“人类世”的一个特征。一种新的海洋微生物栖息地被命名为“塑料圈”（Amaral-Zettler等人，2020）。

海洋垃圾通过陆地、河流和大气等路径直接或间接进入海洋。海洋中塑料的主要来源包括陆地上未经管控的废物流、处理过和未处理过的废水排放、包括纺织品和汽车轮胎在内的塑料产品的磨损、陆地径流、农用塑料的漏损以及海事行业的直接投入（Geyer，2020）。

包括塑料和微塑料在内的垃圾对海洋生物和生态系统产生不利影响。此外，这些生态系统中的微塑料还可能危及人类健康，例如通过食用海鲜。视类别、大小和方位的不同，海洋垃圾和塑料可以通过缠绕、窒息、摄入和接触到塑料中的化学品，对海洋生物造成致命和亚致命的影响（Aliani和Molcard，2003；Rochman等人，2016；Alomar和Deudero，2017；Franco-Trecu等人，2017；Lusher等人，2017a；Reinert等人，2017；Anbumani和Kakkar，2018；Fossi等人，2018；Thiel等人，2018；Alimba和Faggio，2019；Bucci等人，2019；Windsor等人，2019；Woods等人，2019）。有证据表明，漂浮塑料可以将化学品和致病菌带到沿海地区，危及这些地区的生态系统和人类健康（Rech等人，2016；Turner，2016；Besseling等人，2019；Guo和Wang，2019；Yu等人，2019）。

要有效处理海洋垃圾和塑料污染问题，就要对陆源和海源废物的产生、处置、管理和泄漏采取广泛行动，并在塑料的总产量和化学成分方面采取措施。塑料是有史以来人造材料中用途最广的一种。它改变了数十亿人的生活和全球经济。然而，使用塑料的环境和社会代价是巨大的。海洋塑料污染对旅游业、渔业和水产养殖业的影响，加上包括清理活动在内的其他成本，每年在全球估计至少产生60亿至190亿美元的经济成本（德勤　，2019）。据预测，到2040年时，如果政府要求企业按预期数量和可回收性来支付废物管理成本，预计将泄漏进入海洋的塑料数量可能使企业每年面临1　000亿美元的财务风险（皮尤慈善信托和SYSTEMIQ，2020）。1950年后的全球塑料累计产量预计将从2017年的92亿吨增长到2050年的340亿吨　Geyer，2020）（图1）。因此，迫切需要在生产原生塑料方面“关闭水龙头”，减少未经管控或管理不当的废物进入海洋的数量，提高塑料废物的回收率（目前估计不到10%）（Andrades等人，2018；Boucher和Billard，2019；Geyer，2020）。塑料产业大量排放温室气体（Shen等人，2020），加大塑料对气候的影响（皮尤慈善信托和SYSTEMIQ，2020）。



资料来源：环境署（2021），从污染到解决：全球海洋垃圾和塑料污染评估。改编自：Jambeck等人，2018；欧洲塑料工业协会，2019；Geyer，2020

由全球资源信息数据库——阿伦达尔中心绘制

图1: 全球塑料产量、积累量及未来趋势

[1]. 在本报告中，吨均为公吨。

环境、健康、社会和经济影响

环境影响

海洋垃圾和塑料污染危害海洋的健康运行。2016年环境署报告《海洋塑料废弃物和微塑料：激发行动和指导政策变化的全球经验教训与研究》发布后，大量新的研究表明，海洋垃圾、特别是塑料及其分解产物对海洋生物和生态系统功能造成了广泛的损害，并可能危及人类健康（图2）。

塑料的致命和亚致命影响包括：鲸、海豹、海龟、鸟类和鱼类摄入塑料可能导致饿死和内部脏器撕裂，以及通过覆盖珊瑚礁令其缺氧和缺光；海龟、鸟类和哺乳动物被废弃渔具和塑料包装物缠绕而淹死；浮游生物、贝类、鱼类和海洋蠕虫因摄取微塑料遭受生理压力和毒理学危害，而所有这些生物都对生态系统功能至关重要（Browne等人，2008；Carson等人，2013；Wright等人，2013a， b；Adimey等人，2014；Hämer等人，2014；Rochman等人，2014；Au等人，2015；Brennecke等人，2015；Desforges等人，2015；Wilcox 等人，2015；Holland等人，2016；Green等人，2017；Lusher等人，2017a；Anbumani和Kakkar，2018；Duncan 等人，2018a；Duncan等人，2018b；Hallanger和Gabrielsen，2018；McNeish等人，2018；Reynolds和Ryan，2018；Arias等人，2019；Battisti等人，2019；Donohue 等人，2019；Nelms等人，2019a；Sun等人，2019；Landrigan等人，2020；Vethaak和Legler，2021）。

当塑料在海洋环境中分解时，微塑料、有毒化学物质和金属进入开放地表水中，最终进入沉积物，在那里被吸收到海洋食物链中（Arthur等人，2009；Ashton等人，2010；Mattsson等人，2015；Haward，2018；Karlsson等人，2018；环境署，2018a）。对微塑料危害的作用和致病机理进行的实地研究不够全面。但在实验室条件下已证明它们会导致基因和蛋白质表达出现变化、炎症、摄食行为中断、生长和生殖成功率降低、大脑发育出现变化、过滤和呼吸速率降低以及一系列导致存活率降低的疾病（von Moos，2012；Au等人，2015；Cole等人，2015；Nobre等人，2015；Paul-Pont等人，2016；Sussarellu等人，2016；Cui等人，2017；Lusher等人，2017a；Anbumani和Kakkar，2018；Arthur等人，2019；Bradney等人，2019；Green等人，2019；SAPEA ，2019；欧洲联盟，2019a；Jacob等人，2020；Lindeque等人，2020；Peng， L.等人，2020；de Ruijter等人，2020；Silva等人，2020；Xu等人，2020）。

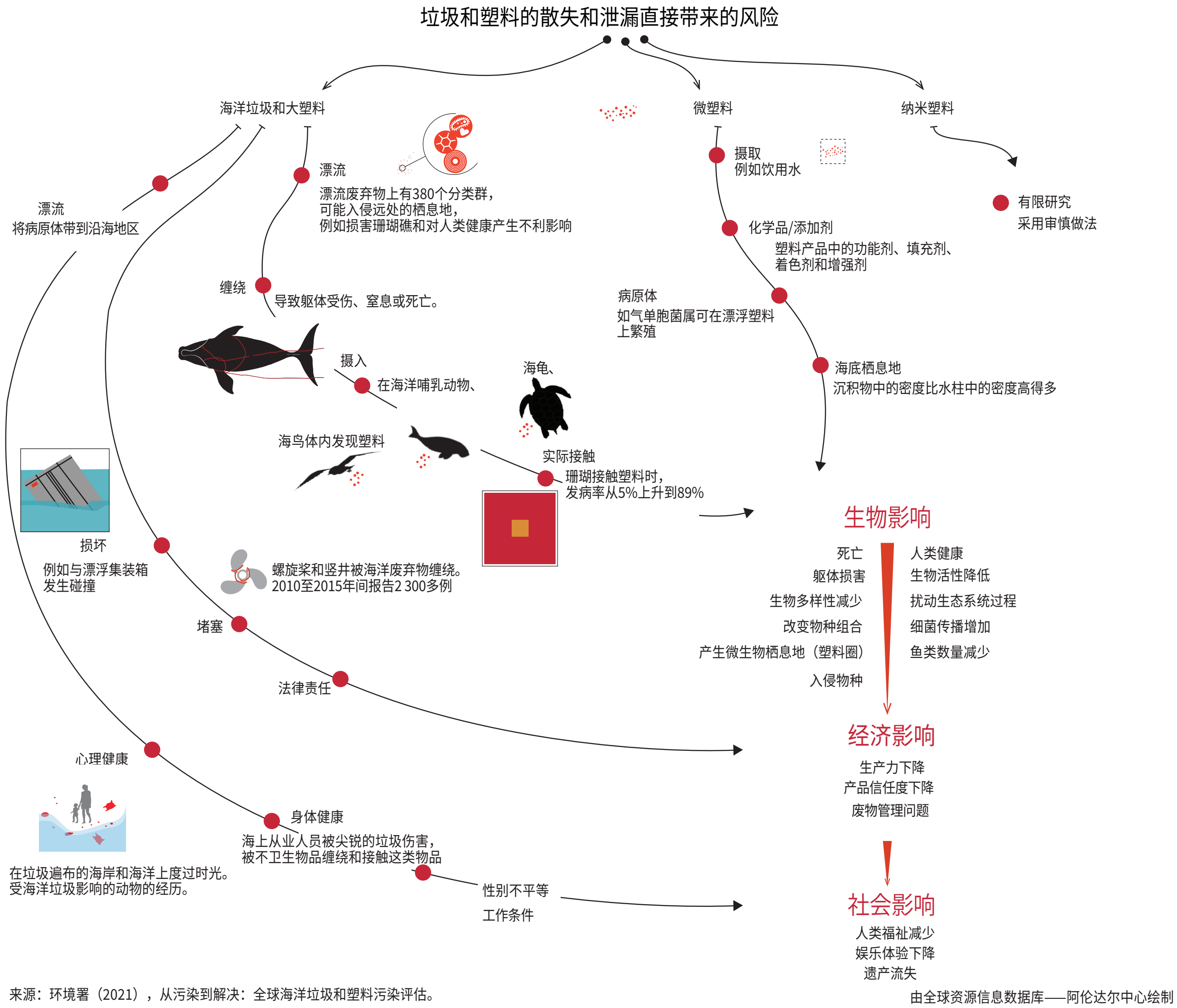


图2: 海洋垃圾和塑料的直接风险和影响

微塑料也可能引起环境物理变化，例如在海滩上，它可能使温度出现波动，对埋在沙子里的海龟卵的性别决定产生影响（Carson等人，2011；Beckwith和Fuentes，2018）。

微塑料可能承载对海洋生物和人类健康都有害的病原生物（如引起霍乱的弧菌这一细菌家族和引起鲑鱼腐烂和败血症的沙门气单胞菌），并为细菌组合中的质粒转移和增强抗菌素耐药性的编码基因的水平转移创造了条件（Kirstein等人，2016；Viršek等人，2017；Huang等人，2019；Arias-Andres等人，2018；Yang等人，2019；Goel等人，2021）。微塑料的尺寸不断减小，在表层形成很大的面积，出现微生物“塑料圈”群落和生物膜。

塑料中的化学品通过沥滤进入海洋环境或通过被摄入后进入海洋生物组织而释放出来的问题日益受到人们的关注，因为其中一些化学品，如双酚a，具有干扰内分泌的特性，另一些则被认为是令人担忧的物质（例如，环境署/化学污染国际专家组，2016；Hermabessiere等人，2017；Hong等人，2017a；M’ Rabat等人，2018；Groh等人，2019；Guo 和Wang，2019；Flaws等人，2020；Thaysen等人，2020；环境署，2020d）。已证明微塑料可吸附持久性有机污染物和痕量金属（Anumani和Kakkar，2018；Camacho等人，2019；Guo和Wang，2019；Fred-Ahmadu等人，2020；Pozo等人，2020）。天然沉积物和有机物也具有吸附疏水性有机化学物质的能力（Koelmann等人，2016；Prata等人，2020a）。

微塑料中的化学品污染和进入海洋水域和海洋生物组织的程度和转移速率在很大程度上取决于化学和物理条件，例如化学品和聚合物之间的化学键的性质和强度、pH值、温度、压力、生物污垢、表面活性剂的存在、不同类型聚合物的摄入量以及肠道浓度和停留时间（Gouin等人，2011；Koelmans等人，2014；Bakir等人，2016；Herzke等人，2016；Koelmans等人，2016；Rummel等人，2016；Anbumani和Kakkar，2018；De Frond 等人，2019；Koelmans等人，2019；环境署，2020d）。

