Material Flow Analysis for Kayangel State, Republic of Palau:

Solid Waste Management on a Small Pacific Island

By

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PREFACE

Research completed for this report took place between September 2006 and August 2008 during my service as a United States Peace Corps Volunteer on Kayangel Island in the Republic of Palau. I served as an environmental health extension agent and local representative of Palau's Division of Environmental Health, as well as working as a teacher for grades 1-8 at John F. Kennedy Elementary School.

This report is submitted to complete my master's degree in environmental engineering from the Master's International Program in Civil and Environmental Engineering at Michigan Technological University. Its focus is on the work I did in assessing local solid waste generation and community-wide solid waste management planning for Kayangel Island.

TABLE OF CONTENTS

PREFACE iii
LIST OF FIGURES vi
LIST OF TABLES vii
ACKNOWLEGDEMENTS viii
ABSTRACT ix
LIST OF ACRONYMS x
1 INTRODUCTION AND OBJECTIVES 1
1.1 Introduction 1
1.1.1 A Case for Sustainable Development 1
1.1.2 Small Island Developing States (SIDS) 2
1.2 Objectives 4
1.3.2 Material Flow Analysis 6
1.3.3 Argument for MFA approach 9
2 BACKGROUND ON REPUBLIC OF PALAU 12
2.1 Geography, Geology 12
2.2 Government, Economy 13
2.2.1 Economic and social factors contributing to waste scenario 16
3 METHODOLOGY 18
3.1 Case Study: Kayangel State, Republic of Palau 18
3.1.1 Location Maps 18
3.1.2 Site-specific context 20
3.1.3 Employment and Income 23
3.2 KHSWGS Survey Methods 24
3.2.1 Seasonality 24
3.2.2 Sampling Scope 25
3.2.3 Survey time period 26
3.2.4 Dates 27
3.2.5 Eco Map of Kayangel 28
3.2.6 Community Participation 29
3.2.7 Waste Categories 29
3.3 Instructions 31
3.4 Material Flow Analysis 33
3.4.1 Material Flow Diagram for Kayangel Island 36

3.4.2 Comparison of KHSWGS survey and MFA 37
3.4.3 Material fate categories 38
3.4.4 Flotsam and Jetsam 40
4 RESULTS AND DISCUSSION 44
4.1 KHSWGS Survey Results 44
4.2 Results in Context of Global Solid Waste Composition and Generation Rates. 45
4.3 Regional Solid Waste Comparison 48
4.4 Analysis of results on local level 51
4.4.1 Kayangel Solid Waste Generation by Season 51
4.4.2 Kayangel Solid Waste Generation by Household Employment 52
4.5 Limitations of KHSWGS Survey 57
4.5.1 Interpretation 58
4.5.2 Time Scale Considerations 58
4.5.3 Population Variability 59
4.5.4 Disposal Mechanisms 60
4.6 Material Flow Analysis Results 60
4.6.1 Comprehensive Kayangel Annual Solid Waste Generation 61
4.6.2 Burning 62
4.6.3 Flotsam and Jetsam 63
4.6.4 Quantitative MFA for Kayangel Island 64
4.7 Degradation Analysis 66
5 CONCLUSIONS AND RECOMMENDATIONS 68
6 REFERENCES 73
APPENDIX A: Palauan Language KHSWGS Survey 79
APPENDIX B: Results of KHSWGS 80
APPENDIX C: Kayangel Solid Waste Generation in Terms of Material Fate 82
APPENDIX D: Global MSW Comparisons Excluding Organics 83
APPENDIX E: Pacific Region Solid Waste Composition Comparison 84
APPENDIX F: Kayangel Average Annual Solid Waste Generation & Composition by Household Employment 85
APPENDIX G: Kayangel Average Annual Solid Waste Generation by Household Employment (weight in lbs.) 86

LIST OF FIGURES

Figure 1: Map of Western Pacific Ocean region, showing Republic of Palau 12

Figure 2: Map of Republic of Palau showing locations for Kayangel State and Koror ... 18

Figure 3: Satellite image of Kayangel State atoll. 19

Figure 4: Population demographics by age and state (OPS, 2006a)................................ 21

Figure 5: Palau population statistics by age (OPS, 2006a). 22

Figure 6: Palau population demographics by age and birthplace (OPS, 2006a). 23

Figure 7: Average annual household income and expenditure information for Kayangel/Angaur and Palau (OPS, 2006b). 24

Figure 8: Kayangel community eco-map with KHSWGS survey locations..................... 28

