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A Sustainable Solid Waste Management Plan for Sagarmatha (Mt Everest) National Park and Buffer Zone, Nepal

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Solid waste management is one of the most challenging issues for authorities in the Mt Everest region of Nepal, exacerbated in recent years by the rapid and continued growth of tourism. Open and unsightly landfills in the vicinity of villages along the main trekking routes are creating serious public health and environmental concerns, primarily because of their routine burning, resultant release of toxic chemicals, and contamination of groundwater supplies. Following 2 community consultations held in Namche Bazaar and Kathmandu in July 2019, a sustainable solid waste management plan was developed by the authors at the expressed request of local stakeholders. Based upon a collaborative approach, the plan proposes the implementation of a 4-point waste management process: (1) routine segregation of waste type at its source by lodges and home owners, (2) collection of recyclable waste from lodges and households and/or transfer of waste by lodges themselves to environmental stations, (3) transfer of all segregated waste to material recovery facilities for preprocessing and packaging, and (4) transfer of preprocessed materials to Lukla airport for transportation to Kathmandu and/or other recycling facilities. In January 2020, the plan was formally presented to local authorities, who, at the time of writing, are considering available options for its implementation. It is suggested that progress toward the sustainable management of solid waste in Khumbu be closely monitored in the coming years, as success here could provide working models for other heavily visited regions throughout the high mountain world.

***Keywords**: solid waste; high mountains; Nepal; Mt Everest; sustainable management.*

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Perhaps the time is not so far distant when travel agencies will include tours to the highest mountain in the world in their itineraries.