塑料在海洋中分解的其他产物包括纤维素和合成微纤维以及纳米塑料（Boucher和Friot，2017；Belzagui等人，2019），它们直接来自废物流、农业径流、处理厂排放的废水，废水中可能含有洗涤合成纤维纺织品带来的微纤维；分解产物还包括海洋中因破碎和物理磨损而产生的塑料颗粒。尽管合成微纤维和纳米塑料会在沉积池中积聚，并可以在那里驻留多年，但海洋和沉积物中的大多数纤维都是由天然聚合物组成的，这些聚合物最终会降解（Obbard等人，2014；Remy等人，2015；Woodall等人，2015；Taylor等人，2016；Welden和Cowie，2016；Avio等人，2017；Bagaev等人，2017；Dris等人，2017；Miller等人，2017；Sanchez-Vidal等人，2018；Windsor等人，2018；Henry等人，2019；Primpke等人，2019；Song等人，2018；Ronda等人，2019；Stanton等人，2019b；Zambrano等人，2019；Harris，2020；Suaria等人，2020）。

可生物降解塑料和生物来源塑料、它们的生物和环境影响以及行业标签和认证是一个快速扩展的研究领域。实地研究结果表明，如果不对这些塑料进行工业堆肥或有控制的堆肥，其中一些塑料在海洋环境中可以持续存在多年而没有任何生物降解的迹象（O’ Brine和Thompson，2010；Alvarez-Zeferino等人，2015；Green等人，2015；Narancic等人，2018；环境署，2018a；Nap-

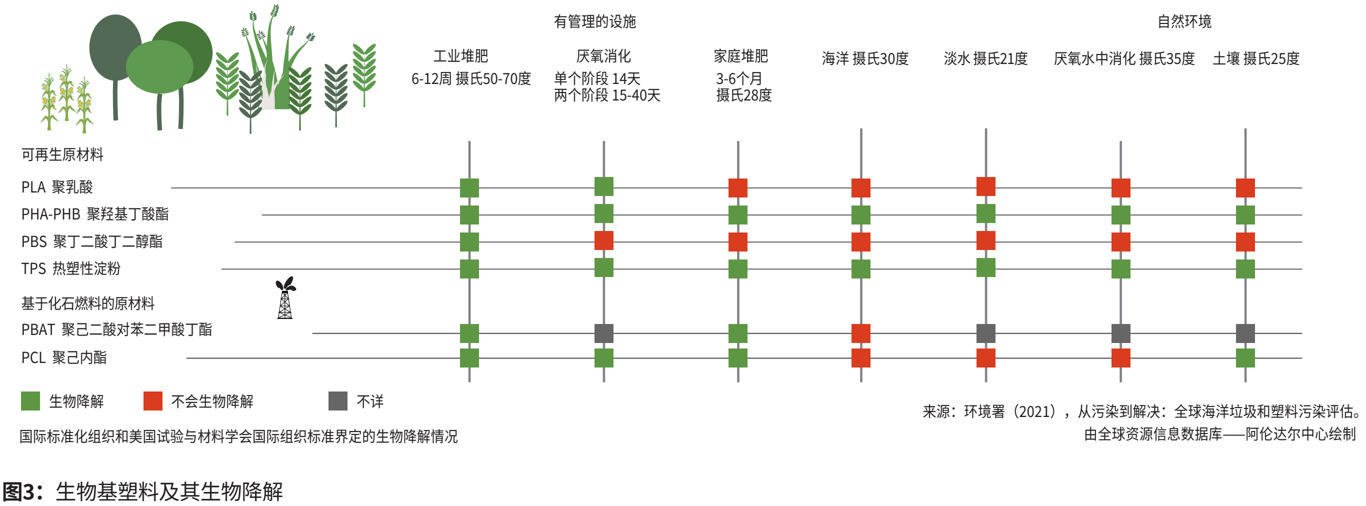


图3： 生物基塑料及其生物降解

per和Thompson，2019）（图3）。因此，在环境中，这些类别的塑料可能会有与传统塑料相同的风险（Alvarez-Zeferino等人，2015；Green，2016；Green等人，2016；Green等人，2017；Green等人，2019；Napper和Thompson，2019；Zimmermann等人，2020；环境署，2021）。

对人类健康的影响

垃圾和塑料污染对人类健康的影响主要来自废物处理不当，特别是在陆地上；食用受污染的海产品；以及接触由漂浮塑料带到沿海水域的致病细菌和令人关切的物质（Landrigan等人，2020）。接触露天焚烧塑料和焚烧不完全产生的有毒烟雾和致癌化学物质被认为是一个重大健康风险，已知其对非正规部门处理废物工人中不同性别产生的影响（van den Bergh和Botzen，2015；劳工组织，2017；环境署，2017；劳工组织，2019；亚太经社会，2019）。

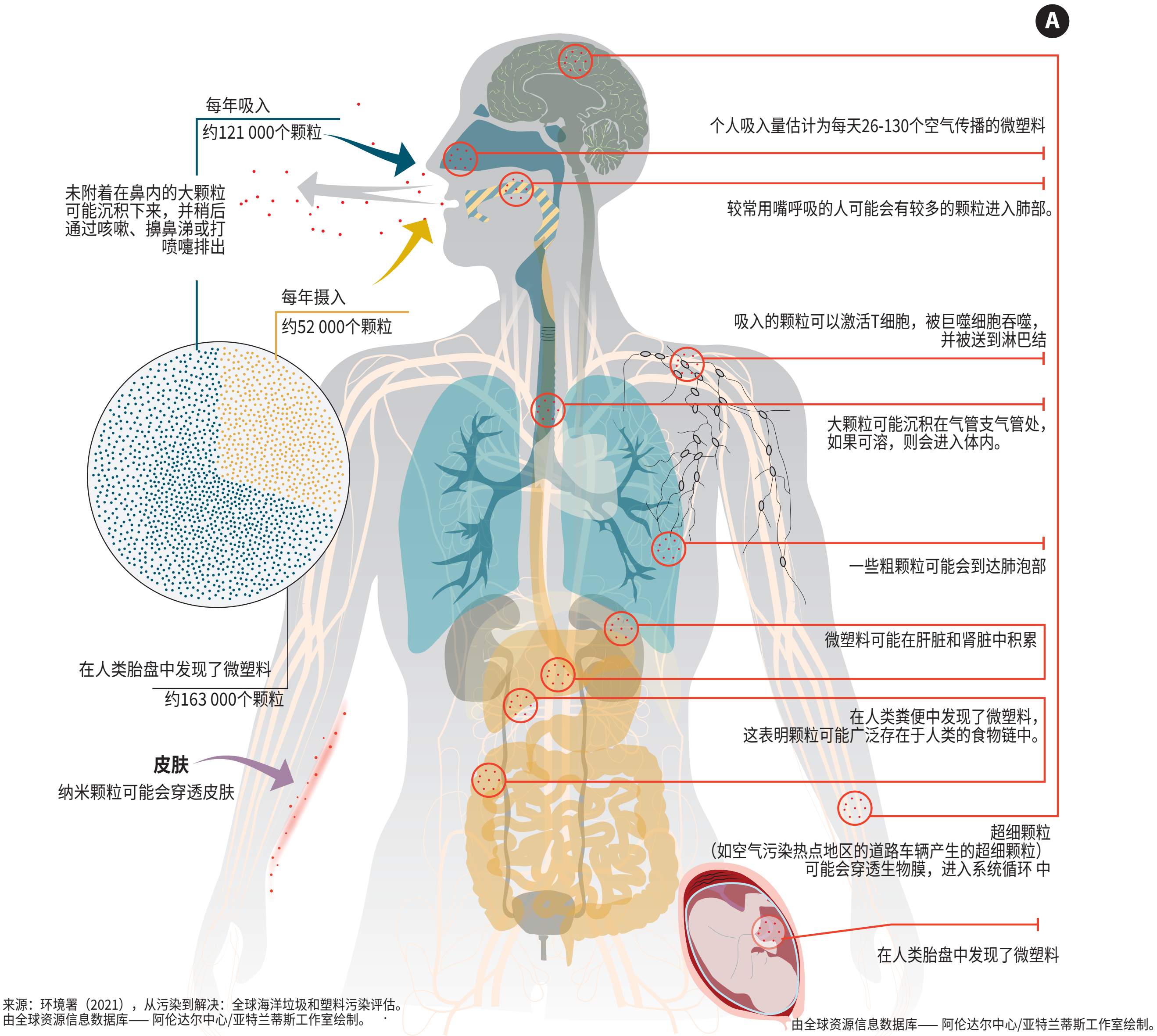


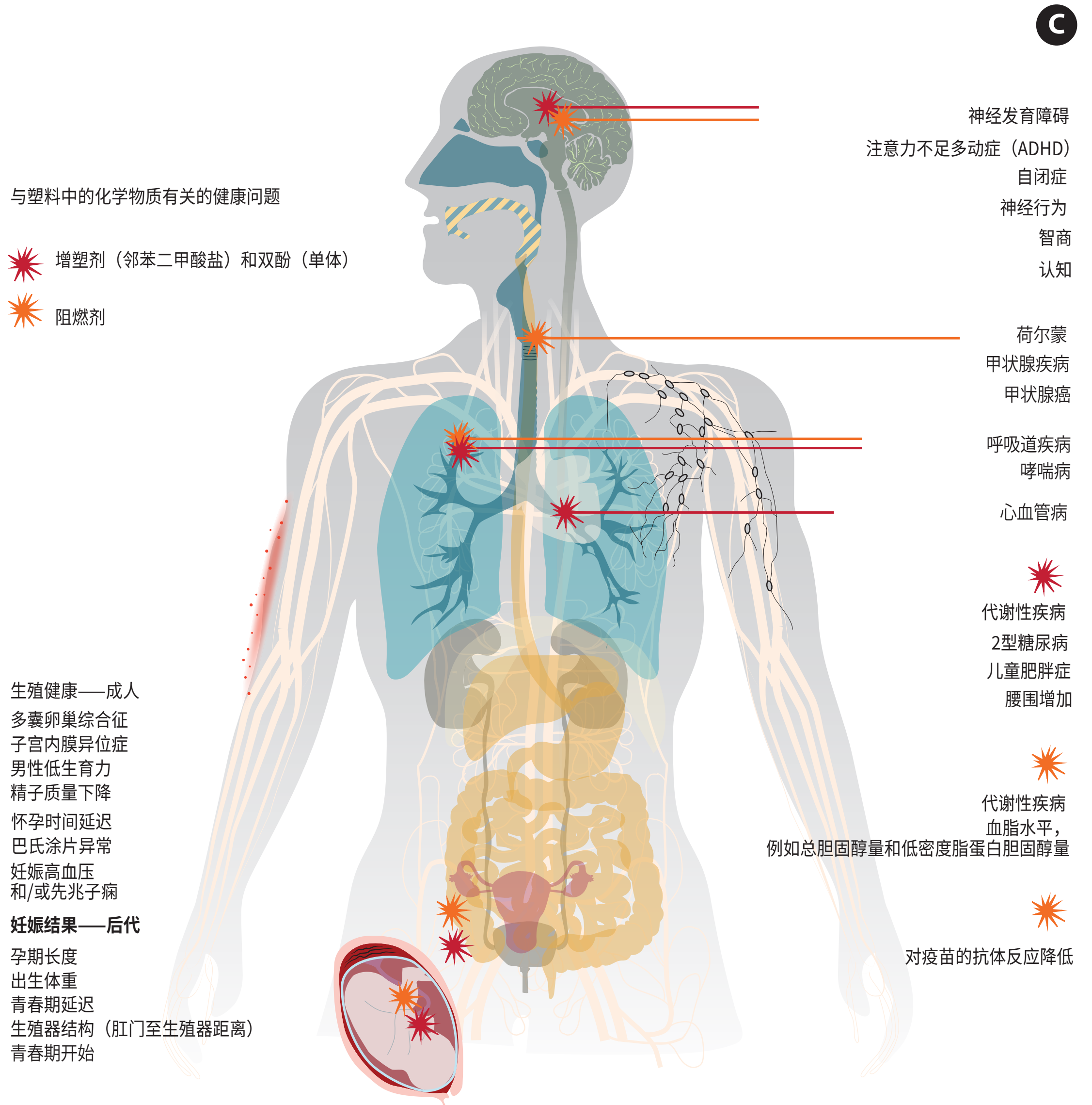
图 4-A: 人体接触微塑料和纳米塑料颗粒

来源：环境署（2021），从污染到解决：全球海洋垃圾和塑料污染评估。

由全球资源信息数据库——阿伦达尔中心/亚特兰蒂斯工作室绘制

图 4-B: 人体接触塑料颗粒和相关化学品

更普遍而言，微塑料和纳米塑料可能对人类健康构成风险。临床研究的证据表明，它们可以通过摄入、吸入和皮肤吸收进入人体，并在包括胎盘在内的器官中积累（Wright和Kelly，2017；Cox等人，2019；Koelmans等人，2019；世卫组织，2019；Landrigan等人，2020）（图4）。虽然未充分证明海洋塑料与海产品之间的联系以及仍未确定海洋塑料总接触量及其对健康的影响，但有大量证据表明，塑料中化学品，如甲基汞、增塑剂和阻燃剂，可以通过这些路径进入人体，并对健康产生严重影响，特别是对妇女和某些沿海土著社区，因为海洋物种是其主要食物来源（Dehaut等人，2016；Wright和Kelly，2017；Koelmans等人，2019；世卫组织，2019；Adyel，2020；Kögel等人，2020；Prata等人，2020；Landrigan等人，2020；Tekman等人，2020）。