Figure 9: Materials flow diagram for Kayangel State, Republic of Palau. 36

Figure 10: Venn diagram comparison of MFA and solid waste generation survey. 37

Figure 11: Kayangel annual household solid waste generation (lbs/yr). 44

Figure 12: Global municipal solid waste compositions, excluding organics, compared with Kayangel. 46

Figure 13: Global MSW Generation Rates (global data from Troschinetz, 2008). 47

Figure 14: MSW composition for Kayangel & SPREP countries, organics excluded. 49

Figure 15: Kayangel State household employment statistics. 53

Figure 16: Kayangel average annual solid waste generation by household employment. 54

Figure 17: Kayangel average annual solid waste generation by composition and household employment. 56

Figure 18: Kayangel annual solid waste generation organized by material fate. 61

Figure 19: Graphical representation of Kayangel MFA on an Annual Basis. 65

LIST OF TABLES

Table 1: General statistics for the Republic of Palau and Kayangel State....................... 16

Table 2: Republic of Palau population statistics by sex, age, and state (OPS, 2006a). 21

Table 3: KHSWGS survey dates, school-year and nonschool-year 27

Table 4: Waste segregation categories for KHSWGS. 30

Table 5: Material fate categories and assumptions for Kayangel MFA. 35

Table 6: Seasonal solid waste generation projections based on school-year (SY) and nonschool-year (NSY) data from KHSWGS. 51

Table 7: Solid waste data and projections from Kayangel coastal clean-up, southeastern quarter of island, May 2008. 63

Table 8: Degradation scales for common materials... 67

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ABSTRACT

Solid waste generation is a universal human activity. Industrialization and globalization have served to alter the composition of goods and to increase access to these products such that management of the resulting solid waste has become a global problem recognized by the United Nations. Nowhere is this more apparent than in the context of a Small Island Developing State (SIDS) like the Republic of Palau.

Using the island setting as a controlled microcosm for assessing the generation, composition, and management of solid waste, it is possible to make a more comprehensive investigation of both local practices and global waste problems. This report documents the implementation of two strategies for achieving these aims, using Kayangel Island in the Republic of Palau as a case study. First, a household solid waste study based on fieldwork conducted by the author from March-June 2008 serves to characterize solid waste by type and mass for 25 of the 30 households within the community of Kayangel. Next, a material flows analysis (MFA) is employed to spatially trace the fate of materials that have been introduced to the island (nonorganic fraction of solid waste generation). MFAs have been implemented as an assessment tool for tracing the movement of specific target elements and streamlining processes in a variety of applications worldwide. To the author's knowledge, this is the first application of MFA in the context of solid waste management for a SIDS.

The results of these two analyses are collectively used in characterizing household solid waste in Kayangel by type and annual generation, as well as assessing current management practices. Twelve waste categories used in classifying the household solid waste generation study are objectified within the MFA to reflect material fate categories: accumulation, removal from the island, or burning. The accumulation category accounts for 93% of total annual household solid waste, and as such is the focus for further analysis of local management practices. Combining the household solid waste characterization and generation data with all material flows for the island serves to broaden the scope of the analysis to include all material flows. Based on this MFA, the Kayangel community collectively produces an average 0.93 lbs. of solid waste per capita per day. This can be subdivided into daily per capita solid waste generation rates for the three material fate categories: 0.87 lbs. of accumulation, 0.04 lbs. removed from island, and 0.02 lbs. burned. Recommendations include segregation of household solid waste, consolidation and possible exportation of goods within the accumulation material fate category, as well as implementation of waste reduction strategies on Kayangel Island, as well as the world at large.

LIST OF ACRONYMS

BESR	Board on Earth Sciences and Resources
BPoA	Barbados Programme of Action
CIA	Central Intelligence Agency
COFA	Compact of Free Association
CTF	Compact Trust Fund
DEH	Palau's Division of Environmental Health
EU	European Union
GDP	Gross Domestic Product
IMF	International Monetary Fund
JFK	John F. Kennedy Elementary School
KHSWGS	Kayangel Household Solid Waste Generation Study
MDGs	Millennium Development Goals
MFA	Material Flow Analysis
MRD	Ministry of Resources and Development
MSW	Municipal Solid Waste
NEHAP	National Environmental Health Action Plan
OPS	Palau's Office of Planning and Statistics
PacIOOS	Pacific Islands Ocean Observing System
PALARIS	Palau Automated Land and Resource Information System
PET	Polyethylene terephthalate
ROP	Republic of Palau
SIDS	Small Island Developing States
SPREP	South Pacific Regional Environment Programme
UN	United Nations