Erwin Schneider, 1963

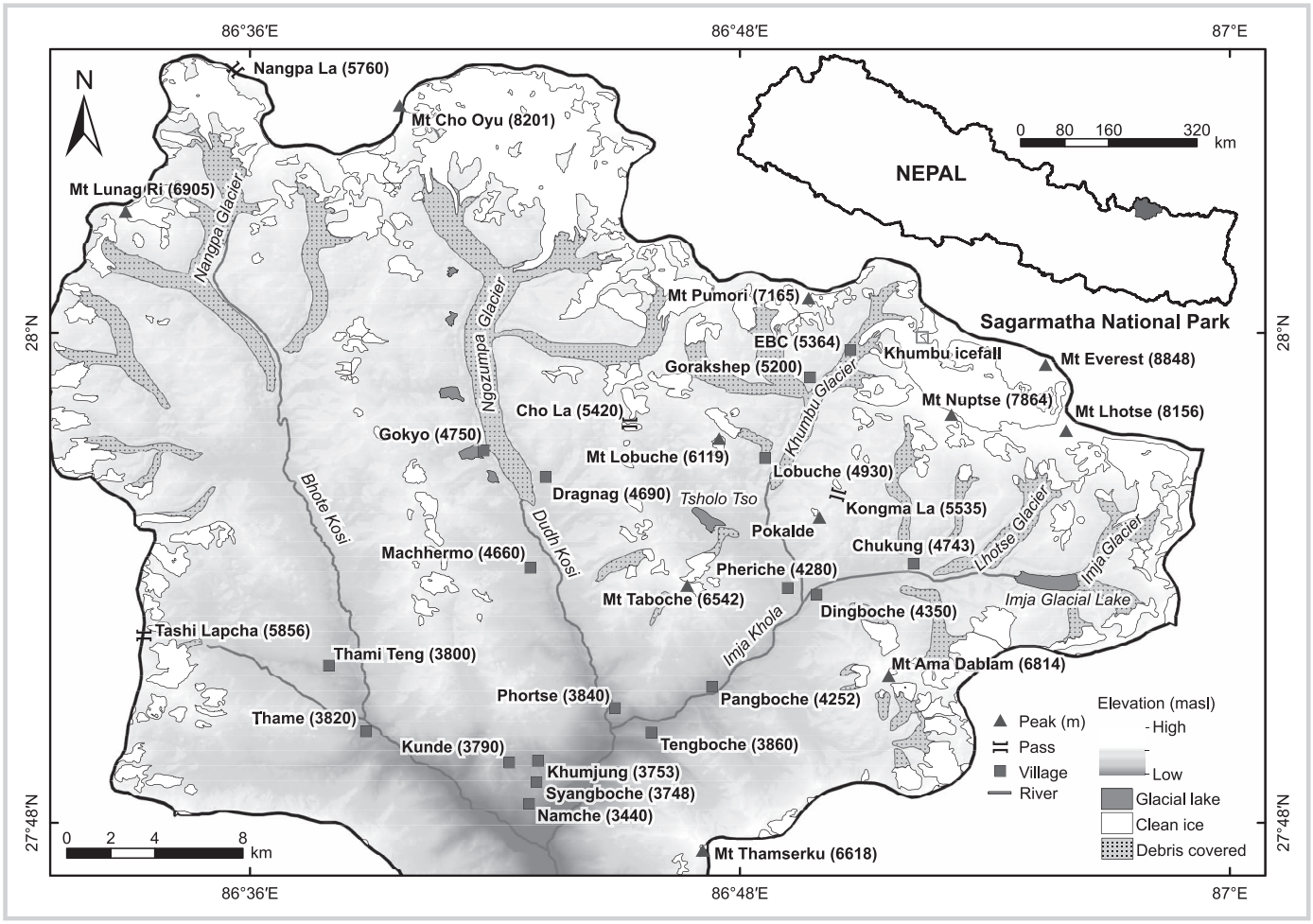
Introduction

The accumulation of solid waste in the world's high mountain camping sites, base camps, and high camps has been a chronic problem facing alpine ecosystems since mountaineering first became popular in the 1850s. The problem has further intensified with the steady acceleration of trekking and mountaineering tourism in the past 4 decades (Byers 2005; Goldenberg 2011; Mu and Nepal 2015).

Nowhere in the high mountain regions of Nepal is the landfill problem becoming more acute or serious than in the Sagarmatha (Mt Everest) National Park and Buffer Zone (SNPBZ) (Figure 1). The issue of garbage and human waste disposal in the Everest base camp and upon the mountain itself has made headlines for decades (Basnet 1984, 1993; Byers and Banskota 1992; Hickok 2018). Rarely, however, is the issue of solid waste management within the region's villages and main trekking routes part of the international dialogue. Tourist numbers continue to rise in the region (reportedly more than 60,000 in 2019, not counting support staff, which would bring the total number of nonlocal visitors to well over 120,000 per year, for a local population of 5000). As they do so, unsightly and unhealthy landfills have become a common sight within a few minutes' walk from most villages and lodges. A recent study (Maharjan and Gustafsson 2019) reports that as of the 2017 sampling season, there were 58 active open landfill pits within the SNPBZ (Figure 2). A more recent survey by the authors revealed that this total has now grown to more than 75 active landfill sites. In terms of volume, Manfredi et al (2010) calculate that 4.6 t per day of solid waste is generated during the peak tourist seasons of October–November and April–May, or 522 t per 90 days of peak tourist visitation per year. This figure has quite possibly doubled since the Manfredi study took place a decade ago, when tourist numbers were half what they are today. If so, more than 1000 tons of solid waste is generated in the park and buffer zone each tourist year, with nearly all of it ending up landfills.

Within the SNPBZ, the growing presence of these landfills (Figures 1, 2) poses a serious health and safety concern for humans and livestock alike (Rogers and

FIGURE 1 Sagarmatha (Mt Everest) National Park, Khumbu, Nepal. Lower-elevation shading shows the approximate areas of forest cover, and higher-elevation shading depicts shrub/grassland cover. (Map courtesy of Rakesh Kayastha, Kathmandu University)



Aitchison 1998; Ghimire, Jha, et al 2013; Posch et al 2015). In addition to being visually unsightly, landfills pose serious public health issues and environmental hazards because of the routine burning of waste materials, release of toxic chemicals, and contamination of local and downstream groundwater supplies (Ghimire, Caravello, et al 2013). Along with the widespread problem of leaking septic tanks from lodges (Byers et al 2020), landfill seepage has been linked to an increase in the incidence of gastrointestinal diseases among tourists and local people (Manfredi et al 2010; McDowell et al 2013). Landfills, and the routine burning and burying of their contents, have become the new norm for a solid waste "management strategy" in Khumbu, a region that ironically is also believed to be a sacred *beyul* (ie a valley blessed by Guru Rinpoche in the eighth century as a refuge for the faithful in times of trouble; see Skog 2010). In fact, proper solid waste management is becoming an issue for all of Nepal's high mountain parks and protected areas, even in its more remote trekking destinations (see Byers 2013a, 2013b; Byers et al 2020). Unfortunately, most developed country solutions, such as trucking or helicoptering garbage out of mountain protected areas, are neither feasible nor affordable in Nepal at this point in time.

Detailed information regarding solid waste amounts, type, and proportions in landfills throughout the park can be found a 2017 field survey conducted by Maharjan and Gustafsson (2019). Most solid waste deposited in landfills is composed primarily of tin, steel, or aluminum cans, glass bottles, plastic bottles, and other plastic goods (Figure 3). Electronic waste such as batteries, computer parts, and old household appliances is increasingly found in the landfills, as is medical waste in the vicinity of health clinics (Posch et al 2015; Maharjan and Gustafsson 2019; Faulon and Sacareau 2020). Local lodge owners and waste management organizations have treated this waste as "burnable garbage" since around 2010, as other options were either absent or perceived to be too costly. This particular nomenclature suggests that once burned, the problem is solved, when in fact the burning catalyzes a multitude of new health and environmental problems in the process (Maharjan and Gustafsson 2019). Additionally, landfills can remain a perpetual source of groundwater contamination for decades, releasing toxic substances to local and downstream regions year after year, particularly during the monsoon. Compost, consisting mostly of kitchen scraps from lodges, is regularly fed to livestock and does not present any sort of disposal problem at this time (Maharjan and Gustafsson 2019).