来源：环境署（2021），从污染到解决：全球海洋垃圾和塑料污染评估。　由全球资源信息数据库— 阿伦达尔中心/亚特兰蒂斯工作室绘制

图 4-C: 接触与塑料有关的化学品对人体健康的影响

社会和经济影响

关于海洋垃圾和塑料对航运、港口作业、渔业和水产养殖的影响的研究着重指出，船舶会因螺旋桨碰撞和缠绕受损，给航行带来危险（Jeffrey等人，2016；Hong等人，2017b）；干扰港口运营（海洋工程、科学和技术研究所，2019）；通过物理缠绕和损坏降低商业渔业和水产养殖作业的效率和生产力（Richardson等人，2019；Deshpande等人，2020）；直接危及鱼类种群和水产养殖（Lusher等人，2017a）；并可产生巨大的视觉和美学影响，例如对游客和其他去海滩的人（Munari等人，2015；Pasternak等人，2017；环境署，2017；Petrolia等人，2019；Williams和Rangel-Buitrago，2019）。

根据对旅游业、渔业和水产养殖等行业的影响以及清理费用，海洋塑料污染的年度成本估计为60-190亿美元（德勤，2019），仅占2020年价值5　790多亿美元的全球塑料市场价值的一小部分（Statista，2021a）。由于现有的研究不全，这些成本未列入对人类健康或海洋生态系统的影响。缺少关于海洋垃圾和塑料污染所有经济成本的综合数额是一个普遍问题（Newman等人，2015；环境署，2017；Gattringer，2018）。

通常需要处理四类经济成本：防止海洋垃圾和塑料污染造成的损害或从中恢复所需的实际支出；产出或收入损失；不再生产塑料这一高价值材料的损失；福祉成本，包括对人类健康的影响和生态系统服务的丧失。已发表的大多数研究重点关注区域、国家和地方各级的经济损害或直接损失以及塑料社会成本内化所需要的价格调整（Hall，2000；Ferreira等人，2007；MacFadyen，2009；Mouat等人，2010；McIlgorm等人，2011；Jang等人，2014；Oosterhuis等人，2014；Newman等人，2015；Krelling等人，2017；Gattringer，2018；Leggett等人，2018；Dalberg　Advisors、世界自然基金会地中海海洋倡议，2019；Qiang等人，2020）。

一些研究调查了海洋垃圾和塑料的非市场的无形环境和社会成本。例如，在泰国安达曼海的一个沿海渔业社区，"海洋垃圾增加"被列为造成环境压力的最大因素（Lynn等人，2017）。其他间接测算包括因有非正规的垃圾收集行业而没有支出的成本；例如，据估算，2016年非正规的垃圾收集者收集了全球55至64%的回收塑料（Lau等人，2020）。然而，许多国家没有关于包括塑料在内的海洋垃圾造成损害的代价的经济数据（Janssen等人，2014；Jambeck等人，2018）。

在区域一级，有更多的研究正在关注这一问题。在公认是受海洋垃圾和塑料污染影响最严重的海域之一的地中海（Eriksen等人，2014；Cózar等人，2015；环境署/地中海行动计划，2015；Suaria等人，2016；环境署/地中海行动计划，2017；Campanale等人，2019；Constantino等人，2019；Dalberg Advisors、世界自然基金会地中海海洋倡议，2019；Fossi等人，2020），三个主要行业（渔业和水产养殖、航运和旅游业）每年大约损失6.96亿美元，仅渔业每年就损失约1.5亿美元（Dalberg Advisors、世界自然基金会地中海海洋倡议，2019）。这些数字不包括塑料造成的收入损失或对生态系统服务的破坏。

在亚太经济合作组织（亚太经合组织）国家，2008年海洋垃圾的年度经济成本估计为12.6亿美元（McIlgorm等人，2008；McIlgorm等人，2011），2015年增至108亿美元（亚太经济合作组织，2017；McIlgorm等人，2020）。亚太地区的这些数字反映了全球塑料产量的增加。Statista（2021b）估计，2017年全球累计产量为830万吨，2030年将增长至3 400万吨。世界海运业也在不断增长：截至2019年，据说仅年度海运贸易总额就超过14万亿美元（国际航运商会，2021）。

很难估算生态系统功能受损的成本。尽管对准确性表示担忧，但Beaumont等人（2019）用De Groot等人（2012）和Costanza等人（2014）提供的信息，估算出海洋自然资本的价值每年因塑料而减少5 000亿美元至25 000亿美元。对损失的海洋生态系统服务的惠益进行分析是估算海洋塑料的非市场无形成本的适当方法；但在该方法可以在全球采用前，需要进行全面的跨学科分析，以考虑经济、社会和生态系统之间的相互依存关系（Gattringer，2018）。

2020年全球塑料市场规模估计为5 800亿美元（Statista，2021a），相比之下，世界贸易组织（世贸组织）称，仅2020年的全球商品出口额大约为17.65万亿美元（而在冠状病毒病大流行开始前，2019年为19.014万亿美元，2018年为19.55万亿美元）（世贸组织，2021）。据计算，从原材料到制成品的塑料近期贸易流量大约为1万亿美元（贸发会议，2020）。然而，原生塑料的价格并没有反映处置塑料的全部环境、经济和社会成本。相反，这些成本被转嫁给沿海社区和海事行业。皮尤慈善信托和SYSTEMIQ（2020）根据到2040年时一切照旧的情况设想预测，届时可能有40亿人得不到预先安排的垃圾收集服务，如果政府要求企业按预期数量和可回收性来支付废物管理的成本，企业可能每年面临1 000亿美元的财务风险。

这些数字表明市场普遍失灵，尤其表明需要采用基于解决方案的全系统做法，重点关注各种挑战——技术挑战（例如不同回收技术和替代材料的可扩展性）、经济挑战（例如不同解决方案的相对成本）、环境挑战（例如不同解决方案的温室气体排放）和社会挑战（例如为拾荒者谋求公平和社会正义），因为需要应对这些挑战才能防止塑料废物管理不善和环境污染进入海洋环境的后续成本（Lau等人，2020）。

全世界越来越多的人意识到海洋环境正受到塑料污染以及过度捕捞的威胁（Lotze等人，2018；Hartley等人，2018b；Wyles等人，2019）。有证据表明，即使对于从未亲眼见过的海洋动物，人们也会因为知道它们会继续存在而感到幸福（Börger等人，2014；Jobstvogt等人，2014；Aanesen等人，2015；Eagle等人，2016）。就海龟、鲸、海豚和海鸟等富有魅力的海洋动物而言，情况更是如此，因为这些动物通常对人具有文化意义和情感意义。主流媒体上频繁出现鲸或海鸟胃里满是塑料碎片的图像和描述（例如，路透社，2017年）可能会在这方面产生强烈的有害影响（Lotze等人，2018）。

因为有海洋垃圾和塑料而无法前往海滩和海岸线可能会影响健康，这意味着没有机会享受体育活动、社交（例如，加强家庭纽带）以及全面改善身心健康等好处的话（Ashbullby等人，2013；Papathanasopoulou等人，2016；Kiessling等人，2017；Hartley等人，2018a；White等人，2020）。另一方面，需要清除这些地区的垃圾可以推动公民采取举措，包括开展海滩清理活动（Brouwer等人，2017；Hartley等人，2018b）。

处理海洋垃圾和塑料可能会对特定群体（例如妇女、儿童、处理废物工人和那些收集和焚烧塑料废物的沿海社区）产生不同的影响（劳工组织，2017；环境署，2017；劳工组织，2019；亚太经社会，2019）。有人建议，在考虑塑料的生产、使用、再利用和再加工方式时，应列入海洋塑料的社会成本（van den Bergh和Botzen，2015）。海洋垃圾和塑料污染会侵犯一系列人权。它们过多地影响弱势群体，包括生活贫困者、土著和沿海社区以及儿童，有可能加剧现有的环境不公正情况（联合国大会，2021）。

海洋垃圾和塑料污染风险框架

海洋垃圾和塑料给生态系统和社会带来的多重和连锁风险意味着它们可能使威胁成倍增加（减灾办，2019）。塑料尤其是压力因素，它可以协同其他压力因素（例如气候变化和过度开发海洋资源）产生作用，造成比单个压力因素更大的破坏（Backhaus和Wagner，2019）。例如，如果世界要避免重大气候变化，那么到2040年时，化石燃料塑料的生产、使用和处置产生的温室气体排放量要占允许总排放预算的19%（皮尤慈善信托和SYSTEMIQ，2020）。包括塑料和微塑料在内的海洋垃圾产生的直接影响致使主要沿海生态系统的栖息地发生改变，不仅影响当地粮食生产和沿海保护，而且可能通过损害生态系统的复原力和沿海社区抵御极端天气事件和气候变化的潜力，引发广泛和不可预测的次要社会后果（Galloway等人，2017；Carvalho-Souza等人，2018；Woods等人，2019；科学专家组，2020a）。这些问题突出表明，迫切需要采用统一的方法来管理海洋垃圾和塑料污染的风险（Hardesty和Wilcox，2017；Royer等人，2018；Adam等人，2019；Backhaus和Wagner，2019；减灾办，2019；科学专家组，2020a；Peng, L.等人，2020；Shen等人，2020）。

海洋环境保护的科学方面联合专家组（科学专家组）（2020a）提出，没有哪个单独的风险应对方法适合评估海洋垃圾的各种相关潜在危害和接触途径，而且能考虑到所有可能的环境、社会和经济后果。因此，有人提议设定一个“风险框架”并采用分层方法来处理海洋垃圾和塑料污染问题（Koelmans等人，2017；科学专家组，2020a）。这一方法表明，在各种不同的应用中开发危险和风险评估工具的经验在不断增加。要考虑的相关因素互不相同。它们包括现有知识和紧迫性。应考虑社会因素和潜在的公共或环境健康风险。这种风险框架的目标是进行“有的放矢”的风险框架，搁置非优先事项，为风险管理提供信息（Koelmann等人，2017）。风险矩阵可以突出表明知识缺口，帮助提明问题。

海洋垃圾、包括塑料和微塑料的来源和路径

陆地和海上来源

一些研究人员算出海洋中估计有7 500万至1.99亿公吨塑料（Jang等人，2015；海洋保护协会和麦肯锡商业与环境中心，2015；Law，2017；国际资源委员会，2019；Lebreton等人，2019；Borrelle等人，2020；Lau等人，2020；皮尤慈善信托和SYSTEMIQ，2020）。全球在1950年至2017年期间累计生产的92亿吨塑料中约有70亿吨变成了塑料废物，其中四分之三被丢弃，最终进入垃圾填埋场、垃圾场、未经管控或管理不善的废流或自然环境，包括海洋（Geyer，2020）。

