Received: 22 January 2021 | Revised: 21 June 2021 | Accepted: 24 June 2021
DOI: 10.1111/cobi.13827
Conservation Biology
CONTRIBUTED PAPER

A decision framework for estimating the cost of marine plastic pollution interventions

Erin L. Murphy[1] | Miranda Bernard[1] | Gwenllian Iacona[2,3] | Stephanie B. Borrelle[4,5,6] | Megan Barnes[7] | Alexis McGivern[8] | Jorge Emmanuel[9] | Leah R. Gerber[1,2]

[1] School of Life Sciences, Arizona State University, Tempe, Arizona, USA

[2] Center for Biodiversity Outcomes, Arizona State University, Tempe, Arizona, USA

[3] Resources for the Future, Washington, DC

[4] David H. Smith Conservation Research Program, Society for Conservation Biology, Washington, DC

[5] Department of Ecology and Evolutionary Biology, University of Toronto, Toronto, Ontario, Canada

[6] College of Engineering, University of Georgia, Athens, Georgia, USA

[7] Centre for Environmental Economics & Policy, School of Agriculture and Environment, University of Western Australia, Crawley, Western Australia, Australia

[8] School of Geography and the Environment, University of Oxford, Oxford, UK

[9] Institute of Environmental and Marine Sciences, Silliman University, Dumaguete, Philippines

Correspondence
Erin Murphy, School of Life Sciences, Arizona State University, Life Sciences Center A Wing, 427 E Tyler Mall, Room 209, Tempe, AZ 85281, USA.
Email: elmurph1@asu.edu

Article impact statement: Identifying economic, social, and ecological costs and benefits of plastic pollution interventions supports conservation decision-making.

Abstract

Marine plastic pollution has emerged as one of the most pressing environmental challenges of our time. Although there has been a surge in global investment for implementing interventions to mitigate plastic pollution, there has been little attention given to the cost of these interventions. We developed a decision support framework to identify the economic, social, and ecological costs and benefits of plastic pollution interventions for different sectors and stakeholders. We calculated net cost as a function of six cost and benefit categories with the following equation: cost of implementing an intervention (direct, indirect, and nonmonetary costs) minus recovered costs and benefits (monetary and nonmonetary) produced by the interventions. We applied our framework to two quantitative case studies (a solid waste management plan and a trash interceptor) and four comparative case studies, evaluating the costs of beach cleanups and waste-to-energy plants in various contexts, to identify factors that influence the costs of plastic pollution interventions. The socioeconomic context of implementation, the spatial scale of implementation, and the time scale of evaluation all influence costs and the distribution of costs across stakeholders. Our framework provides an approach to estimate and compare the costs of a range of interventions across sociopolitical and economic contexts.

KEYWORDS
conservation, decision-making, equity, financial costs, plastics

Un Marco de Decisión para Estimar el Costo de Intervenciones en la Contaminación Marina por Plástico

Resumen: La contaminación marina por plásticos ha emergido como uno de los retos ambientales más prioritarios de nuestro tiempo. Mientras ha habido un aumento en la inversión global para implementar intervenciones para mitigar la contaminación por plásticos, se ha dado poca atención al costo de estas intervenciones. Desarrollamos un marco de soporte a las decisiones para identificar los costos y beneficios económicos, sociales y ecológicos de las intervenciones en la contaminación por plástico para diferentes sectores y partes interesadas. Calculamos el costo neto como una función de 6 categorías de costo y beneficio con la siguiente ecuación: costo de la implementación de una intervención (costos directos, indirectos y no monetarios) menos los costos y beneficios recuperados (monetarios y no monetarios) producidos por las intervenciones. Aplicamos nuestro marco a 2 estudios de caso cuantitativos (un plan de manejo de residuos sólidos y un interceptor de basura) y 4 casos de estudio comparativos evaluando los costos de limpieza de playas y plantas de transformación de desechos a energía en varios contextos para identificar los factores que influyen en los costos de las intervenciones de la contaminación por plástico. El contexto socioeconómico de la implementación, la escala espacial de la implementación y la escala de tiempo de evaluación influyen en los costos y distribución de costos entre las partes interesadas. Nuestro marco proporciona una aproximación para estimar y comparar los costos de una gama de intervenciones en contextos sociopolíticos y económicos.

PALABRAS CLAVE:
Conservación, costos financieros, equidad, plásticos, toma de decisiones

摘要: 海洋塑料污染已成为本时代最紧迫的环境挑战之一。虽然全球在实施干预措施以减轻塑料污染方面的投资激增, 但很少有人关注这些干预措施的成本。我们开发了一个决策支持框架, 以确定塑料污染干预措施对不同部门和利益相关方在经济、社会和生态方面的成本和收益。我们计算净成本作为六种成本及收益类别之间的函数, 计算公式如下: 实施干预的成本 (直接、间接及非货币成本) 减去干预产生的回收成本和收益 (货币及非货币) 。我们将该框架应用于两个定量案例研究 (固体废物管理计划和垃圾拦截器) 和四个比较案例研究, 评估在不同环境下海滩清理和将垃圾转化为能源工厂的成本, 以确定影响塑料污染干预成本的因素。我们发现, 实施干预措施的社会经济背景、空间尺度和评估的时间尺度都会影响成本及成本在利益相关方之间的分配情况。我们的框架为估计和比较一系列跨社会政治和经济背景的干预措施成本提供了方法。**【翻译: 胡怡思; 审校: 聂永刚】**

关键词: 塑料, 保护, 决策, 财务成本, 公平

INTRODUCTION

Marine plastic pollution has detrimental effects on the environment, the economy, and human well-being (Beaumont et al., 2019). Recognizing the implications of this environmental problem, stakeholders—policy makers, nonprofit organizations, and businesses—have made significant investments to address plastic pollution. For instance, financial pledges at the 2017 Our Ocean Conference totaled $8.5 billion (Our Ocean, 2017) (all costs converted to 2019 U.S. dollars). However, funds for conservation efforts are limited, and these commitments have not insufficiently reduced marine plastic pollution and its ecological and social effects (Borrelle et al., 2020). To ensure these investments achieve the desired results and are economically viable, it is necessary to systematically evaluate the cost-effectiveness of interventions before implementation (Murdoch et al., 2007).