The current system of solid waste management within the SNPBZ relies on a "command-and-control" approach, which is a form of regulation that depends on government laws and agencies to enforce rules (eg cash deposits from mountaineering expeditions to encourage the return of

FIGURE 2 Location of the approximately 58 open and active landfills mapped in the SNPBZ in 2017. The number had grown to approximately 75 landfills in 2019 when the current study took place. Lower-elevation shading shows the approximate areas of forest cover, and higher-elevation shading depicts shrub/grassland cover. (Data source: Maharjan and Gustafsson 2019)

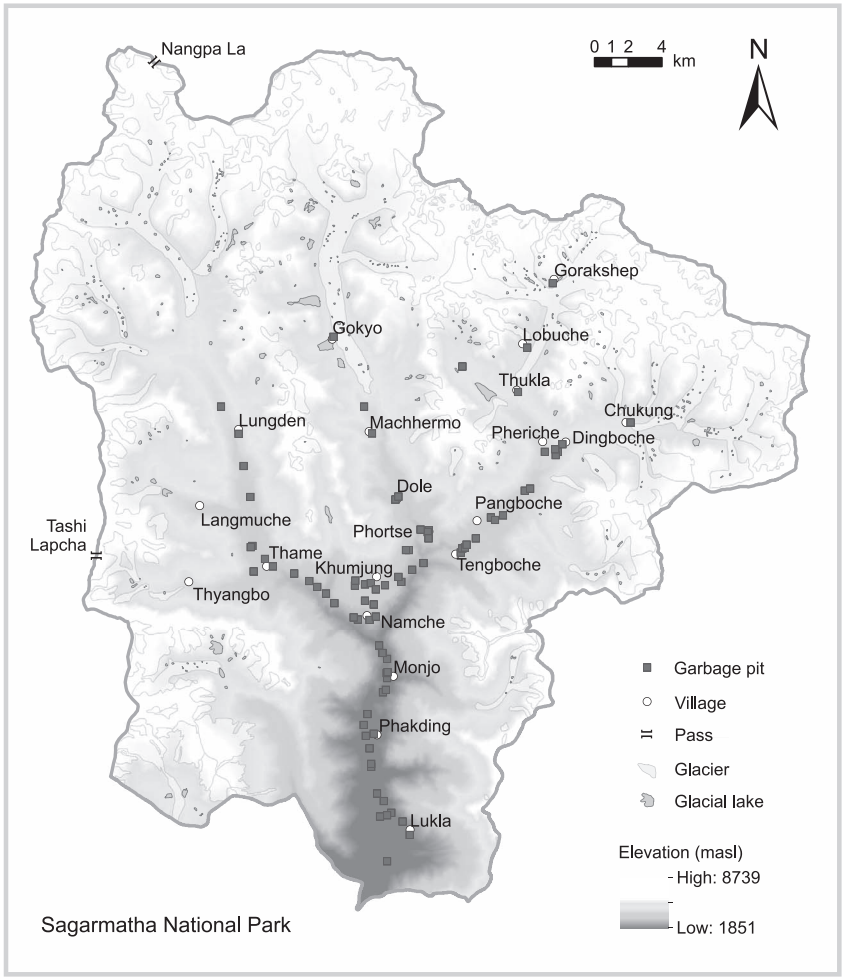


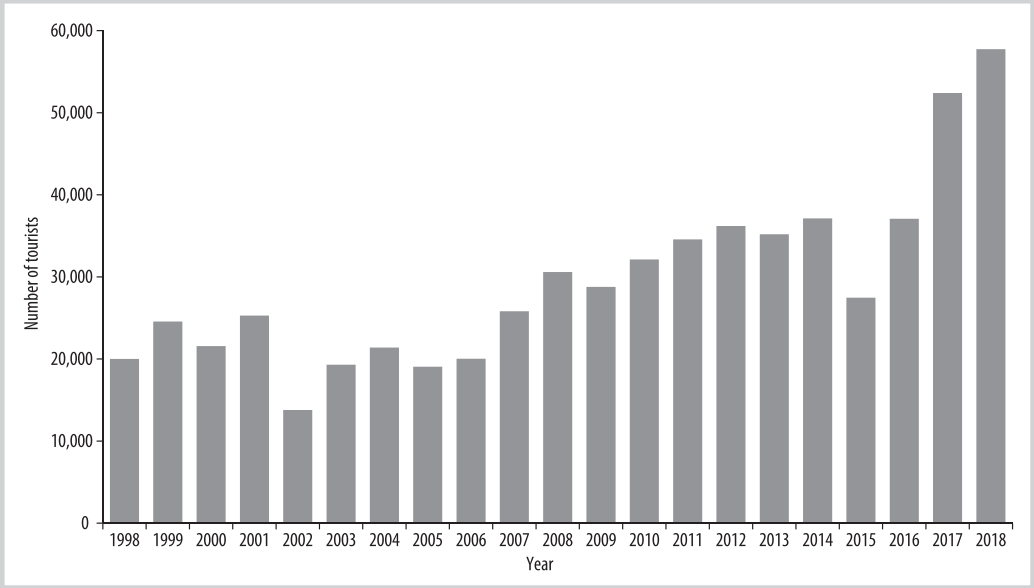
FIGURE 3 Open landfill in the vicinity of Gorakshep (5140 m), 2 hours' walk south of the Everest base camp. The garbage, consisting of plastics, metals, and paper products, is routinely burned and buried when the capacity of the open pit or rock exclosure is exceeded. (Photo by Alton C. Byers)

specified amounts of trash from the mountain; see SPCC 2018). Recognizing and incorporating the potential strengths of the private sector in waste management practices and solutions, such as the use of reducing, reusing, and recycling technologies, has not been common.

In summary, the overall situation of solid waste and its management in Khumbu is socially complex, involving multiple stakeholder groups with differing perspectives; it is environmentally challenging, because of the remote and high-altitude locations involved; and its solutions are poorly understood by the local, tourism, and scientific communities alike. However, most stakeholders (ie the national park, lodge owners, local government) now acknowledge that current practices are nonsustainable, especially given the SNPBZ's status as a World Heritage Site, finite amount of land suitable for landfills, and the sheer volumes of packaging and other waste materials now entering the park each year.

In response, the University of Colorado at Boulder and Arizona State University conducted an interdisciplinary study of the issues involved between July and October 2019, with the goal of identifying plausible, sustainable solutions to managing the problem of solid waste within the SNPBZ. The objectives of the study therefore included (1) further clarification of the key issues and challenges involved, (2)