海洋垃圾主要来自陆地来源，包括农业、污水处理厂、建筑、运输、不必要、可避免和有问题的塑料产品和聚合物，以及种类繁多的个人护理和保健产品；大约60%的大塑料泄漏源于未经管控的废物流（环境署，2018c；国际资源委员会，2019；van Truong等人，2019；Geyer，2020；皮尤慈善信托和SYSTEMIQ，2020）。海上来源包括渔业和水产养殖、航运和近海作业以及乘船旅游（科学专家组，2015；海洋工程、科学和技术研究所，2019；Ryan等人，2019；粮农组织 ，2020；科学专家组 ，2020b）（图5）。COVID-19 大流行期间广泛使用的个人防护用品大大增加了塑料废物目前的数量（Adyel，2020）。陆源塑料废物的全球每年估计排放量因所用计算方法而异。预计进入水生生态系统的塑料废物数量将增加一倍以上，从2016年的1 900万至2 300万吨年估计量增加到2030年的5 300万吨（Borrelle等人，2020）。进入水生系统的排放量预计将增加近两倍，从2016年的900万至1 400万吨，增加到2040年的2 300万至3 700万吨（Lau等人，2020）。Meijer等人（2021）采用另一种方法，估算每年有80万至270万吨塑料废物从河流系统进入海洋（表1）。

垃圾填埋场的渗滤液、污水处理厂的污泥和农业径流中有微塑料（Mason等人，2016；Mahon等人，2017；Li等人，2018；Cowger等人，2019；He等人，2019；Sun等人，2019）（图6）。农业土壤可因有意使用污水厂污泥和污水、塑料包衣种子和农用化学品（例如控释肥料）而成为微塑料的汇（Nizzetto等人，2016a， b；Piehl等人，2018；Accinnelli等人，2019；Corradini等人，2019；Wang等人，2019a, b）。

渔业和水产养殖设施遗弃、丢失或以其他方式抛弃的渔具是在以下地方发现的废弃物数量中最大的一个类别：海滩上（Welden和Cowie，2017；欧盟委员会，2018a）和海上（Veiga等人，2016；Vlachogianni等人，2017；Lebreton，2018；Stelfox等人，2016；Fleet等人，2021）。网、绳索、笼子和尼龙绳会产生尤为严重的影响，因为它们会通过组织磨损

表1: 全球每年从陆地排放的塑料废物估计数量

塑料废物排放估计数量 (每年百万吨)	进入海洋的来源	塑料废物排放预计数量(每年百万吨)	采用的方法
19-23	2016年进入水生生态系统	53 2030年	综合预期人口增长、人均年废物产生量、塑料在废物中的比例；纳入了塑料材料因预计产量增加而出现的增加，以及各国管理不当的废物比例（Borelle等人，2020）
9-14	2016年进入水生生态系统	23-37 2040年 (相当于全球海岸线每一米有50公斤塑料)	采用五种设想情况（2016-2040 年）并假设不采取有效行动，模拟了城市固体废物和四种来源微塑料在全球塑料系统中的存量和流量（Lau 等人，2020 ）
0.8-2.7	2015年从全球河流系统进入海洋	--	基于1 000多条河流，根据实地观察进行调整(Meijer et等人，2021)

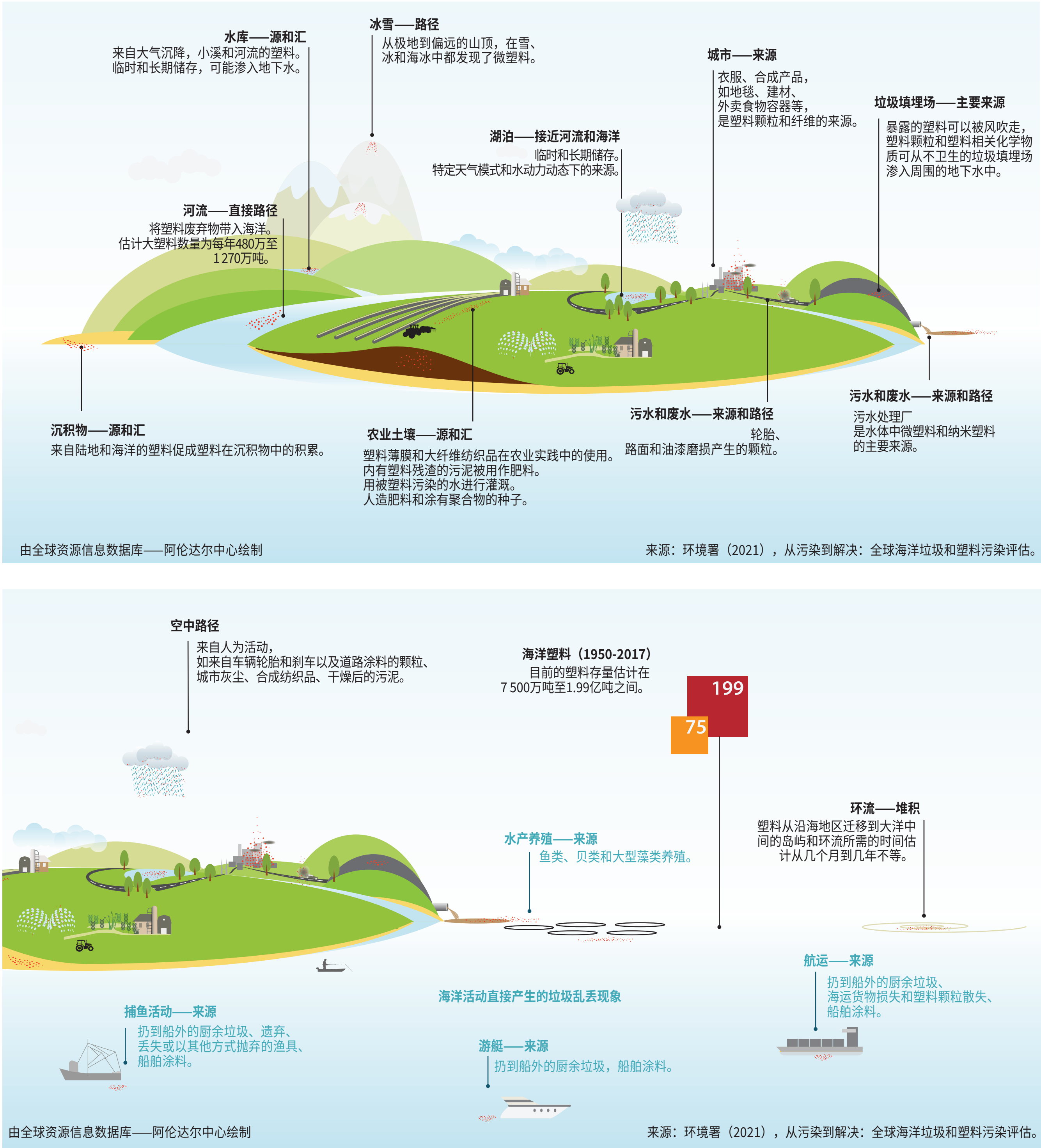


图5 人类产生的塑料废物在海洋环境中的主要路径

和窒息伤害珊瑚和海草等栖息地形成必不可少的海洋生物（Ballesteros等人，2018），有时还会大幅度缩减它们的范围和功能（Richards和Beger，2011；Carvalho-Souza等人，2018）。

一些沿海地区塑料污染的一个主要来源是拆船（《环境政策科学》，2016）。在一个关于印度一家造船厂的研究中，作者发现了成千上万的小塑料碎片，平均每千克沉积物就有81毫克，他们说这是拆船直接造成的（Reddy等人，2006）。据认为，在欧洲持有的600万艘船中，每年有1%至2%（即至少80 000艘）报废，但只有大约2 000艘得到妥善拆解（欧盟委员会，2017）（图7）。

海洋垃圾和塑料污染通过多种路径进入海洋，如陆地径流、河流流动、废水和灰水流动、空气传播，以及直接源于海上作业（图6和图7）（Alomar等人，2016；Nizzetto等人，2016a；Nizzetto等人，2016b；Auta等人，2017；Lebreton等人，2017；Alimi等人，2018；Horton和Dixon，2018；Best，2019；Akarsu等人，2020；Chen等人，2020；Birch等人，2020；Peng, L.等人，2020）。洪水、风暴和海啸等极端事件也可能带来沿海地区的大量废弃物，致使垃圾在河岸、河口和海岸线堆积（WerBowski等人，2021），并使沿海基础设施受损产生的废弃物流入海洋（国家海洋和大气管理局，2015；Lusher，2017b；Murray等人，2018；科学专家组，2019）。海底废弃物调查有助于确定垃圾和微塑料最有可能使用的路径，可以用品牌标签来确定它们的年龄和最有可能的来源（Cau，2019）。

