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Baseline

Case report of plastic nurdles pollution in Galicia (NW Atlantic) following the Toconao's spill in December 2023: The VIEIRA Collaborative

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ABSTRACT

Plastic nurdles pose a significant environmental threat due to recurrent accidental spills into marine ecosystems. This report examines the nurdle pollution over the 1498 km of the Galician coastline (Spain) following the spill of 25 t of nurdles into the Northwest Atlantic after the loss of six containers from the Toconao vessel in December 2023. This accident highlights the urgent need for proactive, effective measures in maritime transport to prevent and mitigate such environmental catastrophes. The complexity of nurdle dispersion challenges the evaluation of their fate at sea, and the potential long-term consequences on the marine ecosystem and food web remain uncertain and yet to be investigated. This report also presents the VIEIRA collaborative and underscores the critical role of citizen-led initiatives in responding to such environmental disasters, and advocates for efficient policy reforms, involving cross-border collaboration. Furthermore, we call for greater international cooperation to underpin effective regulatory frameworks to address the growing hazard of plastic nurdle pollution worldwide.

1. Introduction

Plastic nurdles (or pellets) are the raw material commonly used in the production of many thermally molded plastic products. Nurdles can feature different sizes, colors and shapes, although white or transparent nurdles with cylindrical or disk shapes of up to 5 mm in diameter are the most common ones (Turner and Holmes, 2011; Yeo et al., 2015). In Europe alone, more than 60,000 companies use them at some stage of the plastic supply chain ("Transforming the Global Plastics Economy | GEG", n.d.). Since the 1970s, plastic pellet pollution has been reported at beaches worldwide, with varying concentration depending on proximity to and nature of the source, sediment characteristics or tidal dynamics (Harris, 2020). In 2023 the European Commission estimated that between 52 and 184 thousand tonnes were damped yearly in water bodies across the European Union due to mishandling throughout the plastic supply chain ("Reducing microplastic pollution from plastic pellets", n. d.). Nurdles may be accidently or purposely introduced into the environment at any stage of the plastic supply chain (i.e., from production to transportation to recycling), and are transported either by river streams that may eventually discharge them into the sea, or directly dumped into

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the sea, where tidal currents and wind drive their transport (Díez-Minguito et al., 2020; Lofty et al., 2023b; Nava et al., 2023; Turra et al., 2014).

Plastic nurdles are known to have negative impacts on natural ecosystems. First, they pose a risk to wildlife. For instance, marine mammals, fish, and birds may ingest them (Lim et al., 2022; Lin et al., 2023; Savoca et al., 2021; Thiel et al., 2018), which may eventually lead to harm or death (Ahrendt et al., 2020; Beck and Barros, 1991; Charlton-Howard et al., 2023; Gall and Thompson, 2015; Naidoo and Glassom, 2019; Santos et al., 2015), and shellfish and small invertebrates may be exposed to higher amounts of micro and nanoplastics (Setälä et al., 2014; Wang et al., 2020; Ward et al., 2003; Ward and Shumway, 2004) following nurdles' mechanical breakdown (Costa et al., 2010). Additionally, nurdles can be entrained into the sediment bed, with the risk of endangering benthic ecosystems and habitats (Lofty et al., 2023b, 2023a). In addition to the negative consequences on the natural environment, nurdles may pose a risk to human health. First, eating fish and seafood which ingested pellets is a concern (Neves et al., 2015; Rochman et al., 2015; Van Cauwenberghe and Janssen, 2014), although its threat to human health is yet to be studied. Also, pellets have been reported to enable attachment of toxic substances (Pozo et al., 2020) and organic pollutants that can concentrate 1000,000 times more on nurdles' surface than on water (Thacharodi et al., 2024). Additionally, pellets may act as fomites of human pathogens such as *Escherichia coli* and *Vibrio* spp., which were found in pellets collected from public bathing beaches in the UK (Rodrigues et al., 2019). A better understanding of the effects of microplastics on human health is urgently needed ("Microplastics are everywhere — we need to understand how they affect human health", 2024). Importantly, a recent study in patients of carotid artery disease found that those who showed microplastics and nanoplastics in carotid