Identifying the cost-effectiveness of plastic pollution interventions requires understanding the cost of an intervention, its efficacy, and the benefits it produces (Cook et al., 2017). Current evaluations for effectiveness of plastic pollution interventions are insufficient (Löhr et al., 2017). Still, there are strategies for measuring the effectiveness of conservation policies (Sutherland et al., 2004) that could be applied to plastic pollution interventions. The literature on costs for conservation efforts, however, is sparse, and key costs are often omitted (Iacona et al., 2018), making it difficult to inform cost analyses for plastic pollution interventions. Most evaluations of plastic pollution interventions consider only the direct costs of intervention and recovered costs (e.g., taxes) to generate revenue (e.g., Crawford, 2008). Some consider the financial or nonmonetary benefits of plastic removal (Lavee, 2010), but many costs and benefits remain overlooked. Further, the inconsistent characterization and reporting of costs make it difficult to interpret studies or use them to inform decision-making (Iacona et al., 2018).

The challenge of standardizing the cost of interventions for plastic pollution is exacerbated by the breadth of intervention types. Interventions are implemented along the entirety of the plastic life cycle, yet cost analyses are only available for a small subset of these—such as cleanups (Mouat et al., 2010), deposit refund schemes (Lavee, 2010), and plastic bag bans (Zhu, 2011)—and analyses are predominantly conducted after implementation (Oosterhuis et al., 2014). Generalizable evaluations are complicated by the fact that the costs and possible benefits of interventions are influenced by factors specific to the context in which they are implemented (Oosterhuis et al., 2014). Different interventions place the burden of costs on different stakeholders. This is especially salient for marginalized populations, who are often disproportionately affected when the full distribution of costs is ignored (Adams et al., 2010). Thus, an approach for estimating the net costs of plastic pollution interventions is critical for helping decision makers better prioritize actions to achieve their conservation goals (Wilson et al., 2009).

We developed a decision support framework to identify the costs and benefits of plastic pollution interventions accrued by a range of stakeholders. We first identified the relevant categories of costs and benefits associated with plastic pollution interventions. We then used an equation to calculate the net cost as a function of these categories. We applied the framework to two quantitative case studies informed by specific

TABLE 1 Cost and benefit categories and subcategories for interventions to mitigate marine plastic pollution, where costs on the left increase net cost and costs and benefits on the right decrease net cost

Positive costs	Negative costs and benefits
Direct costs:	Recovered costs:
1. Overhead (e.g., administration, disposal, permits)	1. Direct (e.g., taxes, fines, fees)
2. Labor (e.g., salaries, benefits, insurance	2. Indirect (e.g., job creation, substitutes)
3. Capital assets (e.g., infrastructure, vehicles, equipment)	
4. Consumables (e.g., materials, gasoline)	Monetary benefits:
	1. Decreased cost of marine/coastal activities
Indirect costs:	a. Fisheries (e.g., propeller entanglement, fishing plastics)
1. Opportunity cost (e.g., volunteer time)	b. Shipping/yachting (e.g., entanglement, obstruction)
2. Job loss	c. Aquaculture (e.g., prop entanglement, blocked pipes)
3. Substitution (e.g., cost of alternative products)	d. Agriculture (e.g., coastal agriculture pollution)
	e. Increased revenue in recreation and ecotourism
	f. Increased provisioning of marine resources
	2. Reduced healthcare costs (e.g., injuries from plastic encounters)
Nonmonetary costs:	Nonmonetary benefits:
1. Environmental impacts of intervention (e.g., air pollution)	1. Social benefits
2. Social impacts of intervention (e.g., value of plastics lost)	a. Human welfare (e.g., sense of place, happiness)
	b. Social justice (e.g., reduced inequity)
	2. Environmental health (e.g., intrinsic value, bequest value)

interventions and four comparative case studies informed by the literature. Finally, to encourage more equitable decision-making, we examined how context influences the distribution of costs across stakeholders. We sought to provide an approach to estimate and compare the costs of a range of interventions across sociopolitical and economic contexts.

METHODS

A conventional cost–benefit analysis sums the benefits and subtracts the costs to yield the net benefits. However, our approach follows and extends on methods developed by Iacona et al. (2018), who examined the total costs of conservation interventions. We developed an equation to describe the net cost of mitigating marine plastic pollution, which we used to inform the development of our framework. Net cost is equal to the cost of implementing an intervention (direct, indirect, and nonmonetary [NM]) minus recovered costs and benefits (monetary and NM) produced by the interventions. If the sum is positive, there is a net cost. If it is negative, there is a net benefit:

$$\text{Net cost} = (\text{direct costs} + \text{indirect costs} + \text{NM costs}) - \left(\text{recovered costs} + \text{monetary benefits} + \text{NM benefits}\right). \quad (1)$$

The cost and benefit categories were informed by a Web of Science search using a combination of the following terms: "*cost*" OR "*economic*" AND "*marine*" OR "*ocean*" AND "*debris*" OR "*litter*" OR "*plastic*." We supplemented this with a Google Scholar search for gray literature (Appendix S1).

Direct costs represent the costs of actions required to implement the intervention (National Center for Environmental Economics, 2010). There are four categories: overhead, labor, capital assets, and consumables (Iacona et al., 2018). Indirect costs are associated with the intervention but not directly tied to the financial cost of implementing actions, such as the opportunity cost of volunteers (National Center for Environmental Economics, 2010). Recovered costs are the revenue created by the intervention to reduce net costs. They are categorized as direct costs, which are implemented to reduce the implementer's cost, or indirect costs, which may benefit other stakeholders. Monetary benefits are the savings that would be accrued by stakeholders due to resulting reduction in marine plastic pollution. There are two categories of monetary benefits: benefits to marine sectors and healthcare savings (McIlgorm et al., 2011; Mouat et al., 2010; Newman et al., 2015). Nonmonetary costs represent the nonfinancial costs of an intervention (e.g., environmental trade-offs), and the nonmonetary benefits represent the nonfinancial benefits of implementation. Nonmonetary costs and benefits are categorized as environmental or social (McIlgorm et al., 2011; Newman et al., 2015). Table 1 provides examples of each cost and benefit.

The framework provides a section for users to input the intervention's description, its objectives (i.e., the primary goals of the intervention), and the spatial–temporal scale of evaluation (Table 2). Then, users record the stakeholders involved in or affected by the intervention. To identify the costs accrued by a specific stakeholder group, each stakeholder is listed in a new row. Next, the user evaluates each of the cost and benefit subcategories, as outlined below. Nonmonetary costs and benefits should be identified, even if users cannot estimate their monetary value because they often relate directly to the intervention objectives. The user can quantify them with nonmonetary units (e.g., number of animals saved). If the user wants to further enumerate nonmonetary costs and benefits, there are methods for doing so, such as ecosystem service accounting (Crossman et al., 2012). The final section provides an opportunity for users to conduct an equity evaluation, in which users identify stakeholders who would benefit or be harmed by each intervention and list net costs accrued by each stakeholder group.