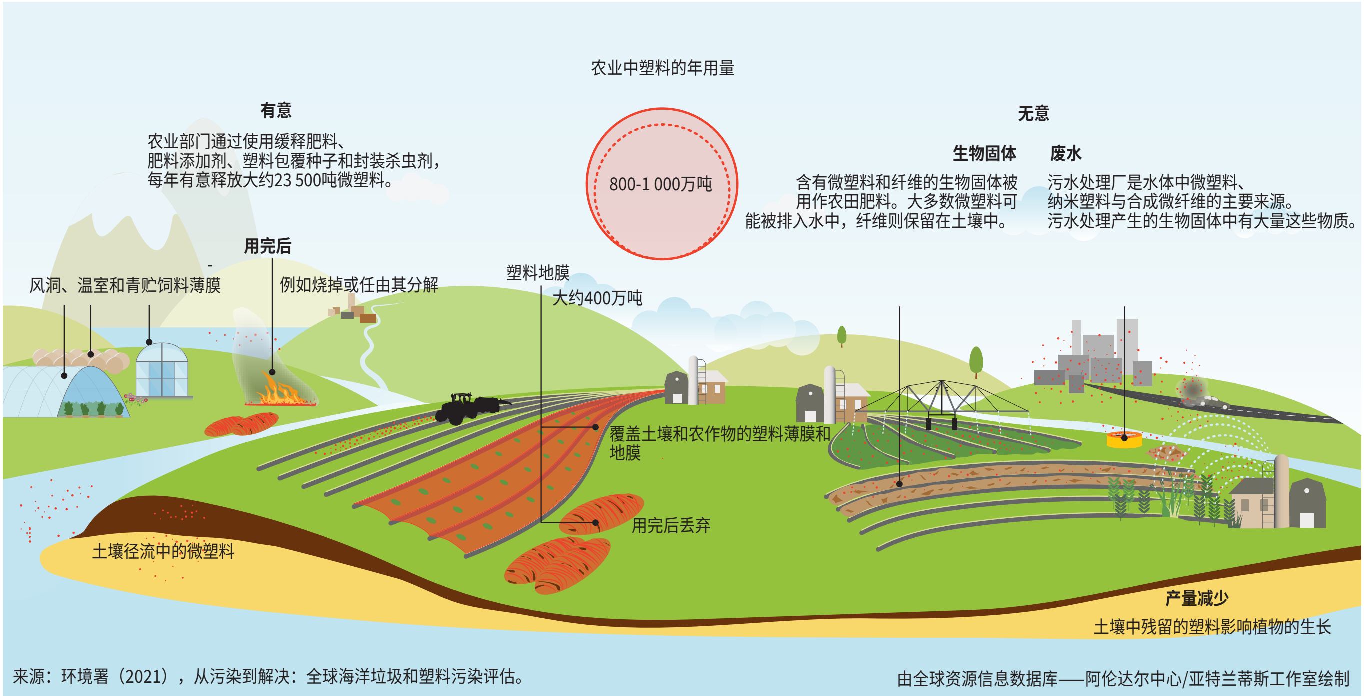


图6: 属于海洋垃圾和塑料污染原因之一的农业做法

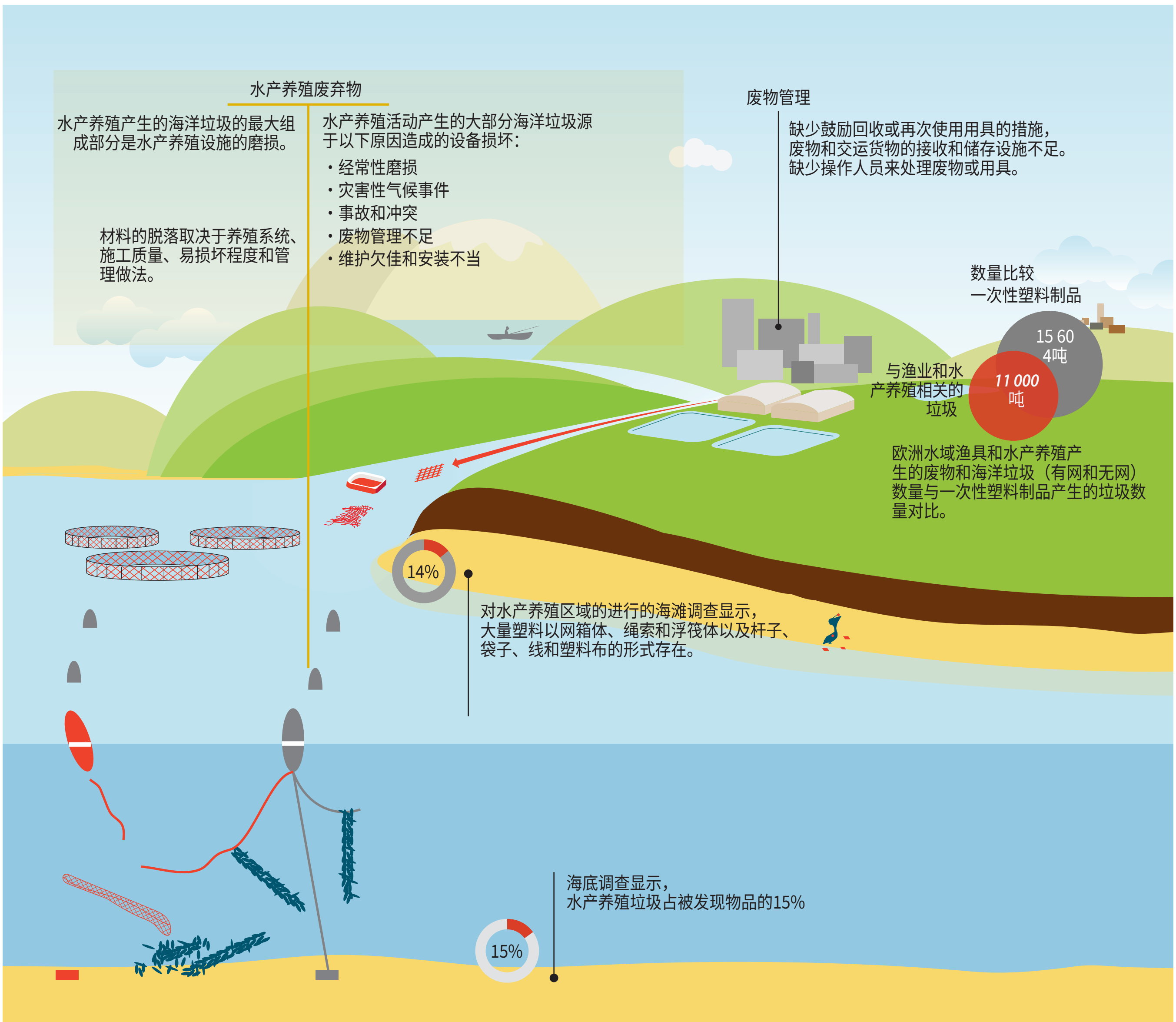


图 7: 属于海洋垃圾和塑料污染原因之一的渔业和水产养殖做法

垃圾和微塑料一旦进入海洋环境，它们的移动就会受海洋潮汐、洋流、海浪和海风的控制。在沿海地区，潮汐与海岸线特征相互发生作用，视垃圾的化学成分、表面电荷、密度、大小和形状，把垃圾冲上岸和冲下岸（Mattsson等人，2015；Chubarenko等人，2016；Fazey和Ryan，2016；Kooi等人，2016；Pedrotti等人，2016；Zhang，2017；Alimi等人，2018；Chubarenko等人，2018；Dussud等人，2018a,b；Lebreton等人，2018；Castro-Jiménez等人，2019；Lebreton等人，2019；Napper和Thompson，2019；Onink等人，2019；Peng, G.等人，2020；van Sebille等人，2020；Harris等人，2021）（图8）。

漂浮的海洋垃圾，包括塑料，会陷入漩涡；它们可以沉下去或漂浮起来，这取决于破碎率、密度、风和波浪以及与海洋生物的相互作用，它们会聚集在大型近海环流中（Cózar等人，2014；Law等人，2014；Duhec等人，2015；Díaz-Torres等人，2017；Imhof等人，2017；Lavers和Bond，2017；Collins和Hermes，2019；Lebreton等人，2019；van der Mheen等人，2019；Wichmann等人，2019；Dunlop等人，2020）。亚热带近海水域中塑料总质量有将近一半是超过15年的大塑料碎片组成的（Lebreton等人，2019）。海岸沉积是一个重要的过程，因为塑料的磨损和破碎产生了微塑料，有毒化学品和重金属从塑料中释放出来（Nakashima等人，2016；Lavers和Bond，2017）。

虽然人们对塑料的路径和去向有广泛的了解，但其绝对体积，特别是微塑料的绝对体积，因采样覆盖面小和没有标准化的采样方案，仍然不为所知（Galgani等人，2021；Harris等人，2021）。因此，现有的全球估算量主要是根据人口密度等替代指标建模确定的，而不是直接测量得出的（Galgani等人，2021）。陆地流失与在近海水域和深海沉积物中积累之间也可能会间隔很长的时间；例如，一些海上环流中发现的塑料是几十年前生产的（Kedzierski等人，2018；Lebreton等人，2019；van Sebille等人，2020）。

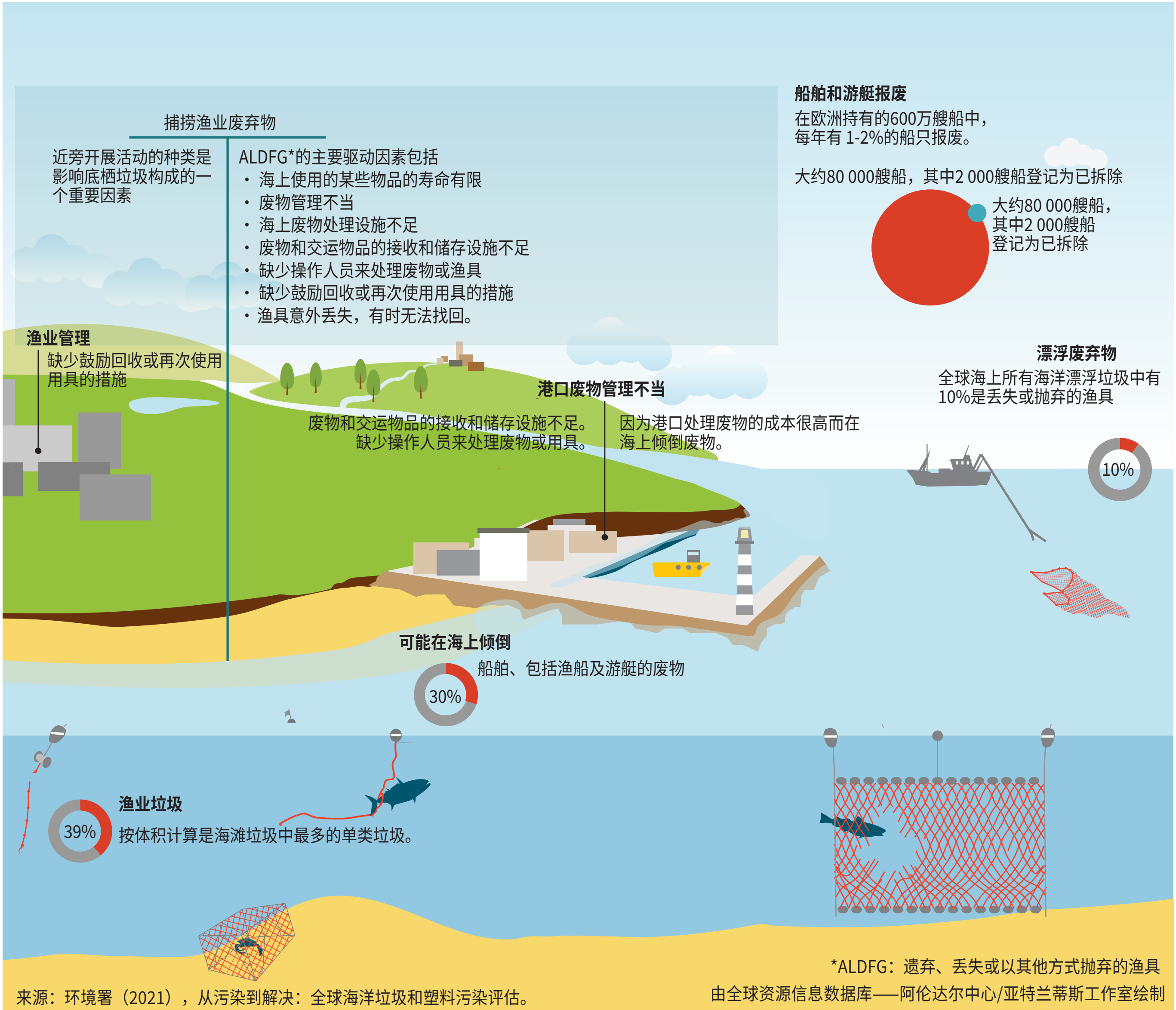
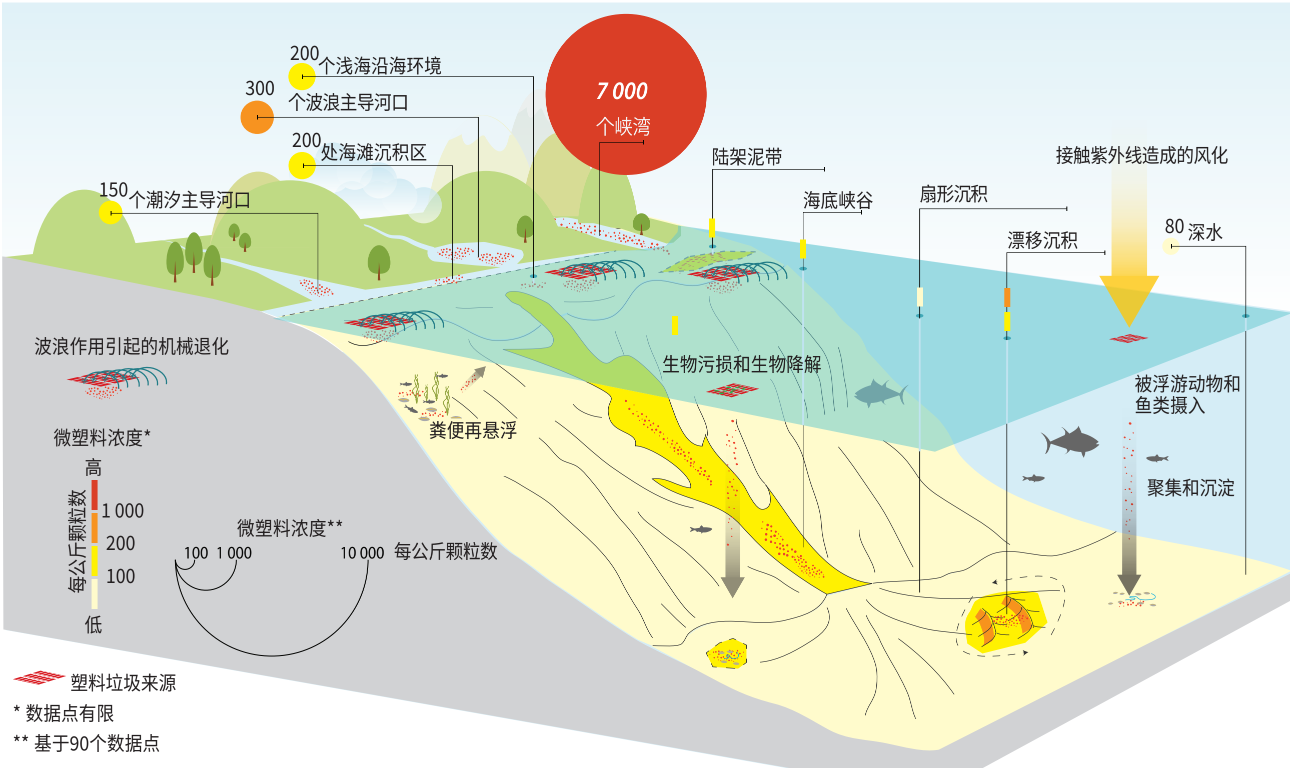