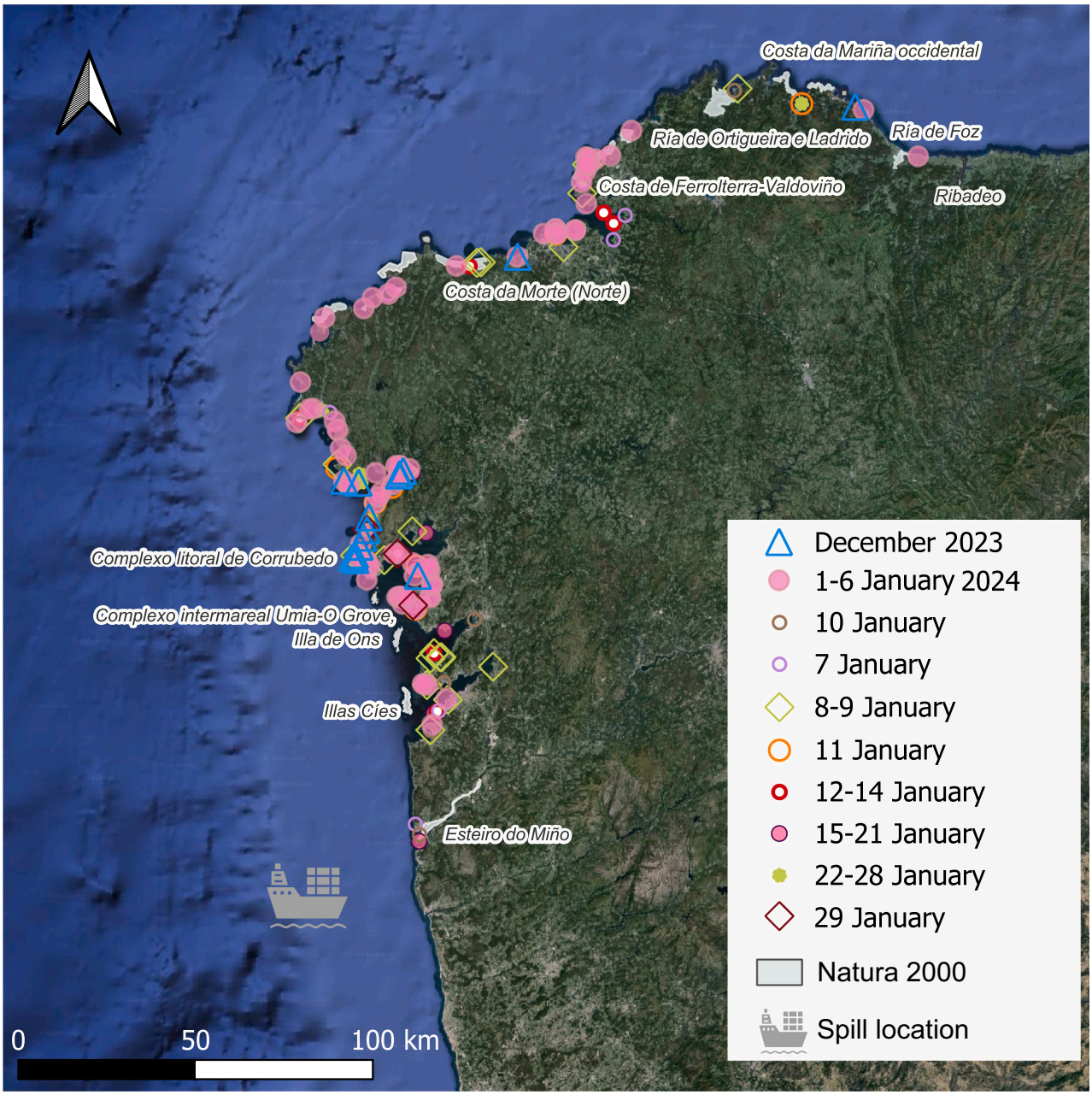

Fig. 1. Schematic showing beaches around the Galician coastline that reported contamination of plastic pellets from the Toconao's spill. For the timespan shown, nurdles were present for over 1498 km of shoreline.
Data collected by "Unha vez máis" volunteers (Unha Vez Máis, 2024) shown up to end of January 2024.

artery plaques had a higher risk of cardiovascular disease or all-cause death in comparison with patients with undetectable plastics in carotid artery plaques (Marfella et al., 2024), but these would come from a variety of sources.