FIGURE 4 Tourism growth since the late 1990s. (Source: Baral et al 2017)



mobilization of key stakeholders into a series of solution-oriented workshops, and (3) the development of a sustainable solid waste management plan for further testing and eventual park-wide implementation.

This paper presents a summary of project results, including efforts to develop a sustainable solid waste management plan for the Khumbu region at the expressed request of local stakeholders.

The setting

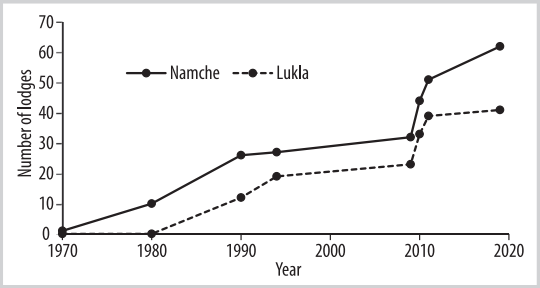
The Sagarmatha National Park is located in the Solukhumbu District of Province Number 1, Federal Republic of Nepal (Figure 1). It was officially designated a new national park in 1976 following years of study by Nepali and New Zealand park specialists (eg Lucas et al 1974; see Mishra 2008). The park covers an area of 1114 km^2 that is enclosed by some of the highest and most spectacular mountain peaks in the world. In 2002, a 275 km^2 buffer zone was added to the south that encompassed the Lukla and Phakding regions up to the check post and park border at Monjo. Vegetation formations broadly consist of south-facing shrub grasslands, north-facing fir/birch/rhododendron forests, alpine ecosystems above 4000 m, and perennial snow and ice above 6000 m (Byers 2005). The park is inhabited by the indigenous Sherpa people, who are said to have migrated from Tibet some 500 years ago. There is, however, evidence to suggest that the Sherpa and other ethnic groups had been visiting and modifying the landscape, primarily through pasture expansion, for at least the past 1000–5000 years (Byers 2005).

Visitors to Khumbu following Nepal's opening in 1950 consisted primarily of climbers (eg Hunt 1954), cartographers (eg Schneider 1963), and a few scientists (eg von Fürer-Haimendorf 1963). Tourism to the region began in the early 1960s, with some of the first known records listing 20 visitors in 1964 (Naylor 1970: 6); 3200 in 1973 (Mishra 1973: 3); and 5000 per year in 1980 (Pawson et al 1984). By the end of the 1980s, these number had increased to an average of 8000 tourists per year (Stevens 1993). Numbers grew steadily throughout the 1990s to approximately 20,000 per year in 1998, in spite of the commencement of the Maoist insurgency 2 years before.