TABLE 2 Decision framework to identify all costs and benefits[a] associated with an intervention for marine plastic pollution and the partial costs accrued by different stakeholders

Intervention: Description of the intervention				
Objective: The overall goals of the implementing party				
Scale: Spatial and temporal scale (e.g., municipality or nation; 1 year or 2 decades)				
Stakeholder	**Actions and direct costs**	**Indirect costs**	**Recovered costs**	**Monetary benefits**
Actions and those affected (e.g., NGO, the public, government)	Steps to intervention and associated costs (e.g., enforcement, infrastructure)	Not associated with direct action (e.g., job loss, opportunity cost)	Direct or indirect revenue from implementation (e.g., fines, job creation)	Savings from plastic reduction (e.g., increased tourism)
Nonmonetary costs[b] (e.g., environmental trade-offs, social costs)				
Nonmonetary benefits[b] (e.g., ecosystem services, human welfare)				
Equity: Payers vs. beneficiaries				

[a]Even if the decision maker is unable to quantify every cost, the framework allows them to better understand the costs they are and are not considering.
[b]Nonmonetary costs and benefits may be included qualitatively or quantitatively based on the decision makers preference and available data.

Quantitative case studies

To demonstrate how the framework can be used to examine relative costs of alternative interventions, we applied it to two cases in which comprehensive cost evaluations were completed prior to intervention implementation. These cases allowed us to explore different interventions implemented by different actors under contrasting socioeconomic conditions.

The first case study explored implementation of a solid waste management (SWM) plan in the city of Bayawan, Negros Oriental, Philippines. The Philippines is ranked as the third largest producer of plastic pollution in the world, and plastic pollution has been found in the guts of marine species, including commercially important fish (Bucol et al., 2020). Bayawan is a 700-km^2 coastal city on the island of Negros with a population of 117,900 (Philippines Statistics Authority, 2015). We explored the cost of implementing a 10-year SWM plan in Bayawan. Our examination was informed by the public document, *Solid Waste Management Plan (2019–2028)*. The key objectives of the plan were to expand waste management services, increase recycling and composting rates, and reduce open burning to ensure the city is prepared for anticipated population growth and urbanization. Key stakeholders for implementation include the municipal government, the local community, schools, barangays (neighborhoods), and industry (marine sectors and recycling sectors). The city identified actions required to achieve these objectives: purchase more equipment, build a new special waste facility, build a water monitoring pond, implement and enforce new SWM ordinances, support the establishment of barangay-based SWM facilities, and administer school education and innovation programs (City of Bayawan, 2019).

The second case study explored the implementation of a trash interceptor at the mouth of the Jones Falls River in Baltimore over a 10-year evaluation period (Clearwater Mills, 2013). Baltimore is a large coastal city—population of 593,490—in Maryland, USA (United States Census Bureau, 2019). It is located on the Chesapeake Bay, an ecologically and socially important body of water that is negatively affected by large amounts of plastic debris and microplastic pollution (Hale et al., 2020). The Waterfront Partnership is a group of businesses that agreed to pay additional taxes into a fund for cleaning up the waterfront. We obtained cost information from the Waterfront Partnership and the CEO of Clearwater Mills, the company that built and maintains the trash wheel. Cost data were provided at the project level and focused predominantly on the cost to the Waterfront Partnership. The key objectives of the trash wheel were to improve the sanitation and water quality of Baltimore's Inner Harbor. Key stakeholders for implementation were the Waterfront Partnership, the city of Baltimore, the public, and a local marina. Actions taken to achieve the objectives were constructing, operating, and maintaining the trash wheel and educating the public (correspondence with Clearwater Mills and Waterfront Partnership).

Comparative case studies

To better understand three key factors that influence the net costs of intervention—temporal scale of analysis, spatial scale of implementation, and socioeconomic condition—we developed four conceptual case studies. In these case studies, we compared the costs of interventions in scenarios that varied one of these factors, while holding all others constant. We explored the influence of temporal scale on costs in case studies on a time scale of one year and 20 years. For the former case, we evaluated the costs of beach cleanups in developed municipalities, and for the latter we evaluated waste-to-energy (WTE) plants in developed municipalities. We explored the influence of spatial scale of implementation by comparing the costs of beach cleanups at the municipality and national scale in a developed country over one year. Finally, we explored the influence of socioeconomic conditions by comparing the costs of a WTE plant in a municipality in a developed versus developing country.

The choice of scenarios for each comparative case study was based on the availability of peer-reviewed and gray literature evaluating interventions with the appropriate socioeconomic conditions and spatial–temporal scale. We characterized all costs and benefits identified in the literature review based

TABLE 3 Summary of the City of Bayawan's plan to expand solid waste management (SWM) and increase plastic waste diversion rates

Intervention: Implement mandatory waste segregation and collection throughout the city

Objective: Expand waste collection in all barangays and achieve 70% waste diversion

Scale: City of Bayawan, Negros Oriental, over 5 years

Stakeholder[a]	Actions and direct cost[b]		Indirect and nonmonetary cost	Recovered cost, monetary benefit, nonmonetary benefit	
City	Total capital assets:	$247,040	Indirect costs:	Recovered costs:	–$38,600
	Purchase 2 garbage compacters	($231,600)	OC[d] of SWM committees	Tipping fees	
	Construct special waste facility	($9,650)		Illegal dumping fines	
	Construct water monitoring pond	($5,790)		Open-dumping fines	
				Garbage stickers	
	Total administration:	$946,086		Sale of recyclables	
	Enact new SWM ordinances	($386)			
	Enforce SWM ordinances	($162,120)		Monetary benefits:	
	School innovation program	($52,110)		Clean-up[c]	
	Collection operations	($248,970)		Tourism[c]	
	Operation of BCWMEC facility	($451,620)			
	Expansion of SWM coverage	($30,880)			
Public	Purchase waste containers		Indirect costs:	Recovered costs:	
	Composting		OC[d] of waste segregation[c]	Recyclable sales	
	Payment of fees/fines	$38,600	Loss of access for informal waste sector[c]		
				Monetary benefits:	
			Nonmonetary costs:	Healthcare costs[c]	
			Environmental costs[c]		
				Nonmonetary benefits:	
				Human welfare[c]	
				Ecosystem health[c]	
Schools	Purchase of waste containers		Indirect costs:	Recovered costs:	
	Payment of fees/fines		Plastic alternatives[c]	Government awards	−$52,110
	Manage compost and MRF facilities			Recyclables sales	
Barangays	Collect/compost biodegradables				
	Enforce SWM ordinances				
Marine sector				Monetary benefits:	
				Interaction costs[c]	
Recycling sector				Recovered costs:	
				Sale of recyclables	

Net costs: Government: $1,154,526. Missing costs include indirect costs (increase net) and monetary benefits (decrease net). Public: $38,600 or $0.33 per capita. Missing costs include some direct costs (increase), indirect costs (increase), recovered costs (decrease), monetary benefits (decrease), nonmonetary costs (increase) and nonmonetary benefits (increase). Schools: -$52,110. Missing costs include direct costs (increase), indirect costs (increase) and more recovered costs (decrease). Barangays: Costs are not available. Missing costs include direct costs (increase). Recycling sector: Costs not available. Missing costs include recovered costs (decrease). Marine Sector: Cost data not available. Missing costs include monetary benefits (decrease).