图 7: 属于海洋垃圾和塑料污染原因之一的渔业和水产养殖做法



来源：环境署（2021），从污染到解决：全球海洋垃圾和塑料污染评估。　由全球资源信息数据库——阿伦达尔中心绘制

图 8: 影响微塑料分布和归宿的自然过程

已经确定了海洋垃圾和微塑料可能对生态系统功能和人类健康构成大范围风险的主要区域热点。例如地中海，因为它是封闭的，每年有大量废物流入，积累了大量垃圾和微塑料，给生活在海岸线上的数百万人带来风险（Dalberg Advisors、世界自然基金会地中海海洋倡议，2019；Boucher和Bilard，2020）；北冰洋，因为原始自然可能受到损害，且通过海洋食物链和海产摄入塑料会伤害标志性物种和土著人民（Sundet等人，2016；Hallanger和Gabrielsen，2018；Kanhai等人，2018；Donohue等人，2019；Kanhai等人，2019）；以及东亚和东盟地区，因为有大量未经管控的废物，而且漫长的海岸线附近居住着高度依赖海洋环境而生存的众多居民（Cai等人，2017；Lyons 等人，2019；Purba等人，2019；Onda和Sharief，2021）。

测量和监测海洋垃圾，包括塑料和微塑料

关于河流、大气、海岸线、沿海和近海环境中的海洋垃圾和塑料污染的实验室工作流程、监测方法和勘查技术已经有了许多改进和修改（González-Fernández和Hanke，2017；Carvalho-Souza等人，2018；Chiba等人，2018；Galgani等人，2018；科学专家组，2019；Karlsson等人，2019；van Calcar和van Emmerik，2019；Enyoh等人，2019；科学专家组，2019；Prata等人，2019；Schulz等人，2019；Stanton等人，2019a；Forrest等人，2020；环境署，2020a，b，c）。在对微塑料进行有效的取样方面也做出了重大努力，尽管有人对不同技术的一致性提出质疑（Besley等人，2017；Costa和Duarte，2017；Lusher等人，2017b；Blettler等人，2018；da Costa，2018；Borja和Elliott，2019；van Emmerik和Schwartz，2019；Koelmans等人，2020；Ryan等人，2020）。由于制订不同方法对通过饮食接触微塑料进行研究，生物取样也有所改进（Nelms等人，2019b；Maes等人，2020；Markic等人，2020）。

目前的主要挑战是所有技术相互进行校准，以提高结果的可靠性和可重复性，使数据可用于建模和预测不同生境中海洋垃圾和塑料污染的分布情况和数量（Braun等人，2018；科学专家组，2019；Maximenko等人，2019）。科学家仍然广泛对用于识别和确定环境中微塑料数量的不同实地和实验室技术存在采样偏差感到关切。塑料的尺寸、形状、颜色和降解程度可变性很大，这必然带来难题。质量保证以及采样和分析技术标准化如果没有重大改进，将很难协调已公布的结果，证明其可靠性和可重复性。

由于有数字技术、卫星、飞机和无人机，加上船载传感器、采样器和自主平台（例如浮标、滑翔机、海底着陆器和爬行器）、船舶搭载和建模，因此有可能制订负担得起的全球监测方案，从河流、沿海地区起跟踪海洋垃圾、特别是塑料，一直跟踪到公海和深海深处并确定其密度（Tekman等人，2017；Zambianchi等人，2017；Centurioni等人，2019；Franceschini等人，2019；Maximenko等人，2019；Moltmann等人，2019；Koelmans等人，2019；Lebreton等人，2019；Palatinus等人，2019；Wichmann等人，2019；Lebreton等人，2020；van Sebille等人，2020）。尽管仍然有技术方面的挑战，但此类平台提供的数据对于确定海洋垃圾数量，包括地表水、沉积物和大片河流排放水域中的塑料数量，尤其重要，特别是在结合地面校准时（Garaba等人，2018年；Martínez-Vicente等人，2019；Maximenko等人，2019；van Sebille等人，2020）。

海洋垃圾行动协调		地理范围	活动	应用领域	包括公民科学
海洋垃圾伙伴	海洋垃圾全球伙伴关系	全球	收集/汇编、协调	海滩、海岸线、水柱、海底、生物——摄入的塑料、内陆水体	是
GEOSS	全球综合地球观测系统	全球	收集/汇编、协调	海滩、海岸线、水柱、海底、生物——摄入的塑料、内陆水体	-
-	世界实况地图集	全球	分析、收集/汇编	海滩、海岸线、水柱、海底、生物——摄入的塑料、内陆水体	是
ODIS	海委会海洋数据和信息系统	全球	收集/汇编、协调	海滩、海岸线、水柱、海底、生物——摄入的塑料、内陆水体	-
ODP	海洋数据平台	全球	收集/汇编、协调	海滩、海岸线、水柱、海底、生物——摄入的塑料、内陆水体	是
MDMAP	美国海洋大气局海洋废弃物监测和评估项目	美国西海岸 全球	收集/汇编、协调	海滩	是
MSFD	海洋战略框架指令- EMODnet	欧洲水域	协调	海滩、海岸线、水柱、海底、生物——摄入的塑料、内陆水体	-
EMODnet	EMODnet——欧洲海洋观测和数据网	欧洲水域	收集/汇编、协调	海滩、海岸线、水柱	-
SeaDataNet	泛欧大洋和海洋数据管理基础设施	欧洲水域	收集/汇编、协调	海滩、海岸线、水柱、海底、生物——摄入的塑料、内陆水体	-
数据收集框架					
TIDE	用于教育和解决方案的垃圾信息和数据	全球	收集/汇编	海滩、水柱、内陆水体	是
-	垃圾基地	全球	收集/汇编	海滩、海岸线、水柱、海底、生物——摄入的塑料、内陆水体	是
GGGI	幽灵渔具全球倡议——数据库和应用程序	全球	数据采集、分析、协调	海滩、海岸线、水柱、海底	是
-	资源观察	全球	收集/汇编	海滩、海岸线、水柱、海底、生物——摄入的塑料、内陆水体	是
MEDITS	地中海国际底拖网调查	地中海	数据采集	水柱、海底	-
大规模数据存储库/门户计划					
COASST	海岸观测和海鸟调查小组——海洋废弃物	美国	数据采集	海滩、海岸线、生物——摄入的塑料	是
-	深海废弃物数据库——JAMSTEC*	太平洋和印度洋	数据采集	海底	-
AMDI	澳大利亚海洋废弃物举措数据库	太平洋、大洋洲	数据采集	海滩、海岸线	是
DOME	海洋环境数据门户——海考会数据门户	欧洲水域[1]	收集/汇编、协调	海滩、海岸线、水柱、海底、生物——摄入的塑料、内陆水体	-
DATRAS	拖网调查数据库——海考会数据门户	欧洲水域[1]	收集/汇编	海底	-
-	海洋垃圾观察	欧洲水域	数据采集	海滩、海岸线	是

活动[2]：数据采集、分析、收集/汇编、协调

应用领域[2]：海滩、海岸线、水柱、海底、生物——摄入的塑料、内陆水体

*日本海洋地球科学技术局

[1] 波罗的海、斯卡格拉克、卡特加特、北海、英吉利海峡、凯尔特海、比斯开湾和设得兰群岛至直布罗陀的东大西洋

[2] 包括但不限于

来源：环境署（2021），从污染到解决：全球海洋垃圾和塑料污染评估。

由全球资源信息数据库——阿伦达尔中心绘制

图9: 一些数据协调、收集、存储库和门户举措

目前有15个主要业务监测方案，分布在不同的地理区域，涉及三类活动：协调海洋垃圾行动、数据收集框架以及大规模数据储存库和门户举措（Maes等人，2019）。迄今为止，正在收集的数据和信息基本上仍然互不关联和零散不全，但正在努力实现收集、分析和报告方法的标准化和统一（Maximenko等人，2019；Michida等人，2019）（图9）。

除大规模监测方案外，还在特定地点开展指标工作和基线数据收集活动。它们包括旨在满足联合国可持续发展目标要求的方案，例如可持续发展目标指标14.1.1（富营养化指数和漂浮塑料污染物浓度）（科学专家组，2019）和各项区域海洋公约和行动计划，以及关于海洋垃圾的具体计划（见附件二）。越来越多参与测量和处理海洋垃圾和塑料污染的网络、公民科学项目和参与性进程正在产生有助于地方决策的结果（Hidalgo-Ruiz和Thiel，2015；Wyles等人，2016；González-Fernández和Hanke，2017；Zettler等人，2017；Kandziora等人，2018；Rehn等人，2018；Turrell，2019）。全球海洋垃圾伙伴关系（海洋垃圾伙伴）通过构建多利益攸关方数字平台2来支持各种努力，以便汇编和众包不同的资源，包括创新来源的资源；整合涉及可持续发展目标6（清洁水和环卫）、11（可持续城市和社区）、12（负责任的消费和生产）和14（保护海洋生态）的塑料从源头到海洋整个生命周期的数据；让利益攸关方相互建立联系，以指导和协调行动。

[2].https://digital.gpmarinelitter.org

认证、核查、标签和可追溯性的技术标准

管理海洋垃圾和塑料污染的一个重要内容是制定认证、标签和核查工作的技术标准。就海滩和沿海地区而言，已经有蓝旗方案、优质海岸奖、海滨奖、绿色海岸奖和生态蓝旗等方案。关于塑料产品，在塑料制造和加工方面有一些国际公认的标准以及认证和核查制度。它们涵盖了工业堆肥过程和海洋环境中的生物降解性、再利用和降解等方面（Harrison等人，2018；环境署，2018a；环境署国际消费者协会，2020）。例如国际标准化组织的标准 ISO 15279（塑料废物的回收和再利用）；ISO 22526（碳和环境足迹）；ISO/CD 22722（海洋生境中塑料材料的分解）；ISO 18830（生物降解测试）。然而，对塑料袋的生物降解性进行的审查发现，由于现有测试程序有缺陷，大多数未经管理的水生生境缺乏相关标准以及缺乏在现实情况下对塑料材料的生物降解性进行的更广泛的研究，目前的国际标准和区域测试方法不足以实际预测塑料袋在废水、内陆水域和海洋环境中的生物降解性（Harrison等人，2018）。

此外，制造和加工回收物的核查制度非常少，而且都没有要求列出消费品成分中的聚合物或化学添加剂或提供可追溯性（环境署和国际贸易中心，2017）。缺乏回收物的信息是提高回收率和开发市场的障碍。因此，迫切需要提高塑料的标签标准和可追溯性。举例说，购买受消费者欢迎的被称为“用海洋塑料制成”的产品并不能阻止塑料进入海洋。

塑料产品在其整个生命周期中的可追溯性对于确定何时采取干预措施最有效是必不可少的（艾伦·麦克阿瑟基金会，2016）。近期的进展包括使用区块链技术追踪生产过程中添加到塑料中的化学物质以及供应链上的材料损失（Roos等人，2019）。

减少海洋垃圾和塑料污染的挑战和对策

全球塑料产量在过去的四十年里翻了两番（Geyer，2020）。需求在继续增长，2020年全球塑料市场规模估计在5 800亿美元左右，而2016年估计为5 020亿美元（Statista，2021a）。与此同时，生产出的塑料中估计只有不到10%被再次利用（Dauvergne，2018；Zheng和Suh，2019；Geyer，2020）。.