Although major spills do occur, few large-scale disasters have been reported following the accidental release of plastic nurdles to the marine environment during their transport via shipping containers. These accidents have affected countries across the globe such as South Africa, the US and European countries such as France, Denmark, Norway, Sweden, the Netherlands, Belgium, and Spain (Surfrider Foundation Europe and Rethink Plastic alliance, 2020). The worst reported disaster to-date occurred in Sri Lanka in 2021, with more than 1670 t of plastic nurdles polluting its coast and territorial waters and propagating deeply within the sediment bed (Jayathilaka et al., 2022). Here, we report a new accidental release of 25 t of plastic nurdles transported in six containers lost from the Toconao vessel, which initially polluted the Galician coastline (Northwestern Spain). We have built a citizen-led platform with three aims: i) to raise awareness of this recurrent problem (i.e., likelihood of pellet contamination due to naive transport restrictions) that continues to threaten the marine and coastal environment; ii) to generate rigorous evidence on its consequences; and, iii) to inform policies to both prevent plastic pellet pollution and produce mitigation protocols following an accidental spill.

2. Case study: Toconao's spill, Galician coastline, December 2023

2.1. Overview

On 8th December 2023, the Liberia-registered vessel Toconao, chartered by the shipping company Maersk, lost six containers overboard while sailing from Algeciras (Southern Spain) to Rotterdam (The Netherlands). The accident took place in Portuguese territorial waters, specifically 80 km West of Viana do Castelo (Fig. 1). One of those containers held over 1000 sacks, each containing over 25 kg of plastic nurdles manufactured by the Indian company Coraplast. According to authorities and media coverage, the vessel reported the accident to Portuguese authorities, and these gave notice to Spanish authorities and the European Maritime Safety Agency on the same day of the accident. However, as the lost freight (e.g., pneumatics, aluminium bars, cling film rolls, and tomato paste) was not listed in the International Maritime Dangerous Goods Code, pollution alarms were not triggered (IMO, 2022).

2.2. Polluted beaches

Following the spill, tonnes of plastic nurdles have washed up along the Galician shore, including protected beaches and coastal areas. Forecasting the fate of the particles is complex due to the particular Galician coastline, featuring numerous rias, which show complex intertidal dynamics derived from the discharge of freshwater from rivers and the presence of large wet-dry areas (Jalón-Rojas et al., 2024). The first evidence of pellet presence in the Galician coastline was in Corrubedo (Ribeira municipality), where the competent authorities were alerted on 13th December 2023 and collected 40 and 18 sacks (1.5 t of nurdles) in the first and second day, respectively. This occurrence was followed by Espiñeirido, Seráns, As Furnas (Porto do Son municipality), O Vilar and A Ladeira beaches (Ribeira municipality) on that same day. This stretch of the coastline is part of the European Special Area of Conservation "Complexo Húmido de Corrubedo". Volunteers monitored the dispersion of nurdles at polluted beaches in the weeks following the incident (Fig. 1; "Unha Vez Máis", 2024). By 3rd January 2024, nurdles had already arrived at beaches in Muros municipality, and spread both North and South of the Ría de Muros-Noia on the weekend of 6th and 7th January 2024. As of 10th January 2024, plastic nurdles were still found in Galician beaches and had spread to neighbour regions in northern Spain (Asturias, Cantabria and Euskadi).

Official records from Galicia's local Government indicated that, by 15th January 2024, an equivalent to 92 25-kg sacks of dispersed nurdles (2.3 t) had been collected, with an additional 4.2 t of other plastics also retrieved at beaches. Thus, 18.5 t of pellets remain stranded.

2.3. Chemical composition: knowns and unknowns

The spilled sacks were labelled as "UV9000 light stabilizer", which posed potential toxicity concerns. The official composition of the spilled nurdles consisted of 87–90 % polyethylene (Chemical Abstracts Service, CAS, number 25087-34-7) and 10–13 % UV622 additive (CAS number 65447-77-0) ("Composición química del vertido de pellets en Galicia | ECOTOX", n.d.). UV622 is a non-biodegradable polymer containing a synthetic substance (CAS 52722-86-8) classified by the European Chemicals Agency as a substance with long-lasting harmful effects on aquatic life and which causes serious eye irritation, skin irritation, and may cause respiratory irritation ("Substance Information - ECHA", n.d.).