Figure 4 shows the number of visitors to Khumbu per year since 1998. Several patterns of interest can be discerned. As mentioned, during the Maoist insurgency years (1996–2006), tourist numbers remained relatively stable in Khumbu at about 20,000 per year, when elsewhere in Nepal tourism had declined dramatically during the same time frame. The comparative stability of tourism in Khumbu was most likely linked to the Sherpas' lack of interest in a Maoist presence there. A significant drop in numbers in 2002 most likely reflects the reluctance of people to visit Nepal after the "Palace Massacre" the year before (Gregson 2002; Baral et al 2017), and decreases due to the attacks of 11 September 2001 (Byers 2005). After 2006, the end of the insurgency, tourist numbers increased steadily to 30,000 per year up to 2015, the year of the Gorkha earthquake, when they once again declined. From 2016 onward, however, the numbers of annual visitors increased dramatically to the 60,000 per year reported for 2019, only to drop to near zero at the time of writing (April 2020) as a result of the COVID-19 pandemic (see Ramming 2020). Collectively, these patterns of tourist numbers demonstrate how vulnerable international visits to Nepal can be in the face of national and global events.

As shown in Figure 5, the growth of tourism during the 1990s and 2000s coincided with the building of dozens of new lodges throughout the Khumbu (Byers 2005; Jacquemet 2017). As will be seen, the combination of increased tourism and lodge numbers also accelerated demands for imported food and goods, such as wine, whiskey, and other hard liquors (glass bottles); beer and soft drinks (aluminum cans); water and soft drinks (plastic bottles); canned food items (tin or steel containers); and shipping and packaging materials. This was the primary cause of the rather sudden and new accumulation of tons of solid waste in need of some sort of disposal mechanism. Such a phenomenon was something that had never before been experienced by the Sherpa people during 500 years of traditional farming, livestock

FIGURE 5 Lodge number increases in Namche Bazar and Lukla since 1970. (Courtesy of Dr Teiji Watanabe, Hokkaido University)



raising, and trade in the Khumbu (see von Fürer-Haimendorf 1984). Nor has it been seen in the 70 years of tourism development within the region since the first westerners visited in 1950.

Methods

We considered the entire SNPBZ to be a system of several major nodes (ie major towns and villages), each connected by a network of trails and other infrastructure critical to the tourism industry. Our main premise was that any initiative designed to address solid waste issues in the region would have to be closely tied to the tourism sector. That is, tourism has been the primary source of income for local economies since the mid-1990s. It has also been the driver for lodge owners to import tons of packaged goods in response to tourist demand, with the packaging and containers ultimately ending up as solid waste in landfills.

Our systems approach provided the space and means for different stakeholders to participate in solid waste management discussions as guided by a "collaborative governance" framework (Ansell and Gash 2008). Collaborative governance as used in this study is a process that utilizes and maximizes the strengths of different interest groups or stakeholders. In the case of the Everest region, we considered the 3 most critical sectors to be (1) local government and public agencies, (2) the private sector, and (3) community-based organizations. This framework ensured that all 3 sectors communicated with each other routinely, and in a collaborative manner, in order to achieve more than any one sector could have alone.

The collaborative governance framework also included private tourism entrepreneurs as active and integral parts of solid waste management. Our underlying premise was that adventure tourism, which has driven local economies for the past several decades, has now also created a number of significant social and environmental challenges (Stevens 2003; Nepal and Nepal 2004; Spoon 2013). Previous attempts to address solid waste issues in the SNPBZ have been fragmented and isolated (Rogers and Aitchison 1998; Manandhar et al 2010; Manfredi et al 2010; SPCC 2018), primarily because the "command-and-control" approach of solid waste management used tended to alienate the private sector from the management process. Likewise, in the past, the private sector had little incentive to contribute toward minimizing solid waste, eg through the development of income-generating opportunities in recycling, tax incentives for reducing the uses of plastic and other disposable materials, a cash deposit system for aluminum and other valuable containers, and/or the promotion of local foods and beverages over the importation of external products.

Steps taken to achieve the project's objectives included:

1. Mapping the major landfills, their connectivity, and the flow of major solid waste categories;
2. Developing a comprehensive inventory of major types and sources of solid waste (metal, plastic, organic);
3. Analyzing the types and feasibilities of technologies and/or policies available to determine which would be most appropriate for the different types of solid waste in the region;
4. Developing a collaborative governance framework of solid waste management that is participatory, responsive, and robust.