再利用率如此之低的主要原因之一是缺乏塑料产品成分的信息，质量和价值因不同废物流混合在一起而降低（Leslie等人，2016；艾伦·麦克阿瑟基金会， 2021）。这意味着，包装废物每年会造成大约800-1 200亿美元的损失（艾伦·麦克阿瑟基金会， 2016）。最终，它会导致数百万吨塑料废弃物流失到环境中，或被运往数千公里外的目的地，它们通常在那里被焚烧或倾倒在水道中（环境署，2019a）。

另一个挑战是传统化石燃料塑料在其全球生命周期中排放出的温室气体量；2015年的排放量为17亿吨二氧化碳当量；到2050年时预计将增长到大约65亿吨二氧化碳当量，占全球碳预算的15%（Zheng和Suh，2019）。另一个重要问题是管理塑料垃圾的成本不断上升。据估计，在一切照旧的情况下，全球城市固体废物管理成本将从2019年的380亿美元增长到2040年的610亿美元（Kaza等人，2018）。即使增加税收和政府监管，对资源实行限制，通过储备减少需求（商业研究公司，2020），到2040年时，每年的海洋塑料污染预计会增加两倍（皮尤慈善信托和SYSTEMIQ，2020）。

普通公众、企业和政府的担忧也在增加（Avio等人，2017；Borrelle等人，2017；Maeland和Staupe-Delgado，2020），而COVID-19大流行期间使用的个人防护用品和其他塑料物品产生大量废物，加剧了这种担忧（Adyel，2020）。

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虽然没有一个单独的减少海洋垃圾和塑料污染的全球性条约（Muirhead和Porter，2019；Karasik等人，2020；Raubenheimer和Urho，2020），许多全球、区域和国家承诺和活动正在帮助动员国际社会根除海洋塑料污染（环境署，2018b）。例如，市政主管部门和大公司一直在减少流向垃圾填埋场的废物（Dauvergne，2018），在塑料构成风险的证据越来越多和公众压力的推动下，监管工作也在扩大（Koelmans等人，2017a；科学专家组，2020a）。地方人士的活动和地方政府的行动激增，以增加路边收集和回收、社区清理和提高认识活动（Schneider等人，2018）。在地方和国家一级取得成功的同时，区域和国家一级也开展直接减少海洋垃圾和塑料污染的立法工作（Black等人，2019）。

现有的各项国际承诺包括旨在减少塑料污染和海洋垃圾、特别是来自陆地的污染和垃圾的承诺，例如，作为《2030年可持续发展议程》目标14的一部分的承诺，以及各项具有约束力的国际协定、公约、议定书、举措和合作进程（联合国大会，2015；环境大会，2017）（图10）。其中有《联合国海洋法公约》（《海洋法公约》）；《国际防止船舶造成污染公约》（《防污公约》）、《防止倾倒废物及其他物质污染海洋的伦敦公约》和防止向海洋环境倾倒含有塑料或类似合成材料的废物流的《伦敦议定书》；《控制危险废物越境转移及其处置巴塞尔公约》；《关于在国际贸易中对某些危险化学品和农药采用事先知情同意程序的鹿特丹公约》；《关于持久性有机污染物的斯德哥尔摩公约》（Chen，2015；Raubenheimer和McIlgorm，2018）。还有其他适用的国际协定和软法律文书，其中涉及塑料贸易或支持减少海洋垃圾。它们包括世界贸易组织（世贸组织）；《生物多样性公约》；《保护野生动物迁徙物种公约》；粮食及农业组织（粮农组织）的《负责任渔业行为守则》和《联合国鱼类种群协定》；《保护海洋环境免受陆上活动污染全球行动纲领》（环境署/全球行动纲领，2020）；檀香山战略；国际化学品管理战略方针（化管方针）（Lyons，2019；Birkbeck，2020；Borrelle等人，2020；皮尤慈善信托和SYSTEMIQ，2020）。

区域安排在加速采纳政策和倡议方面发挥着至关重要的作用。对海洋垃圾和塑料来说，[3] 最重要的是区域海洋公约和行动计划，其中包括各种减少海洋垃圾和塑料污染的措施，以及监测和提高公众认识运动（环境署，2018b）。在非洲，约有30个国家根据与《巴塞尔公约》、《鹿特丹公约》和《斯德哥尔摩公约》相关的区域文书《巴马科公约》，商定加强对包括塑料和电子废物在内的危险废物的管理。一些国家行动（例如，专门针对塑料购物袋、含有塑料微珠或塑料瓶的产品的行动或反垃圾运动）可以帮助减少某些类别的塑料污染（Xanthos和Walker，2017；Dauvergne，2018；Schuyler等人，2018）。此外，海洋保护区和沿海区管理政策也是减少废物的重要政策工具，在整个流域或生态系统采取的政策尤其是这样（Windsor等人，2019）。

总的来说，目前是一个情况混杂的局面：商业做法各不相同，塑料产量不断增加，国家监管和自愿安排差别很大。各国之间几乎没有政策协调，国家和国家以下各级的政策不一致，存在漏洞，执行情况时好时坏，标准不一（Dauvergne，2018；Forrest等人，2019；Birkbeck，2020）。越来越多的废弃塑料废物是市场多重失灵的产物，这些市场失灵与下列因素有关：化石燃料原料价格低，存在补贴，废物管理欠佳，塑料回收物产量和使用量低，用完丢弃的行为普遍存在（Law，2017；环境署，2019b；Borrelle等人，2020；皮尤慈善信托和SYSTEMIQ，2020）。

随着应对海洋垃圾和塑料污染危机的压力和复杂性增加，有必要通过开展治理流程来应对，这一流程应考虑到情况的严重性并帮助从全球角度来看待这一问题（Borrelle等人，2017；Dauvergne，2018；Schneider等人，2018；Forrest等人，2019；Maeland和Staupe-Delgado，2020）。但2000年后商定的各项国际政策缺少一个限制海洋垃圾和塑料污染的具有约束力的具体和可衡量的全球目标，致使一些国家政府、企业和民间社会呼吁制定一项关于海洋垃圾和塑料污染的具有约束力的全球条约（Muirhead和Porter，2019；Karasik等人，2020；Raubenheimer和Urho，2020；世界自然基金会、艾伦·麦克阿瑟基金会和波士顿咨询公司，2021）。

没有一个单独解决方案战略可以在2040年前将每年向海洋泄漏的塑料减少到哪怕是低于2016年的水平（Borrelle等人，2020；Lau等人，2020）；相反，上游和下游都将需要协同采取一些系统性干预措施（皮尤慈善信托和SYSTEMIQ，2020）。例如，在没有塑料废物定价政策的情况下（Matheson，2019），政府可以利用各种财政工具，如税收、收费、押金退还制度、生产者延伸责任制度、可交易许可证制度和补贴来加强废物管理

[3] 一些区域海洋公约和行动计划有具体的海洋垃圾计划，其他行为体也是如此。见附件二。

（Xanthos和Walker，2017；经合组织，2019；Parts，2019；Walker等人，2020）。可能需要调整这些工具以处理塑料问题。例如，人们普遍认为生产者延伸责任是废物政策的基石（Filho等人，2019），但用它来减少塑料垃圾的关键则是鼓励有关行业提高可回收性和推行生态设计（Forrest等人，2019）。可以通过更多地披露塑料产品中使用的树脂、化学品和添加剂，指导消费者和废物中介安全进行再利用或处置，向实现这一目标迈出一步。

全面减少塑料污染产生总量将意味着逐步淘汰特定的塑料产品，引入生产者延伸责任，并转变已建立的提取-制造-处置线性经济，使其中的材料流动遵循闭环、资源效率高或循环等方法（欧盟委员会，2018b；Lieder和Rashid，2015；经合组织，2016；欧洲联盟，2019b；Forrest等人，2019；环境署，2019a；Karasik等人，2020；Raubenheimer和Uhro，2020）。

将需要在多个层面上共同努力才能实现塑料的循环（国际资源委员会，2021）。这些努力需要结合实际情况，把业务流程和社会意识与政策和消费者行动联系起来，以大幅度减少用化石燃料生产的塑料的产量；改进产品设计以减少浪费；加强材料的分散回收（Joshi等人，2019）；消除不必要、可避免和有问题的塑料废物流；改进可生物降解塑料等材料的监管标准（Dauvergne，2018；Carney　Almroth和Eggert，2019；Forrest等人，2019；Zheng和Suh，2019；Borrelle等人，2020；Lau等人，2020；皮尤慈善信托和SYSTEMIQ，2020；环境署和国际消费者协会，2020；艾伦·麦克阿瑟基金会，2021；国际资源委员会，2021）。

人们对塑料污染引起的问题的态度转变促使政治家和行业考虑如何通过原料替代和增加消费者再利用选项来推行旨在维持塑料在经济中的价值的方法（艾伦·麦克阿瑟基金会，2016；环境署和国际贸易中心，2017；ten　Brink等人，2018；Borrelle等人，2020；Lau等人，2020；皮尤慈善信托和SYSTEMIQ，

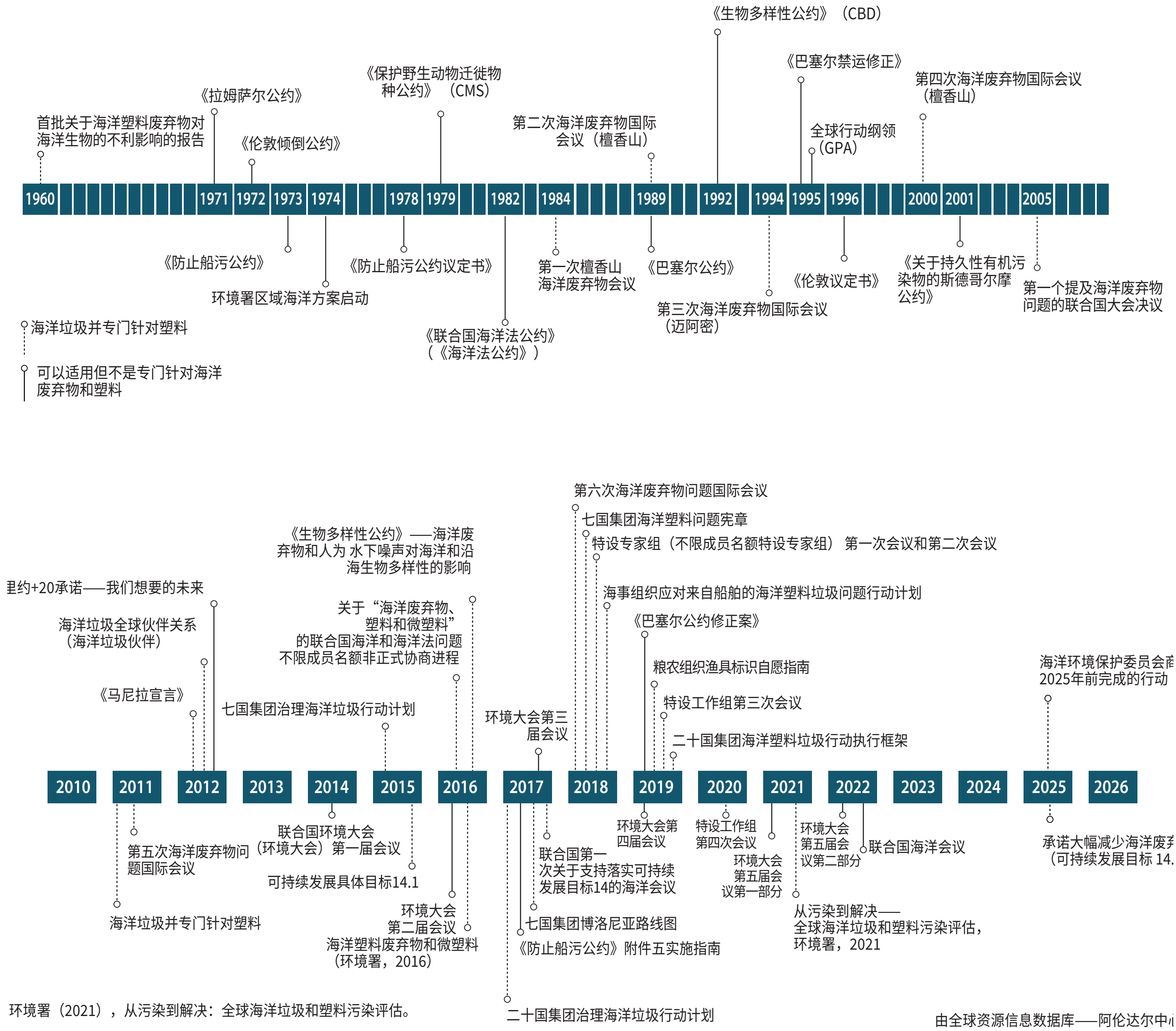

图10：某些国际海洋垃圾和塑料污染举措、法律和政策的时间表


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2020；环境署和国际消费者协会，2020）。许多全球品牌公司已经制定了计划，改变其包装使用方法，与国家收集和回收制度保持一致，使所有包装都可以重复使用、再生或回收。巴塞尔塑料废物伙伴关系、全球海洋垃圾伙伴关系、新塑料经济全球承诺和国家塑料行动伙伴关系等伙伴关系可以通过使废旧塑料变成有价值的商品来展示循环回收的作用，鼓励回收以及加快实现从聚合物到聚合物技术的工业化，来帮助推动经济和社会朝着这个方向发展（Forrest等人，2019；埃伦·麦克阿瑟基金会，2020）。