The University Institute of Environment at the University of Coruña (Spain) and the Chromatography and Chemometrics Research Group at the University of Santiago de Compostela analysed pellet samples from the first polluted beaches, and detected compounds (Supplementary material, Table S1) not declared in the product specification sheet ("Análise cualitativa de tres mostras polo ChromChem (USC) en Plan CAMGAL", n.d.; Instituto Universitario Medio Ambiente, 2024). According to the certificate of compliance, the declared substances, in low concentrations, were pentaerythritol tetrakis (CAS 6683-19-8; with long-lasting harmful effects on aquatic organisms; "Brief Profile - ECHA", n.d.) and phosphorous acid (CAS 31570-04-4; currently classified as under assessment as Persistent, Bio accumulative and Toxic). ("Avaliación da ficha de seguridade de UV9000. CETIM en Plan CAMGAL", n.d.). However, we believe that further work should be conducted to elucidate the possible impacts of these substances, generating more evidence for future regulations.

In addition to the unknown consequences of nurdles' composition, their physicochemical degradation from environmental factors may pose further risks, as seen in the X-Pearl disaster in Sri Lanka (Perera et al., 2022). The potential long-term hazards of these plastic pellets and their derivatives need to be investigated.

2.4. Dynamics and dispersion in the marine environment: knowns and unknowns

Collected samples of the plastic nurdles released during the Toconao incident have shown they are positively buoyant (i.e., lower density than that of the water: 0.9865 kg/m^3), with a nearly cylindrical shape (Fig. 2). Thus, these plastics are transported by (Jalón-Rojas et al., 2024; Lofty et al., 2023b): i) tidal currents, not too strong near the area of the accident; ii) wind, predominantly from the West and South West directions; and, iii) waves, data from a buoy at Cabo Silleiro shows significant wave heights of approximately 8 m at the time of the accident.

As floating particles, nurdles will continue to disperse over the water surface until biofilm grows on their surface. This growth can lead to an increase in density, eventually causing them to sink to deeper levels (Núñez et al., 2023). However, ocean waves could also enforce their horizontal and vertical transportation and drive the entrainment and mixing of microplastics with sediments. These embedded plastics may remain in the seabed for a long time, affecting the benthic ecosystem (Sewwandi et al., 2022). Beaches with coarser sediments will enable plastic nurdles to penetrate the seabed more easily than fine-grain beaches (Karkanorachaki et al., 2018). The latter, being flatter, have a sparser spatial distribution of plastics, and consequently nurdles may undergo an eventual resuspension, which would lead to a never-ending ecological accident.

Fig. 2. Image of the plastic nurdles from the Toconao's spill collected at Mexilloeira beach (Ria de Arousa). Collected pellets were white and had an irregular shape. Microscopy photography (close-up on the left) taken with an Olympus CH30 Microscope at 40× magnification.

2.5. Unknown environmental consequences

Most of Galician coastline belongs to the European Natura 2000 network of protected areas (e.g., the Atlantic Islands of Galicia National Park and the "Complexo Húmido de Corrubedo") ("Natura 2000 - European Commission", n.d.). Galicia's shore gathers a great biodiversity of marine organisms and macrophytes. This is partly promoted by a large phytoplanktonic upwelling, linked to a rich socio-ecological history as a global hotspot for aquaculture, particularly for the shellfish industry (Iribarren et al., 2010). In this sense, the oceanographic characteristics of the impacted area are altered (e.g., surface current velocities, surface temperature and upper-water column salinity), affecting the abundance and distribution of microplastics (Iribarren et al., 2010; Liu et al., 2022). These characteristics, in conjunction with the presence of microplastics, may enhance the possibility of organisms interacting with these pollutants. Also, as consequence of those factors, the toxicity of microplastics on zooplankton may also increase (Lins et al., 2022). Considering the inter- and intra-annual variation in salinity and temperatures in the Galician rias (Alvarez et al., 2005) and the climate change effects, the Toconao's nurdles may be more toxic to organisms at the base of marine food webs and affect the entire ecosystem (Tuuri and Leterme, 2023). In algae, microplastic adsorption could alter growing, photosynthetic and oxygen exchange. Certain phytoplankton species could be affected by microplastics reducing their reproduction rate, and thus impact the whole food chain and ecosystem dynamics (Hitchcock, 2022).