Equity: Costs are negative for industry and the public, and positive for the city, barangays, and schools. This may disproportionately affect low-income communities that could be burdened by waste-segregation costs and rural communities that receive fewer services from the city and have higher burdens for at-home composting and waste management.

[a] Includes the city, the public, schools, barangays, and industry (recycling and marine sectors).

[b] All costs are in 2019 U.S. dollars. Costs included without an estimate were mentioned in the report but not considered as costs. Costs in parentheses represent a subcost of the cost listed.

[c] Costs identified by the authors but excluded from the city's report.

[d] OC is an abbreviation for opportunity cost.

on the categories in our cost–benefit framework. We then identified how the relative costs for each of the cost and benefit categories differed based on the case study scenario (e.g., identified whether direct costs were higher or lower for beach cleanups or WTE on a 10-year time scale) (details available in Appendix S2). To standardize comparisons across case studies, we assumed effectiveness was consistent for all interventions in a scenario (i.e., a bag ban implemented in a developing country and a developed country will reduce bag use by the same proportion).

RESULTS

Implementation of a SWM plan in Bayawan

Based on available information, the net cost estimate for Bayawan over 5 years was $1,154,526 (Table 3). This was the direct costs of the program minus the costs recovered by fees, fines, and sale of recyclables. This estimate did not include indirect costs or monetary benefits, which would increase and decrease net cost, respectively.

The cost to the public was calculated as $38,600 ($0.33 per capita), which was the direct costs of fees and noncompliance fines. This estimate did not include the direct costs of purchasing waste-segregation containers, indirect costs, or nonmonetary costs, which would increase net cost. It also did not include recovered costs or benefits (monetary or NM), which would decrease net cost.

The benefit to schools was $52,110 based on the administration of government awards for the best waste management programs (net cost is negative). Importantly, these recovered costs would not be evenly distributed across schools but would benefit only schools deemed most innovative. This estimate also did not include the direct and indirect costs of implementing waste management plans in schools, which would increase costs. Also not included were additional recovered costs, such as the sale of recyclables, which would further reduce costs. Cost estimates were not available for barangays, the recycling sector, or marine sector.

The partial distributions of costs suggested the cost of this plan would fall primarily on the city. The benefits would be greatest for marine sectors, the recycling sector, and the public. The direct costs to the public appeared to disproportionately affect low-income, rural communities that historically burned or dumped waste at no cost and must either manage waste according to new ordinances or pay fines. Some low-income individuals could experience reduced income due to fewer opportunities for waste picking.

Implementation of a trash wheel in Baltimore

Net cost to The Waterfront Partnership over 10 years was $2,250,202 (Table 4). This was based on the direct cost of implementing the trash wheel minus costs recovered through financial support from the city, sale of trash wheel memorabilia, and tours of the trash wheel. This estimate did not include most recovered costs, monetary benefits, or nonmonetary benefits that would decrease net cost.

The cost to Baltimore was $619,900 and included the direct costs for operation and maintenance and the dumpster disposal fee. This did not include monetary and nonmonetary benefits that would decrease net costs. The primary monetary benefit to the city was reduced cleanup costs and the main nonmonetary benefits were positive perceptions and aesthetic values.

The cost to the marina was $21,600. This was the indirect cost of providing a slip for the vessel at half price. This estimate did not include the benefits gained by the marina. Finally, an estimate was not available for the cost to the public, but they accrued costs and benefits as well. The monetary benefits to the public were reduced healthcare costs. The nonmonetary costs were the environmental costs of waste collection and the nonmonetary benefits were the improvements to human welfare and environmental health. Overall, every stakeholder group felt they benefitted from implementation of the intervention.

Comparative case studies

The net cost of coastal cleanups in developed cities was larger when evaluated on a longer time scale (Han et al., 2010; Mouat et al., 2010; Stickel et al., 2012) (Table 5). Average annual direct costs were higher in the 10-year time scale because of anticipated increases in hourly wages and increases in plastic production and pollution that demand more hours of cleanup to achieve the same outcomes (Mouat et al., 2010; Stickel et al., 2012). Disposal costs also increased over time (Mouat et al., 2010). Generally, as landfill space decreased, disposal fees increased, and alternative disposal methods (e.g., controlled incineration) often had higher fees (Crawford, 2008). Monetary benefits decreased over the 10-year period because tourist expectations for cleanliness increase over time, which reduces the benefits of cleanups if effectiveness is held constant (Leggett et al., 2014; Mouat et al., 2010).

For WTE plants, net costs decreased as operational time increased (Crawford, 2008; Jamasb & Nepal, 2010). This was because of high direct costs. The most significant costs for WTE were capital assets, which are cheaper per annum the longer a plant operates (Lombardi et al., 2015). Some direct costs increased over time, such as operation, maintenance, and labor costs—due to increases in salaries (Crawford, 2008; Jamasb & Nepal, 2010), but capital assets dominated these other direct costs for WTE. The indirect costs of WTE also decreased with time. As technology and emission standards improved, the amount of air pollution released decreased, reducing human health costs. Decreased pollution reduced nonmonetary costs of WTE as well (Jamasb & Nepal, 2010). Energy capture also improved with advances in technology and quality of feedstock, which increased recovered costs through energy sales and increased nonmonetary benefits associated with reducing net greenhouse gas emissions (Crawford, 2008; Jamasb & Nepal, 2010).