UNDESA	United Nations Department of Economic and Social Affairs
UNEP	United Nations Environment Programme
USDOSBEAPA	U.S. Dept. of State, Bureau of East Asian & Pacific Affairs
USEPA	United States Environmental Protection Agency

1 INTRODUCTION AND OBJECTIVES

1.1 Introduction

1.1.1 A Case for Sustainable Development

Solid waste generation is a universal human activity, the management of which at times plagues the world as a whole. Although solid waste management must ultimately be micromanaged at the local level, numerous global initiatives have been established in recognition of the ubiquitous nature of this problem. Specifically, international collaboration on the part of the United Nations (UN) has resulted in framing the problems of development in a global context, supported by significant resolutions for cooperative action.

The General Assembly of the UN first established the need for international cooperation and coordinated, multi-faceted approaches for achieving *sustainable development* during the World Commission on Environment and Development in 1983. This commission, alternatively known as the Brundtland Commission (for chairwoman Gro Harlem Brundtland of Norway), formerly introduced this now ubiquitous approach to contemporary international development work by acknowledging the contributing elements of environment, economics, and social factors. Perhaps the most famous quote from the report of the Brundtland Commission was the assertion that “humanity has the ability to make development sustainable -- to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs” (United Nations, 1987, p. 24). Furthermore, the commission suggested that “the real world of interlocked economic and ecological systems will not change; the policies and institutions concerned must” (p. 25). This not only established the concept of sustainable development, but it also called for accountability within the international political arena. The message was clearly intended to empower, yet it was sufficiently vague in its demands for future collaboration and more specific definition of these problems.

In 1992, the international community reaffirmed its commitment to collectively address sustainable development. This time, more than 178 member countries of the UN adopted the Rio Declaration on Environment and Development. If the Brundtland Commission served as a baseline call for action in sustainable development, then the Rio Declaration took the next step in outlining specific objectives and the required principals for establishing the necessary global partnership in fulfilling these aims (UN, 1995). Following the adoption of the Rio Declaration, a plan of action was devised for implementing these commitments, outlining specific activities, cost assessments, and means of implementation from an international to regional and local levels. This plan, Agenda 21, was unveiled between 26 August and 4 September 2002 at the World Summit on Sustainable Development in Johannesburg, South Africa.

The UN adopted the Millennium Development Goals (MDGs) in 2000. The MDGs effectively mandated a paradigm shift in international development work aimed at ending poverty by way of benchmark targets and a global partnership guided by the official doctrine of sustainable development (UN, 2008). This directive by the UN included specific and time-constrained objectives, which have served to facilitate reforms by requiring a more comprehensive approach to the age-old problems of development. The Millennium Development Goals did not introduce the concept of sustainable development; however they marked a departure from previous UN resolutions in establishing concrete steps for achieving these goals.

1.1.2 Small Island Developing States (SIDS)

The unique geographic constraints of small islands isolated from each other by wide stretches of ocean puts nations like the Republic of Palau in a distinctive category of development, deemed small island developing states (SIDS). Specific obstacles to sustainable development facing these low-lying coastal nations include small populations, limited resources, isolation, susceptibility to natural disasters, vulnerability to external shocks (e.g., climate change, economics), and excessive dependence on international trade (UNDESA, 2007). Challenges to development in SIDS were addressed at the 1992 UN Earth Summit in Rio de Janerio, Brazil. The resulting report, Agenda 21, devotes an entire chapter (UNDESA, 2005, Chapter 17) to defining measurable goals and directives specific to international cooperation and the role of SIDS as stewards in conservation and sustainable use of the world's coastal and marine environments.

The Global Conference on Sustainable Development of Small Island Developing States convened in 1994 to define measurable actions to be taken by SIDS and supported by the international community in accordance with Agenda 21. The Barbados Programme of Action (BPoA) was adopted by attendees, including a representative on behalf of Palau, committing to instill regulatory measures for reducing, preventing, controlling, and monitoring pollution (UNDESA, 2000). This included a mandate for the development of information systems and baseline data for waste management and pollution control. Of particular note was the call to monitor the types and quantities of wastes, including both land- and sea-based sources of pollution. The BPoA was formally adopted by the General Assembly of the UN in 1995, under Resolution 49/122 (UN, 1995), thus renewing momentum for and commitments toward global partnerships and directives from the Rio Earth Summit. Palau's 10-year progress report on the BPoA (MRD, 2004) cites progress in fulfillment of the directives it adopted at the Global Conference on Sustainable Development of Small Island Developing States.