Ingestion of plastic particles can lead to clogging or damage of the digestive system of some marine animals (e.g. intertidal fish *Girella laevifrons*) causing a physical and ecological downgrading (Ahrendt et al., 2020). Furthermore, smaller plastic particles obtained from the weathering of plastic nurdles (Andrady, 2011) and their derived pollutants and byproducts can enter the trophic chain via ingestion by filter- and deposit-feeders (e.g., bivalves), which may ingest them due to their low selective feeding behavior (Browne et al., 2008). Additional risks may be linked to the environmental and biotic degradation of additives contained in plastic pollutants resulting in toxic compounds (Gómez et al., 2023; Page et al., 2022). For instance, leachates originating from plastic debris have been shown to inhibit intertidal mussels' ability to self-organize and produce byssal threads. In addition, more evidence has been provided on the impact of the chemical compounds from marine debris leachates by means of different toxicity tests (Zardi et al., 2024).

Persistent emerging pollutants, such as those derived from pharmaceutical and personal care products (Atugoda et al., 2021), have already been detected in Galicia's estuaries and coastal waters (Montes et al., 2023), and these may concentrate on the nurdles surface, considering other studies (Thacharodi et al., 2024). Also, the ability to act as fomites of potential human and marine pathogens is worrisome, especially regarding antibiotic resistance genes (Magalhães et al., 2024).

Beyond the environmental risk posed by the nurdles themselves, beach clean ups may have an indirect negative impact on the local ecosystem (i.e., disturbing sensitive species in the *epi* and meiofauna or shorebirds), particularly in protected areas (Zielinski et al., 2019).

2.6. Social impact and community response

The Toconao's environmental disaster led to the rapid self-organization of thousands of citizens and community-led clean ups, which were supported by local workers at some of the polluted beaches. Hundreds of volunteers organized themselves using social networks (accurate numbers are difficult to ascertain) to protect the Galician coastline and sea, and to protest against the lack of a coordinated response by the responsible authorities. Most citizens joined virtual communities and channels during the first week of January 2024.

This citizen movement is named by some as "Unha vez máis" (*Once Again*) which refers to the previous social movement "Nunca Máis" (*Never Again*), a symbol for the Galician community in the face of the inaction and passivity of governmental bodies (Aguilar Fernández and Ballesteros Pena, 2005). The movement started as a civic platform after the Prestige environmental catastrophe (oil spill) in November 2002 (Diz Otero and Lois González, 2005). The 2024 movement returns to the idea that environmental disasters affecting the sea and traditional socio-economic systems, together with administrative and political silence, threaten the future of younger generations and part of the Galician identity. In fact, an alternative name is "En defensa do noso mar" (*In defense of our sea*). However, this new lexical variation also reflects the public discontent with the governmental bodies and legislative frameworks that deal with this type of crisis. Additionally, the rapid engagement of citizens may respond to both current habits of communication via the most popular social networks (non-existent back in 2002), and

the growing concerns for the environment worldwide.

Some volunteers from the groups organizing the clean ups through social networks joined forces to start the *Volunteer Initiative for Environmental Innovation and Research of the Atlantic* (VIEIRA) collaborative, which has two aims: (i) to generate/collect robust evidence and generate rigorous reports to inform policy; and (ii) to conduct multidisciplinary research related to both this case of pellet pollution, and its consequences on nature, health, and society (Supplementary material, Table S2, Fig. S1). Collaborators were recruited using an online form shared on those virtual networks, and include from citizen scientists to researchers in related topics.

2.7. Responsibilities, causes and corrective measures

A sequence of undesired events needs to be acknowledged: a lack of nurdle stowage regulations, the slow information flow from the ship operator, the reduced transparency from the official authorities and their slow reaction, and the absence of protocols for this kind of environmental disasters (Saliba et al., 2022).

The Toconao's spill started to be investigated by "Salvamento Marítimo" on 13th December 2023, when the firsts nurdles were found in the Galician coastline. The spill was not confirmed until 20th December 2023 by the ship's disponent owner (MAERSK). Although spills occurring in waters of a neighbouring country should activate an alert level 3 for extreme pollution events, Galicia was at alert level 0 (local) until 4th January 2024. On that date authorities were informed about the spill magnitude and proceeded to activate the Territorial contingency plan for accidental marine contamination in the region of Galicia on the following day. On 9th January 2024, pellets were found at beaches in the neighbour region of Asturias, which led to activation of alert level 2 and a strategy at Spanish level ("Plan CAMGAL", n.d.).