Net costs of coastal cleanups were higher per unit cleaned when cleanups were implemented at the national level than at the municipal level (Han et al., 2010; Mouat et al., 2010; Stickel et al., 2012). Coastal cleanups implemented at the local level were most often carried out in popular tourist sites with sandy beaches (true for more than 90% of municipalities in the United Kingdom [Mouat et al., 2010]). Cleanups on these beaches had lower direct costs, including labor, transportation, and possible healthcare costs, because sandy beaches have lower plastic retention rates, are easier and safer to access, and are faster to traverse than rocky shores (Mouat et al., 2010). These beaches also provided higher monetary benefits because they received more recreational use (Han et al., 2010; Leggett et al., 2014). National-level cleanups would include a higher proportion of isolated coastlines and other shore types, such as rocky and muddy shores. Higher direct costs, including higher transport and labor costs for these regions, would raise the average cost per kilometer of coastline, whereas the monetary benefits to tourism and human health per kilometer cleaned would decrease.

TABLE 4 Summary of case study of Baltimore, Maryland's, trash wheel

Intervention: Establish a trash wheel at the mouth of the Jones Falls River

Objective: Clean up Baltimore harbor

Scale: City of Baltimore, Maryland, USA; 10 years

Stakeholder[a]	**Action and direct cost**[b]		**Indirect cost and nonmonetary cost**		**Recovered cost, monetary benefit, and nonmonetary benefits**	
Waterfront Partnership	Overhead	$54,000			Recovered costs:	
	Total capital assets	$704,000			Funds from Baltimore	–$50,000
	Floating platform	($113,400)			Sale of memorabilia	
	Waterwheel	($19,400)			Trash wheel tourism	
	conveyor	($48,600)				
	Power transmission	($22,700)			Monetary benefits:	
	Solar panels	($58,300)			Increased tourism	
	Covering structure	($147,900)			Higher property values	
	Controls/sensor	($13,000)			Less plastic interaction	
	Pump system	($20,500)				
	Dumpster float/dumpster	($52,900)			Nonmonetary benefits:	
	Debris rake system	($13,000)			Positive perceptions[c]	
	Log lift system	($9,700)				
	Miscellaneous expenses	($7,600)				
	Installation	($77,700)				
	Service vessel modification	($19,400)				
	Facilities, equipment	($79,900)				
	Total labor	$1,217,100/10yrs				
	Insurance	($43,700/yr)				
	Monitoring	($19,400/yr)				
	Maintenance	($10,400/yr)				
	Dumpster transport	($37,400/yr)				
	Communications	($10,800/yr)				
	Total consumables	$325,102/10yrs				
	Vessel operations	(65,702/10yrs)				
	Fuel	($3,200/yr)				
	Registration	($162+$54/yr)				
	Maintenance	($1,100/yr)				
	Slip fee	($2,200/yr)				
	Equipment expenses	($65,400/10yrs)				
	Fuel	($540/yr)				
	Maintenance	($1,100/yr)				
	Parts and materials	($4,900/yr)				
	Dumpster disposal	($194,000/10yrs)				
Public			Nonmonetary costs:		Monetary benefits:	
			Environmental[c]		Healthcare costs[c]	
					Nonmonetary benefits:	
					Human welfare[c]	
					Ecosystem function[c]	
Municipality	Operations & Maintenance	$500,000/10yrs			Monetary benefits:	
	Funds to support WFP	($50,000/yr)			Clean-up costs	
	Disposal	$119,900/10yrs			Nonmonetary benefits:	
	Disposal fees	($11,100/yr)			Positive perceptions[c]	
Marina			Indirect costs:		Monetary benefits:	
			Slip donation	$21,600/10yrs	Clean-up costs[c]	
					Increased recreation[c]	

Net costs: Waterfront partnership: 2,250,202. Missing costs include recovered costs (decrease cost), monetary benefits (decrease) and nonmonetary benefits (decrease). Public: Cost not available. Missing costs include monetary benefits (decrease), nonmonetary costs (decrease) and nonmonetary benefits (increase). Municipality: $619,900. Missing costs include monetary benefits (decrease), and nonmonetary benefits (decrease). Marina: $21,600. Missing costs include monetary benefits (decrease).

Equity: Positive for all stakeholders

[a]Includes the city, the public, schools, barangays, and industry (recycling and marine sectors).

[b]All costs are in 2019 U.S. dollars. Costs included without an estimate were mentioned in the report but not considered as costs. Costs in parentheses represent a subcost of the cost listed.

[c]Costs identified by the authors but excluded from the stakeholder's reports.

TABLE 5 Summary of comparative case studies indicating how costs and benefits of a plastic pollution intervention vary when evaluated under different time scales, spatial scales, and socioeconomic contexts

Factor	Cost category	Comparative case studies[a]			Reference
Time scale		Coastal cleanup, developed city			
		1 year		20 years	
	Direct	Labor	<	Labor	Ballance et al., 2000; Han et al., 2010; Mouat et al., 2010; Stickel et al., 2012; Leggett et al., 2014
	Direct	Disposal	<	Disposal	
	Avoided	Tourism	>	Tourism	
		Waste-to-energy, developed city			
		1 year		20 years	
	Direct	Maintenance	<	Maintenance	Crawford, 2008; Yang et al., 2012; Lombardi et al., 2015
	Indirect	Human health	>	Human health	
	Recovered	Energy sales	>	Energy sales	
	Nonmonetary cost	Pollution	>	Pollution	
	Nonmonetary benefit	Greenhouse gas sink	>	Greenhouse gas sink	
Spatial scale		Coastal cleanup, developed locale, 1 year			
		City		Country	
	Direct	Labor	<	Labor	Ballance et al., 2000; Han et al., 2010; Mouat et al., 2010; Leggett et al., 2014; Stickel et al., 2012
	Direct	Transportation	<	Transportation	
	Direct	Disposal	<	Disposal	
	Monetary benefit	Human health	<	Human health	
	Monetary benefit	Tourism	>	Tourism	
Socioeconomic conditions		Waste to energy, 20 years			
		City in a developed country		City in a developing country	
	Direct	Infrastructure	<	Infrastructure	Dijkgraaf & Vollebergh, 2004; Consonni et al. 2005; Crawford, 2008; Fobil et al., 2005; Jamasb & Nepal, 2010; Lombardi et al., 2015; Yang et al., 2012; Zhang et al., 2015; Mavrotas et al. 2015; Xin-gang et al., 2016; Wang et al. 2016; Kaza et al., 2018
	Direct	Labor	>	Labor	
	Direct	Maintenance	<	Maintenance	
	Indirect	Human health	<	Human health	
	Indirect	Job loss informal sector	<	Job loss informal sector	
	Recovered	Energy sales	>	Energy sales	
	Nonmonetary cost	Environmental trade-offs	<	Environmental trade-offs	
	Nonmonetary benefit	Greenhouse gas sink	>	Greenhouse gas sink	

[a]Differences between cost categories are identified as being relatively higher or lower than the case study of comparison.