Fieldwork was conducted between July–August 2019, with a follow-up visit in October 2019 to finalize the management plan. Field activities consisted of (1) landfill and litter collection bin mapping throughout the park, using Global Positioning System and ArcGIS technologies; (2) interviews with key stakeholders in major villages; (3) the hosting of 2 community consultations in Namche Bazaar and Kathmandu on the topic of contemporary solid waste management in Khumbu; and (4) the development of the solid waste management plan based upon the collective information and data received. The final plan was presented to stakeholders in December 2019.

Local solutions to date

The Sagarmatha Pollution Control Committee (SPCC) is a local nonprofit organization that was established in 1991 as "the authorized local organization responsible for monitoring garbage in the permit required mountains and peaks." It "works with local communities to manage garbage in major settlements and along trekking trails" (SPCC 2018). Manfredi et al (2010) and Manandhar et al (2010) report that the SPCC has had some success in raising awareness and controlling litter along major trails and within a number of climbing base camps, including the periodic Everest base camp cleanups that receive the bulk of the global publicity (see Picheta 2019). However, both papers report that the SPCC is a small organization with limited technical capacity to address the range and complexity of tourist-related waste management issues in the region.

To their credit, the SPCC and its partners have installed about 70 waste collection bins throughout the park (Figure 6; see Figure S1, *Supplemental material*, https://doi.org/10.1659/MRD-JOURNAL-D-20-00018.1.S1), banned the importation of glass beer bottles, organized yearly Everest and trekking peak base camp cleanups, and conducted village compost training workshops. They continually look for new and innovative solutions to the challenges of managing the waste generated by the tourist trade (SPCC 2018). The SPCC also works closely with Sagarmatha Next (https://sagarmathanext.com/about-us/), a nonprofit organization focused on issues of sustainable tourism within the park and buffer zone. Sagarmatha Next is establishing a new interpretation center at Syangboche that includes exhibits promoting innovative approaches to solid waste management, reduction, and reuse, in addition to interactive natural and cultural history displays. Other planned or ongoing programs include the hosting of workshops where artists turn waste into art and

FIGURE 6 One of the approximately 70 litter bins installed by the SPCC throughout the national park and buffer zone. (Photo by Alton C. Byers)

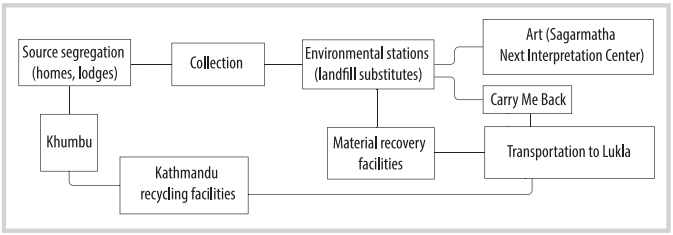
useful products (eg handbags, jewelry), museum exhibits of solid waste recycling methods, and the establishment of a "Carry Me Back" program where volunteer tourists carry out 1 kg of preprocessed garbage to collection facilities in Lukla.

Community consultations

In July 2019, 2 solid waste workshops were facilitated in Namche Bazaar and Kathmandu by the University of Colorado at Boulder and Arizona State University. Participants in the Namche Bazaar meeting included elected representatives of the local government, national park, buffer zone committee, lodge owners, SPCC, Sagarmatha Next, and private citizens. Joining the Kathmandu meetings were members of the SPCC, Nepal Tourism Board, Solukhumbu District representatives, and Sagarmatha Next. Participants in both meetings were clearly aware of the problem of solid waste and its management in Khumbu, as well as of prospective strategies and actions needed to resolve the issue. However, they also expressed a need for specific guidance regarding a realistic, sustainable, and cost-effective plan for the management of solid waste in Khumbu. The University of Colorado and Arizona State University were thus requested to develop a detailed management plan for consideration by the Khumbu management authorities.

During the consultation, the concurrent and growing problems of freshwater supply, water contamination, and human waste management were also highlighted as priorities by stakeholders. All 3 represent chronic problems that have been exacerbated by contemporary increases in tourist and lodge numbers, as well as by the lack of expertise and resources to adequately deal with them (see Aubriot et al 2020; Manfredi et al 2010). In recent years, changing weather patterns in Khumbu have had an impact upon traditional freshwater sources, especially springs (McDowell et al 2013). Additionally, Byers and Thakali (2014: 76) note that there "are also other nonclimatic stressors, such as pollution from leaking septic tanks [mostly from lodges] or toilets situated over or near seasonal water courses, and increases in waterborne diseases may further amplify the water scarcity problem..." The problem of human waste management in villages has been a concern for several decades (see

FIGURE 7 Schematic flowchart illustrating the cycle of waste collection, preprocessing, exportation, and recycling system.