若干举措旨在通过以下方式"关掉原生塑料生产的水龙头"（Birkbeck，2020；Borrelle等人，2020；皮尤慈善信托和SYSTEMIQ，2020）：淘汰、扩大消费者再利用选项，或提供新的交付模式，并结合其他战略，如替代、改进收集和回收，以及安全处置残余废物，以最大限度地减少塑料污染流。此类举措有可能最大程度地减少塑料污染；为消费者和生产商产生成本净节约，同时减少温室气体排放（皮尤慈善信托和SYSTEMIQ，2020）。一些行动，例如增加生物产品的数量，可能会高度依赖农业（Posen等人，2017；Spierling等人，2018）。或者，绿色化学可以通过设计比目前市场上产品更容易回收和向上循环的分子、材料和产品，帮助对非化石燃料材料作出重大改进（环境署，2021）。

数百种不同塑料聚合物和产品的生产使塑料的回收潜力复杂化（Geyer等人，2016；Zink等人，2018）。目前的回收率（不到所有塑料废物的10%）远低于全球其他商品和资源的回收率（Dauvergne，2018；Geyer，2020）。塑料目前通过机械和化学方式回收。机械回收用于非纤维塑料，越来越多地用于回收聚酯纱线。化学回收综合采用各种把塑料变燃料和塑料变塑料的技术，把塑料转化成可用于制造新塑料的液体或气体。大多数再生尼龙来自制造业废物和消费后废物，如渔网和地毯。

即使扩大使用范围，它也只能解决垃圾总量的一小部分，且能源需求很高（皮尤慈善信托和SYSTEMIQ，2020）。

尽管对海洋垃圾和塑料污染所有方面的研究在迅速增加，但Maes等人（2019）认为，大部分研究仍"处于青春期"。他们发现，关于风险评估、塑料碎裂和评估工具的研究不多。

在存在不确定性时，例如塑料中的化学品的潜在风险（Burns和Boxall，2018），需要相互校准方法和技术，或需要采用综合方法时，这尤其重要（Temmerman等人，2013）。还需要开展研究，根据证据和有的放矢的严格风险评估，为政策分析和评估提供答案和投入（Hurley和Nizzetto，2018；Besselling等人，2019；Karn和Jenkinson，2019；Maeland和Staupe-Delgado，2020）。

总的来说，目前的知识状况可以提供合理的依据，用来确定一般研究优先事项，并确定那些虽有政策和社会需求但研究和发展资金有限的领域（de Sá等人，2018；Carney Almroth和Eggert，2019；Maes等人，2019）。消除海洋垃圾和塑料污染需要多学科的综合研究，并需要不同专业领域和行业的学术研究人员和专业人员的广泛合作。

根据评估结果可以确定一些将从进一步调查获益的系统领域。它们包括一些贯穿不同领域的问题，如性别平等问题和交织性问题（年龄、边缘化和弱势群体），特别是涉及接触、健康影响、对新的创新技术的态度和海洋知识了解程度的问题，因为在这些领域的同行审查文献中，几乎没有任何研究发表；此外，还有以下问题：

- 评估主要塑料产品的整个生命周期，包括海洋塑料、微塑料和纳米塑料对环境和健康的影响、社会和经济成本、生态系统服务的丧失、新材料的潜在影响、塑料和替代品对不同性别的影响，以及塑料中的化学品在食品生产、水产养殖、农业和食品安全方面的风险和影响；
- 根据海洋垃圾和塑料污染从源头到海洋的整个生命周期来制定涵盖生态、社会、经济和健康影响的风险框架；
- 制订用于确定人类和野生生物在水环境中接触微塑料情况所需要的健康和毒理学标准和测试；
- 采用开放存取平台，以便能够建立关于海洋垃圾和塑料的全球性质量平衡模型，以及建立关于从河流、废水处理厂、废物管理、因灾难性事件从雨水沟排出的径流和海事部门进入海洋环境的塑料的通量和流量的全球性质量平衡模型；
- 建立信息学和统一的监测框架，包括制订取样、实验室测试和收集数据的标准方法，对以下各项进行量化：进入环境的塑料的通量和流量、塑料和微塑料的分布情况以及塑料污染产生的微塑料和添加剂在环境中的毒理学，以便能衡量不同干预措施和缓解工作的效力和影响；
- 在关于驱动因素-压力-状况-影响-对策的框架内确定从源头到海洋的各项核心指标集，以监测减少海洋垃圾和塑料污染方面的进展；
- 开展绿色化学创新，最大限度地减少添加剂的使用，采用全生命周期方法开发更安全、更易于处置或回收的替代聚合物和材料，包括生物材料，并寻找转用替代品的途径；
- 在所有广泛使用塑料的主要行业中制定生态设计原则，并制定成本路线图；
- 开发可在塑料废物来源附近使用的小规模废物管理和回收技术，以帮助防止或减少塑料泄漏到环境中；
- 为所有消费者用途塑料制定关于塑料的认证、可追溯性和标签制度、包括生物降解性的标准；
- 对减少塑料（包括微塑料）的有效措施进行政策研究，如生产者延伸责任制度、加强财政工具、所有消费者用途塑料的认证、可追溯性和标签制度的标准，鼓励开展生态设计和绿色化学以开发新的材料；
- 评估海洋垃圾和塑料污染涉及的社会问题，包括性别、消费者认知和社会驱动因素，同时采用基于人权的办法，包括有意义的公众参与和获得补救；
- 制定扫盲和教育方案，提高对海洋垃圾和塑料污染问题的认识，帮助改变人类的行为，从而减少对塑料废物的不当管理；
- 行为经济学和关于知识获取以外的推动、规范和教育工作的教育研究，以便推动行为的改变。

结论

本报告强调迫切需要在各级采取行动，处理海洋垃圾和塑料污染问题。

要找到解决海洋垃圾和塑料污染问题的办法，就需要民间社会、企业、行业和政府更多地参与，在政策、态度和做法方面做出必要的改变（Uyarra和Borja，2016；Hartley等人，2018b；Ashley等人，2019）。公民要继续发挥重要作用，包括采取行动和改变自己的行为，以便大幅减少海洋垃圾和塑料污染。需要进行此类变革的企业和行业将包括石油和天然气开采者和塑料树脂生产商、挤出机和产品制造商、汽车制造商和纺织品制造商、消费品公司、包装企业、零售商、废物运输者和填埋者、材料回收经营商、废物中介和废物回收者。政策制定者有机会创建适当的立法和财政工具组合，鼓励进行更广泛的披露，支持数据共享和数据透明，提供融资，建立透明和有效的监管环境，协助开展研发，以便应对海洋垃圾和塑料污染的挑战。

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附件一：理由说明

联合国环境大会（环境大会）在历届会议上通过了几项关于海洋垃圾和塑料污染的重要决议45。环境署于2016年发表了一份题为"海洋塑料废弃物和微塑料：激发行动和指导政策变化的全球经验教训与研究"的报告（环境署，2016）。报告重点提出相关主要来源和途径以及防止海洋垃圾和微塑料在海洋环境中积累的可能措施和最佳可得技术及最佳环保做法。

2019年，环境大会要求环境署执行主任提供一份2016年评估报告的增订，根据"现有的科学数据和信息和其他相关数据信息"，评估"……垃圾的来源、路径和危害、包括塑料垃圾和微塑料污染及河流与海洋中的这类污染、关于生态系统遭受不利影响的科学知识、可能对人类健康产生的不利影响以及无害环境的技术创新"，以此"加强关于海洋垃圾、包括海洋塑料垃圾和微塑料的科学和技术知识"。

新的2021年评估报告《从污染到解决：全球海洋垃圾和塑料污染评估》阐述了问题的规模和严重性，并审查了现有的解决办法和行动。它针对海洋生物受到的直接影响、对生态系统和人类健康构成的风险以及社会和经济成本方面的现有研究和知识空白，全面介绍了最新情况。评估报告尽可能地描述和量化了海洋垃圾和塑料污染的来源及其进入海洋和在海洋中的直接和间接路径，并列举了监测系统、观测技术和分析方法的改进。它概述了不同行动和政策、包括补救工作的潜在效力以及一系列经济、技术和立法解决方案。

4 UNEP/EA.1/Res.6：海洋塑料废弃物和微塑料（2014）；UNEP/EA.2/Res.11：海洋塑料垃圾和微塑料（2016）；UNEP/EA.3/Res.7：海洋垃圾和微塑料（2017）；UNEP/EA.4/Res.6：海洋塑料垃圾和微塑料（2019）；UNEP/EA.4/Res.9：治理一次性塑料制品污染（2019）。

附件二：区域海洋垃圾行动计划[5]

名称	组织/实体	年份	链接
北极海洋垃圾区域行动计划	保护北极海洋环境（PAME）	2021	https://digital.gpmarinelitter.org/action_plan/10017
波罗的海海洋垃圾区域行动计划	赫尔辛基公约/波罗的海海洋环境保护委员会（HELCOM））	2015	https://digital.gpmarinelitter.org/action_plan/197
黑海海洋垃圾区域行动计划	布加勒斯特公约/保护黑海免受污染委员会	2018	https://digital.gpmarinelitter.org/action_plan/194
海洋垃圾区域行动计划	东亚海洋协调机构（COBSEA））	2019	https://digital.gpmarinelitter.org/action_plan/196
地中海海洋垃圾管理区域计划	保护地中海免受污染公约（巴塞罗那公约）/地中海行动计划	2013	https://digital.gpmarinelitter.org/action_plan/198
东北大西洋预防和管理海洋垃圾区域行动计划	奥斯巴委员会/保护东北大西洋海洋环境公约》	2014	https://digital.gpmarinelitter.org/action_plan/201
西北太平洋海洋垃圾区域行动计划	西北太平洋行动计划（NOWPAP）	2008 预计2021年更新），	https://digital.gpmarinelitter.org/action_plan/200
太平洋区域行动计划——海洋垃圾（2018-2025年）	努美阿公约/太平洋区域环境方案秘书处（SPREP）	2018	https://digital.gpmarinelitter.org/action_plan/205
红海和亚丁湾可持续管理海洋垃圾区域行动计划	保护红海和亚丁湾环境区域组织（PERSGA）	2018	https://digital.gpmarinelitter.org/action_plan/203
南亚海域海洋垃圾区域行动计划	南亚合作环境署（SACEP））	2019	https://digital.gpmarinelitter.org/action_plan/204
东南太平洋区域的海洋垃圾	南太平洋常设委员会（CPPS）	2007	https://digital.gpmarinelitter.org/action_plan/238
西印度洋海洋垃圾区域行动计划	内罗毕公约	2018	https://digital.gpmarinelitter.org/action_plan/199
大加勒比区域海洋垃圾管理区域行动计划	卡塔赫纳公约 – 环境署加勒比环境方案（CEP）	2014	https://digital.gpmarinelitter.org/action_plan/195
东盟成员国打击海洋废弃物东盟区域行动计划	东南亚国家联盟（ASEAN）	2021	https://digital.gpmarinelitter.org/action_plan/10008
七国集团打击海洋垃圾行动计划	七国集团	2015	https://digital.gpmarinelitter.org/action_plan/190
二十国集团海洋垃圾行动计划	二十国集团	2017	https://digital.gpmarinelitter.org/action_plan/191
解决船舶海洋塑料垃圾问题的行动计划	国际海事组织（IMO）	2018	https://digital.gpmarinelitter.org/action_plan/237
亚太经合组织海洋废弃物路线图	亚洲太平洋经济合作组织（APEC）	2019	https://digital.gpmarinelitter.org/project/177

5 里海、东北太平洋、非洲西部、中部、南部区域正在制定海洋垃圾区域行动计划草案。

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