The net cost of implementing a WTE plant was higher in municipalities in developing countries than in developed countries (Lombardi et al., 2015; Yang et al., 2012). Although labor costs were lower in developing countries (Kaza et al., 2018), infrastructure costs were higher for developing countries as a function of gross domestic production, making capital costs more prohibitive (Fobil et al., 2005). Additionally, WTE plants in developing countries typically used older technology and had waste with a higher moisture content, which affected several costs and benefits. This increased maintenance costs because waste with high moisture content generates more corrosive by-products that damage boiler tubes (Zhang et al., 2015). Indirect and nonmonetary costs were also higher because both older technology and high-moisture-content waste produced more air pollution and greenhouse gasses (Lombardi et al., 2015; Yang et al., 2012). Increased rates of groundwater contamination further elevated these costs because toxic ash must be put in a landfill (Kaza et al., 2018) and landfill leakage rates were generally higher in developing countries (Zhang et al., 2015). Finally, plants in developing countries produced less energy, which decreased recovered costs (Lombardi et al., 2015).

DISCUSSION

Many decision makers try to maximize efficiency through wise investment when they are implementing conservation interventions (Murdoch et al., 2007). However, most assessments fail to capture the full suite of costs and benefits associated with a given intervention. As a result, investments in conservation often fail to achieve their stated objectives. Our framework provides an approach for evaluating the net cost of alternative interventions for mitigating marine plastic pollution and supports a more standardized and equitable assessment of costs and benefits. Employing our approach facilitates deliberation about the possible costs that may influence the efficiency of an intervention, allowing decision makers to compare an intervention to a business-as-usual scenario or other possible interventions before their implementation.

Decision makers can also use this framework to compare costs across locations. When costs are not fully considered or clearly presented in studies, it is difficult for decision makers to interpret these costs and understand how they may differ in their own context. Our costing framework promotes consistency in costing and reporting that will also allow researchers to better study relationships between cost and efficacy and understand how implementation context affects cost.

Use of this framework can also help increase the equity of interventions by ensuring decision makers consider the full distribution of costs to stakeholders across time. Plastic pollution disproportionately affects marginalized and low-income communities (Newman et al., 2015). Unfortunately, many conservation interventions have high social costs as well (Adams et al., 2010). For instance, WTE plants are promoted as a solution to high levels of plastic pollution interaction for marine organisms (McKinsey & Company & Ocean Conservancy, 2015). However, their historic construction in marginalized communities places higher health costs and nonmonetary costs on these individuals (UNEA, 2019). This framework enables decision makers to understand cost distributions across stakeholders, allowing them to choose more equitable interventions or implement secondary policies (e.g., benefit transfers) to reduce an intervention's burden on vulnerable populations. To ensure this objective is achieved, it is critical that decision makers use a participatory approach, engaging with a diverse group of stakeholders in the process of identifying and analyzing costs.

Key factors for cost

We identified three factors decision makers should consider with the implementation of interventions for plastic pollution: temporal scale of analysis, spatial scale (i.e., international, national, municipal) of implementation, and socioeconomic conditions. The net cost of a coastal cleanup per kilometer of beach cleaned at the municipality scale increased with time scale of analysis, whereas the net cost of a WTE plant decreased. This indicates the importance of the temporal scale of cost–benefit analyses when evaluating the feasibility of individual interventions and when comparing interventions. Some interventions, such as coastal cleanups, may be cost-effective when evaluated annually because of tourism benefits (Ballance et al., 2000; Stickel et al., 2012). However, other interventions may achieve the same objective while being more cost-effective when evaluated on a longer time scale (de Araújo & Costa, 2006). Alternatively, WTE may be infeasible if considered on a short time scale, but many cities in developed countries have achieved net negative costs over the course of a few decades (Crawford, 2008). Notably, costs may shift again over time as waste streams change. There are developed countries that must now import feedstock waste to maintain their plants (Olofsson et al., 2005). Therefore, the temporal scale of analysis should be in line with the objective. If the objective is long-term sustainability, then the temporal scale of evaluation should be longer. Ultimately, it may be best for communities to implement multiple interventions that aim to achieve objectives with different time scales.

Spatial scale of implementation may significantly change the cost of an intervention; however, many interventions are advocated for across dramatically different scales of implementation. For example, plastic bag reduction policies are often implemented at the national level, but in the United States, where no federal policy has been implemented, hundreds of states and cities have implemented their own legislation (Giacovelli, 2018). Economies of scale can significantly influence the feasibility of conservation efforts (Armsworth et al., 2011). Before adopting policies that have been implemented at different scales, implementers should evaluate the cost of the intervention at their scale of implementation to ensure cost-effectiveness is not hindered.

Decision makers must also consider socioeconomic conditions when implementing interventions. Following the lead of the developed world, developing nations are investing heavily in WTE plants (UNEA, 2019). However, without external investment, low-quality technology may be implemented, which has detrimental impacts for ecosystem and human well-being (Lombardi et al., 2015; Yang et al., 2012). Additionally, indirect economic costs for local communities may be more severe in developing nations because WTE reduces the availability of high-quality waste for informal waste pickers (Kaza et al., 2018). Without consideration of the socioeconomic context, these interventions, which may be effective in certain countries, may be infeasible or detrimental in other contexts.

Recommendations for framework use

This framework should be used by any actor (e.g., municipality) considering the implementation of an intervention for marine plastic pollution. First, they should identify the objective of the intervention and the socioeconomic and environmental context of implementation. This information will help inform which interventions may be most effective, the time frame of consideration, and relevant stakeholders. Next, all key stakeholders must be identified and engaged early. Decision makers may be unaware of potential costs and benefits important to other stakeholders. A participatory approach will help ensure a complete assessment of costs and benefits. Finally, net costs can be quantified for each stakeholder group. Transparency throughout this process can help ensure costs are more equally shared and that social, economic, and environmental objectives will be achieved.

Hard to quantify costs and benefits

Many costs and benefits can be difficult to quantify—particularly indirect costs, nonmonetary costs, monetary benefits, and nonmonetary benefits. Decision makers can improve their estimates by applying other methods for quantifying costs and benefits in concert with our framework. For example, cost-effectiveness analyses—first used in public health—can be used (Bojke et al., 2018). Additionally, methods such as ecosystem service valuation can be used to estimate the value of nonmonetary costs and benefits of plastic pollution interventions (e.g., Beaumont et al., 2019), but the lack of standardization in these approaches may create challenges for comparing values across studies and contexts (Seppelt et al., 2012).