Lachapelle 1995, 1998), and managing the 8000 kg of human waste generated by the Everest base camp each climbing season continues to make international headlines each year (see Gurubacharya 2019).

Stakeholders also agreed that one the of first and most fundamental challenges of any new program, including waste management and control, will be achieving clarity of roles and responsibilities with the more empowered local government, the Khumbu Pasang Lhamu Rural Municipality, under Nepal's new federalism system. The improvement of recycling facilities in Kathmandu was also recognized as a critical component of any new solid waste management system in Khumbu (Pathak 2019), as was a greater focus on reducing the amount of incoming packaging materials while reusing those that do arrive.

With the above caveats in mind, participants agreed that the focus of the consultations would be upon the development of a sustainable solid waste management plan, which remained the focus of our efforts during the next several weeks of interviews and field site visits.

Results: a sustainable solid waste management plan proposal

Building upon the previous work of the SPCC, the nonprofit Sagarmatha Next, and local government departments, we recommended that a 3-step process be followed. The first step included 4 separate components: (1) source segregation (ie the manual segregation of waste into separate collection bins), (2) routine collection by the SPCC, (3) establishment of environmental stations (ESs; waste collection stations designed to replace landfills and waste enclosures), and (4) the establishment of material recovery facilities (MRFs) or solid waste preprocessing stations, where plastics can be shredded, aluminum cans compacted, etc. The second step involved the transportation of the preprocessed solid waste to transfer centers at Lukla airport. The third step, once the entire system within the Namche/Khumjung/Kunde region is functioning, was replication of the system throughout the remaining national park and buffer zone. Each component is described briefly in Figure 7. All 3 steps assume that concurrent sensitization and awareness-building activities are being provided to lodge owners, tourists, schoolchildren, the national park, local government, and other concerned entities.

Source segregation

Source segregation refers to the precollection separation of plastics, glass, aluminum, and other forms of inorganic waste into aggregate groups, each stored in a separate bin, by

households, lodges, restaurants, bakeries, and other entities. This practice greatly facilitates the collection process by the SPCC as well as the later preprocessing, packaging, and shipping activities described below.

Collection

The collection of solid and organic waste should continue to be supervised by the SPCC. A system of daily waste pickup should be developed based upon the particular material, for example Monday for plastics, Tuesday for metals, Wednesday for paper, and Thursday for organic wastes. Fridays and Sundays would be used by the SPPC for work at designated ESs and MRF locations described below.

Environmental stations

ESs are fenced and roofed structures with collection bins that are designed to replace the open pits located throughout the park and buffer zone. They are provided specifically for those businesses or households choosing to transport their own solid waste to an ES facility as opposed to participating in the SPCC-directed system of waste collection and preprocessing program (see Figure S2, *Supplemental material*, https://doi.org/10.1659/MRD-JOURNAL-D-20-00018.1.S1). They should be well fenced and roofed to avoid rainwater coming into contact with the recyclables, and also to protect contents from foraging animals.

Material recovery facilities

The MRF further segregates and preprocesses waste materials into forms more suitable for transportation back to Lukla and Kathmandu. In most cases, a single MRF can serve multiple villages (eg Namche/Khumjung/Kunde or Chukung/Dingboche/Pheriche). Like the ES, an MRF is a covered and cement-floored facility that contains adequate storage space for the raw materials; appropriate, repairable waste preprocessing machines that can include shredders (for plastics), compactors (for aluminum and steel cans), and balers (for plastics, metals, papers); and adequate storage space for all preprocessed waste materials (see Figure S3, *Supplemental material*, https://doi.org/10.1659/MRD-JOURNAL-D-20-00018.1.S1).

Preprocessed material export to transportation facilities

A number of options exist for moving raw and preprocessed materials from their points of origin to transportation to Kathmandu and/or other recycling facilities. The relative costs of each will need to be determined over time. Within the Khumbu (ie from village to ES and MRFs), they include:

- **Porter:** Until a system of ES and MRFs is established throughout the park and buffer zone, porters may be the most appropriate option for the transport of solid waste to existing preprocessing facilities. Syangboche is recommended as an initial MRF site, since it is centrally located for villages to both the west (eg Thame) and the east (eg Tengboche). Additionally, porters returning without loads after ferrying supplies to the Everest and other base camps could also be employed to carry waste to preprocessing facilities.
- **Yak/*dzopkio*:** Some of the more remote villages, such as Gorakshep, utilize yaks and *dzopkios* to transport supplies from Namche Bazaar back to their lodges. As the yaks usually make the journey to Namche without a load, they could be utilized for the transportation of solid waste to the MRF in Syangboche.