Marine contamination events are studied under the regulations of the affected country (Finska and Howden, 2018; Kleverlaan and Reichelt-Brushett, 2023). In Spain the regulation for pollution events in the sea states that the shipowner should compensate for the damage (Law article 385.1) ("BOE-A-2014-7877 Ley 14/2014, de 24 de julio, de Navegación Marítima.", n.d.). Toconao was operated by Maersk and managed by Columbia Ship management. The case is under investigation to elucidate responsibilities ("C.G.P.J | Poder Judicial | Noticias Judiciales | Un juzgado de Noia abre diligencias por un posible delito contra los recursos naturales y el medio ambiente por el vertido de pellets a la costa gallega", n.d.).

Accidental container loss from cargo ships is a recurrent issue in maritime transport. Approximately 1556 containers are officially reported to be lost annually (World Shipping Council, 2023). Preventive measures are crucial to stop these accidents and to mitigate their consequences. Corrective measures proposed after the X-Press Pearl Accident in Sri Lanka in 2021 recommended to improve labeling, loading and handling practices in all cargos transporting plastic nurdles and to stablish emergency protocols for nurdles spills ("Marine Environment Protection Committee (MEPC) 77, 22-26 November 2021", n.d.). In this sense, the importance of the relationship between different stakeholders (policy makers, industry and society) is of capital importance. Thus, we believe that a bottom-up approach could be of importance, empowering local governments and social organizations demanding regulations from regional and national governments (Urbina et al., 2021). This also allows for a virtuous circle where environmental demands that arise from civil society and local governments interact and force, to a certain extent, the appearance of top-down proposals by policy makers. In this way, mechanisms are adopted that can provide a governance solution to the problem of plastic pollution in general and the present case as a particular example (Cowan and Tiller, 2021).

As of 23rd April 2024, the EU Parliament approved a proposal on preventing plastic nurdles losses to reduce microplastic pollution ("Register of Commission Documents - COM (2023)645", n.d.). We proposed the use of rigid and sealed containers or tanks, which would increase the container's integrity, prevent water infiltration, and improve buoyancy. This is one of the processes within the plastic production life cycle where there is still room for improvement as pointed out in the *Oslo and Paris convention for the protection of the marine environment of the North-East Atlantic* (OSPAR) regional plan, whose objective is zero plastic nurdles/pellets loose in the environment ("Action 52: Zero pellet loss in the manufacturing chain | OSPAR Commission", n.d.).

3. Conclusions and future prospects

A recent environmental disaster from the loss of 25 t of plastic nurdles from the Toconao's vessel in the Northwest of the Iberian Peninsula, mainly affecting the Spanish region of Galicia (1498 km of coastline). The mid- and long-term effects of the pollutant pellets on the ecosystem are yet to be quantified. Although beach clean ups across Galicia managed to remove 6.7 t over the first two months after the catastrophe, these efforts are not cost efficient, and fall short of 100 % removal of the pollutants. Tackling the contamination sources (i.e., manufacturers, supply chain, transportation, use and disposal) remains the most effective strategy. This case report builds up on similar previous events of plastic nurdle pollution, and calls for both research on nurdles' environmental and socio-economic consequences, and the implementation of effective legal regulations by local, regional and national governments, including international agreements for enforcement and responsibility for clean-up.

CRediT authorship contribution statement

Alejandro Vidal-Abad: Writing – review & editing, Writing – original draft. **Miguel A. Casal:** Writing – review & editing, Writing – original draft. **José Manuel Rey-Aguiño:** Writing – review & editing, Writing – original draft, Methodology. **Alejandra Pichel-González:** Writing – original draft, Investigation. **Andrea Solana-Muñoz:** Writing – original draft. **Verónica Poza-Nogueiras:** Writing – review & editing, Writing – original draft. **Zulema Varela:** Writing – review & editing, Writing – original draft. **Cristóbal Galbán-Malagón:** Writing – review & editing, Writing – original draft. **Pablo Ouro:** Writing – review & editing, Writing – original draft, Methodology. **Alba Fernández-Sanlés:** Writing – review & editing, Writing – original draft, Project administration, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data were used for the research described in the article.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.marpolbul.2024.116442.

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