Addressing data gaps

It will not always be feasible to quantify every cost and benefit for an intervention. In instances where costs and benefits cannot be financially quantified, other metrics can be used (e.g., animal deaths avoided) to inform decision-making. Additionally, decision makers can rarely identify all costs and benefits to each stakeholder group but must make the decisions with the data they have (Iacona et al., 2018). Therefore, systematic identification of costs and benefits to all stakeholders can improve the decision-making process.

Considering long time horizons

Though we noted the importance of evaluating interventions on the appropriate time horizon, applying the framework over long time horizons requires additional consideration. First, quantifying costs is more difficult over long time frames. Therefore, when considering an intervention, decision makers must acknowledge the uncertainty in expected cost estimates and anticipate realized costs may be greater. Additionally, costs and benefits accrue on different time horizons (O'Mahony, 2021). Therefore, when using the framework on a long time horizon it is important to appropriately discount expected costs and benefits that are realized at different points in the future. This will allow the decision maker to make fairer comparisons across interventions in terms of their net present value.

Ultimately, use of our framework can help ensure conservation goals can be met with the limited funds available. As research on the cost of plastic pollution and the efficacy of policy measures improves, it will strengthen the quality of the cost–benefit estimates the framework provides. Future research should seek to engage decision makers in various geopolitical and socioeconomic contexts and at different scales of action to validate the efficacy of this tool and generate cost data that can be compared across contexts.

ACKNOWLEDGMENTS

We acknowledge the Plastic Pollution Emissions Working Group for their continued support throughout the completion of this project. We thank C. Perrings, C. Rochman, B. Polidoro, and K. Dooley for feedback on this manuscript. We also thank the city of Bayawan, Clearwater Mills, the city of Baltimore, and the Waterfront Partnership for providing information for our quantitative case studies and taking the time to speak to us about their development. This work was funded by the National Socio-Environmental Synthesis Center under funding received from the National Science Foundation (grant DBI-1639145).

ORCID

Erin L. Murphy https://orcid.org/0000-0003-4910-4903
Miranda Bernard https://orcid.org/0000-0002-8637-6265
Gwenllian Iacona https://orcid.org/0000-0002-7408-3895
Stephanie B. Borrelle https://orcid.org/0000-0002-1802-7354
Megan Barnes https://orcid.org/0000-0002-8300-0975
Alexis McGivern https://orcid.org/0000-0003-0806-9654
Jorge Emmanuel https://orcid.org/0000-0001-6628-4913
Leah R. Gerber https://orcid.org/0000-0002-6763-6842

LITERATURE CITED

Adams, V. M., Pressey, R. L., & Naidoo, R. (2010). Opportunity costs: Who really pays for conservation? *Biological Conservation*, *143*, 439–448.

Armsworth, P. R., Cantú-Salazar, L., Parnell, M., Davies, Z. G., & Stoneman, R. (2011). Management costs for small protected areas and economies of scale in habitat conservation. *Biological Conservation*, *144*, 423–429.

Ballance, A., Ryan, P. G., & Turpie, J. K. (2000). How much is a clean beach worth? The impact of litter on beach users in the Cape Peninsula, South Africa. *South African Journal of Science*, *96*(5), 210–230.

Borrelle, S. B., Ringma, J., Law, K. L., Monnahan, C. C., Lebreton, L., McGivern, A., Murphy, E., Jambeck, J., Leonard, G. H., Hilleary, M. A., Eriksen, M., Possingham, H. P., De Frond, H., Gerber, L. R., Polidoro, B., Tahir, A., Bernard, M., Mallos, N., Barnes, M., & Rochman, C. M. (2020). Predicted growth in plastic waste exceeds efforts to mitigate plastic pollution. *Science*, *369*, 1515–1518.

Beaumont, N. J., Aanesen, M., Austen, M. C., Börger, T., Clark, J. R., Cole, M., Hooper, T., Lindeque, P. K., Pascoe, C., & Wyles, K. J. (2019). Global ecological, social and economic impacts of marine plastic. *Marine Pollution Bulletin*, *142*, 189–195.

Bojke, L., Schmitt, L., Lomas, J., Ricahrdson, G., & Weatherly, H. (2018). Economic evaluation of environmental interventions: Reflections on methodological challenges and developments. *International Journal of Environmental Research and Public Health*, *15*(11), 2459.

Bucol, L. A., Romano, E. F., Cabcaban, S. M., Siplon, L. M. D., Madrid, G. C., Bucol, A. A., & Polidoro, B. (2020). Microplastics in marine sediments and rabbitfish (*Siganus fuscescens*) from selected coastal areas of Negros Oriental, Philippines. *Marine Pollution Bulletin*, *150*, 110685.

Clearwater Mills. (2013). *Jones Falls waterwheel powered trash interceptor budget detail*.

Cook, C. N., Pullin A. S., Sutherland W. J., Stewart G. B., & Carrasco L. R. (2017). Considering cost alongside the effectiveness of management in evidence-based conservation: A systematic reporting protocol. *Biological Conservation*, *209*, 508–516.

Crawford, S. (2008). *Waste-to-energy facilities provide significant economic benefits*. The Solid Waste Association of North America.

City of Bayawan. (2019). *Final waste management plan (2019-2028)*.

Consonni, S., Giugliano, M., Grosso, M. (2005). Alternative strategies for energy recovery from municipal solid waste. *Waste Management*, *25*(2), 137–148.

Crossman, N. D., Burkhard, B., & Nedkov, S. (2012). Quantifying and mapping ecosystem services. *International Journal of Biodiversity Science, Ecosystem Services & Management*, *8*(1-2), 1–4.

de Araújo, M. C. B., & Costa, M. F. (2006). Municipal services on tourist beaches: Costs and benefits of solid waste collection. *Journal of Coastal Research*, *22*(5), 1070–1075.

Dijkgraaf, E., Vollebergh, H. R. J. (2004). Burn or bury? A social cost comparison of final waste disposal methods. *Ecological Economics*, *50*(3-4), 233–247.

Fobil, J. N., Carboo, D., & Armah, N. A. (2005). Evaluation of municipal solid wastes (MSW) for utilization in energy production in developing countries. *International Journal of Environmental Technology and Management*, *5*(1), 6–86.

Giacovelli, C. (2018). *Single-use plastic: A roadmap for sustainability*. United Nations Environmental Programme.

Hale, R. C., Seeley, M. E., & Cuker, B. E. (2020). Plastic pollution and the Chesapeake Bay: The food system and beyond. In B. Cuker (Ed.), *Diet for a sustainable ecosystem* (pp. 325–348). Springer.