For transportation from the ES and MRFs to Lukla and Kathmandu, options include:

- **Carry Me Back:** In October–November 2019, the SPCC and Sagarmatha Next conducted a pilot test of the Carry Me Back initiative. Tourists and trekking guides carried 1 kg of preprocessed waste from Namche Bazaar back to Lukla on a voluntary basis. From there, it was then transported back to Kathmandu by the airlines (see Figure S4, *Supplemental material*, https://doi.org/10.1659/MRD-JOURNAL-D-20-00018.1.S1).
- **Plane:** Nepali airline companies have long cooperated with recycling initiatives within the Khumbu by transporting the collected Everest base camp garbage free of charge back to Kathmandu. These relationships should continue to be explored and developed as the sustainable solid waste program gains momentum. However, nearly all Kathmandu–Lukla–Kathmandu flights were recently moved to Ramechaap, a 4–5-hour drive from Kathmandu, because of their excessive number and disruption of other air traffic at Tribhuvan International Airport. This location change will require the provision of additional transport mechanisms (ie trucks) from the drop-off point at Ramechap to Kathmandu that were not previously needed.
- **Helicopter:** Helicopters making longline cargo deliveries (Shree Airlines MI17 Cargo Helis, B3s) often return to Phaplu and/or Takshindu empty once their cargos have been off-loaded. The possibility of utilizing the helicopters for preprocessed waste transportation out of the Khumbu should be investigated.
- **Ropeway:** Discussions are currently underway regarding the construction of a ropeway system (see Post 2004) that could deliver food and other supplies to Namche Bazaar in place of the current system of using mules and yaks/*dzopkios*. A ropeway system could likewise be used to transport preprocessed solid waste out of the Khumbu and back to Lukla for delivery to recycling facilities in Kathmandu.
- **Road:** A road is currently under construction that will terminate in Lukla, in part a response to the growing delays and cancellations of air traffic in recent years due to increased cloudiness (Byers and Thakali 2014). Once completed, the road could provide another means of transporting preprocessed solid waste from the Khumbu to recycling centers in Kathmandu or the Tarai.

Phased regional replication

Expansion of the program from Namche to other nodes will depend upon the SPCC's desire to do so, the cooperation and desires of all stakeholders, and the level of support available from local government, SNPBZ, and other in-country funding entities. A spatially phased replication process was recommended as follows:

- **Year 1:** Lukla–Namche;
- **Year 2:** Namche–Khumjung–Kunde;

- **Year 3:** Phakding–Monjo–Tengboche–Deboche–Pangboche;
- **Year 4:** Dingboche–Chukung–Pheriche–Lobuche–Gorakshep;
- **Year 5:** Phortse–Dole–Machhermo–Gokyo;
- **Year 6:** Thamo–Thame–Marlung–Lungdhen.

Treatment of existing and older landfills

The approximately 75 open garbage and landfill pits documented by this study do not include the many dozens of older, buried landfills located throughout the park. Both the active and historic landfills can continue to contaminate freshwater supplies for downstream villages and communities for decades to come. They will, therefore, ultimately need to be excavated, segregated according to waste type (eg plastic, aluminum, steel), and integrated into the recycling process established through the steps recommended above.

Conclusion

Solid waste management and disposal issues have emerged as major challenges for high mountain regions throughout the world, particularly those with growing adventure tourism industries. The results of this study suggest that collaborative approaches to the development of waste management systems, including the public, private, and community sectors, could provide more sustainable alternatives to the conventional practices of landfills, content burning, and burying. The collaborative process can also build trust among the various partners in ways that beneficially leverage the relative strengths and contributions of each.

Following 2 community consultations held in Namche Bazaar and Kathmandu in July 2019, a sustainable solid waste management plan was developed by the authors at the expressed request of local stakeholders. Building upon the previous work of several other local organizations, the plan proposes the establishment of a 4-point waste management process that includes waste segregation, collection, transfer to shipment stations, and transportation to recycling facilities in Kathmandu. Ultimately, the issue of waste buried during the past 15–20 years will need to be dealt with as well, as will other growing problems such as future freshwater supply sources, water contamination, and human waste disposal. Likewise, progress in the implementation of the current plan should be carefully monitored, as success in the Khumbu could provide working models for other high-use mountain regions of the world where solutions to effective solid waste management have remained elusive for decades.

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Supplemental material

FIGURE S1 Location of approximately 70 litter bins installed by the Sagarmatha Pollution Control Committee (SPCC).
FIGURE S2 Model environmental station (ES) located at the Sagarmatha Next Interpretation Center, Syangboche. (Photo by Alton Byers).
FIGURE S3 Material recovery facility (MRF) schematic design. (Figures courtesy of Nabin Maharjan, CEO, Blue Waste to Value, https://bw2v.com/)
FIGURE S4 The "Carry Me Back" initiative. (Photo by Alton Byers)

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