Han, S. G., Kim, H. K., Kim, S. D., & Noh, H. J. (2010). South Korea coastal cleanup program for marine litter. In C. Morishige (Ed.), *Marine debris prevention projects and activities in the Republic of Korea and United States: A compilation of project summary reports* (pp. 9–15). National Oceanic Atmospheric Administration.

Iacona, G. D., Sutherland, W. J., Mappin, B., Adams, V. M., Armsworth, P. R., Coleshaw, T., Cook, C., Craigie, I., Dicks, L. V., Fitzsimons, J. A., McGowan, J., Plumptre, A. J., Polak, T., Pullin, A. S., Ringma, J., Rushworth, I., Santangeli, A., Stewart, A., … Possingham, H. P. (2018). Standardized reporting of the costs of management interventions for biodiversity conservation. *Conservation Biology*, *32*, 979–988.

Jamasb, T., & Nepal, R. (2010). Issues and options in waste management: A social cost–benefit analysis of waste-to-energy in the UK. Resources. *Conservation and Recycling*, *54*, 1341–1352.

Kaza, S., & Bhada-Tata, P. (2018). *Decision maker's guides for solid waste management technologies*. World Bank.

Lavee, D. (2010). A cost-benefit analysis of a deposit-refund program for beverage containers in Israel. *Waste Management*, *30*(2), 338–345.

Leggett, C., Scherer, N., Curry, M., & Bailey, R. (2014). *Assessing the economic benefits of reductions in marine debris: A pilot study of beach recreation in Orange County, California*. Industrial Economic.

Löhr, A., Savelli, H., Beunen, R., Kalz, M., Ragas, A., & Van Belleghem, F. (2017). Solutions for global marine litter pollution. *Current Opinion in Environmental Sustainability*, *28*, 90–99.

Lombardi, L., Carnevale, E., & Corti, A. (2015). A review of technologies and performances of thermal treatment systems for energy recovery from waste. *Waste Management*, *37*, 26–44.

Mavrotas, G., Gakis, N., Skoulaxinou, S., Katsouros, V., Georgopoulou, E. (2015). Municipal solid waste management and energy production: Consideration of external cost through multi-objective optimization and its effect on waste-to-energy solutions. *Renewable and Sustainable Energy Reviews*, *51*, 1205–1222.

McIlgorm, A., Campbell, H. F., & Rule, M. J. (2011). The economic cost and control of marine debris damage in the Asia-Pacific region. *Ocean & Coastal Management*, *54*(9), 643–651.

McKinsey & Company, & Ocean Conservancy. (2015). *Stemming the tide: Land-based strategies for a plastic free ocean*. Ocean Conservancy.

Mouat, J., Lozano, R. L., & Bateson, H. (2010). *Economic Impacts of marine litter*. KIMO International.

Murdoch, W., Polasky, S., Wilson, K. A., Possingham, H. P., Kareiva, P., & Shaw R. (2007). Maximizing return on investment in conservation. *Biological Conservation*, *139*, 375–388.

National Center for Environmental Economics. (2010). Guidelines for preparing economic analysis. Washington, D.C. Environmental Protection Agency.

Newman, S., Watkins, E., Farmer, A., Brink T. P., & Schweitzer, J. P. (2015). The economics of marine litter. In M. Bergmann, L. Gutow, & M. Klages (Eds.), *Marine anthropogenic litter* (pp. 367–394). Springer.

O'Mahony, T. (2021). Cost-Benefit Analysis and the environment: The time horizon is of the essence. *Environmental Impact Assessment Review*, *89*, 106587.

Olofsson, M., Sahlin, J., Ekvall, T., & Sundberg, J. (2005). Driving forces for import of waste for energy recovery in Sweden. *Waste Management & Research*, *23*(1), 3–12.

Oosterhuis, F., Papyrakis, E., & Boteler, B. (2014). Economic instruments and marine litter control. *Ocean & Coastal Management*, *102*, 47–54.

Our Ocean. (2017). *OUR OCEAN 2017 commitments*. Our Ocean. https://www.oceanactionhub.org/our-ocean-2017-commitments

Philippines Statistics Authority. (2015). *POPCEN 2015 report*.

Seppelt, R., Fath, B., Burkhard, B., Fisher, J. L., Grêt-Regamey, A., Lautenbach, S., Pert P., Hotes S., Spangenberg J., Verburg P. H., & Van Oudenhoven, A. P. (2012). Form follows function? Proposing a blueprint for ecosystem service assessments based on reviews and case studies. *Ecological Indicators*, *21*, 145–154.

Stickel, B. H., Jahn, A., & Kier, B. (2012). *The cost to West Coast communities of dealing with trash, reducing marine debris*. Kier Associates.

Sutherland, W., Pullin, A., Dolman, P., & Knight, T. (2004). The need for evidence-based conservation. *Trends in Ecology & Evolution*, *19*, 305–308.

United Nations Environment Assembly. (2019). *UNEA Resolutions Marine Litter and Microplastics*. United Nations.

United States Census Bureau. (2019). *Quick facts*. Author.

Wang, Y., Geng, S., Zhao, P., Du, H., He, Y., Crittenden, J. (2016). Cost–benefit analysis of GHG emission reduction in waste to energy projects of China under clean development mechanism. *Resources, Conservation and Recycling*, *109*, 90–95.

Wilson, K., Carwardine, J., & Possingham, H. (2009). Setting conservation priorities. In R. S. Ostfeld & W. H. Schlesinger (Eds.), *Year in ecology and conservation biology* (pp. 237–264). Wiley-Blackwell.

Xin-gang, Z., Gui-wu, J., Ang, L., & Yun, L. (2016). Technology, cost, a performance of waste-to-energy incineration industry in China. *Renewable and Sustainable Energy Reviews*, *55*, 115–130.

Yang, N., Zhang, H., Chen, M., Shao, L. M., & He, P. J. (2012). Greenhouse gas emissions from MSW incineration in China: Impacts of waste characteristics and energy recovery. *Waste Management*, *32*(12), 2552–2560.

Zhang, D., Huang, G., Xu, Y., & Gong, Q. (2015). Waste-to-energy in China: Key challenges and opportunities. *Energies*, *8*(12), 14182–14196.

Zhu, Q. (2011). An appraisal and analysis of the law of "plastic-bag ban. *Energy Procedia*, *5*, 2516–2521.

SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

How to cite this article: Murphy, E. L., Bernard, M., Iacona, G., Borrelle, S. B., Barnes, M., McGivern, A., Emmanuel, J., & Gerber, L. R. A decision framework for estimating the cost of marine plastic pollution interventions. *Conservation Biology*. 2021;1–11. https://doi.org/10.1111/cobi.13827