With regards to solid waste, Palau is in the process of upgrading the National Landfill in Koror State, Palau's population center, for centralized solid waste management; additionally, the Division of Environmental Health (DEH) has created a Vector Control Unit, as well as a National Environmental Health Action Plan (NEHAP). Among the lingering solid waste-related challenges and constraints to achieving sustainable development specifically mentioned in the report are rapid, unplanned development, pollution, and pressures to develop a viable national economy (DEH, 2004). Rapid, unplanned development in SIDS such as Palau serves to exacerbate the problems of solid waste disposal, as it often introduces more waste into a fragile environment that already has few viable solid waste disposal options. Pollution can also impact solid waste management efforts by further constraining Palau's limited natural resources, and posing additional challenges to waste segregation and mitigation. As a SIDS, Palau has limited options in the development of its national economy, and tourism has been the dominant industry (USDOSBEAPA, 2008). This has resulted in increased volumes of imported goods and solid waste generation, thus compounding solid waste management problems. According to Palau's NEHAP (DEH, 2004), solid waste management in rural areas, such as Kayangel State, will continue to be decentralized, however improvements will be made in collection, segregation, and transport of recyclable wastes to the National Landfill.

1.2 Objectives

This study analyzed the production and consumption of materials within the island community of Kayangel State in order to improve local solid waste management practices. To fulfill some of the waste management measures listed in the Barbados Programme of Action (BPoA), a solid waste characterization and materials flow analysis was performed on the island community of Kayangel State in the Republic of Palau during the author's time as a Peace Corps volunteer (PCV) there from September 2006 to August 2008.

Particular attention was devoted to the waste management and pollution control measures outlined as part of the Barbados Programme of Action, including: 1) characterization of land- and sea-based solid waste generation by type and quantity, 2) identification of recycling and resource recovery potential, 3) documentation of available waste minimization and pollution diversion strategies, and 4) analysis of viable local solid waste disposal options. Additionally, this study compares waste generation rates and waste content in Kayangel State with other Pacific Islands and developing countries.

This first chapter outlines a brief history of global attitudes towards solid waste with the evolution of sustainable development, particularly in SIDS like Palau. Material flow analysis (MFA) is introduced as an assessment tool that has been implemented to improve efficiency and maximize material use in many contexts worldwide. The focus then shifts to the application of MFA for the purpose of evaluating solid waste generation within a defined system and using its more holistic vantage to improve management practices in SIDS.

Chapter 2 provides background information about the Republic of Palau, describing geography, geology, government, and economy. It also includes an overview of social factors influencing local solid waste management attitudes and practices.

Kayangel Island, located within an atoll in the northernmost part of Palau, is used as a case study for assessing solid waste composition and generation in Chapter 3. This chapter defines the methodology for a solid waste generation survey that was conducted between March and July 2008, as well as a MFA designed to characterize solid waste for the community of Kayangel.

The results from the Kayangel solid waste generation study and the MFA are presented and analyzed in Chapter 4. Solid waste composition and generation on Kayangel are compared on local, regional, and global scales.

Finally, Chapter 5 highlights the significance of the solid waste generation study and the MFA on Kayangel, providing recommendations for using the results to improve local solid waste management practices.

1.3 Literature Review: Sustainable Solid Waste Management and Material Flow Analysis

As part of its comprehensive plan, Agenda 21 specifically addresses solid waste management in Chapter 21, characterizing it as a critical component "in maintaining the quality of the Earth's environment and especially in achieving environmentally sound and sustainable development in all countries" (UNDESA,2005). The document seeks to address solid waste management by addressing the root cause of solid waste generation (production and consumption), in addition to defining a holistic management approach. The hierarchy of environmentally sound solid waste management it outlines involves: 1) minimizing wastes, 2) maximizing environmentally sound waste reuse and recycling, 3) promoting environmentally sound waste disposal and treatment, and 4) extending waste service coverage.

While Agenda 21 offers a much needed strategy for action with the solid waste management hierarchy, the more significant outcome is perhaps its identification of unsustainable production and consumption patterns as the root cause of solid waste generation. Prior to outlining any treatment procedures, it is first crucial to assign spatial boundaries for defining the system that is to be managed. Once the system is localized, it is then possible to trace the patterns of consumption and production inherent in the creation of the targeted solid waste.

1.3.2 Material Flow Analysis

Material flow analysis provides a method for connecting the flows of energy and materials into and out of a defined system in order to identify sources of solid waste generation and account for hidden flows and sinks that may be unexplained in a more traditional, end-of-the-pipe solid waste analysis. Using MFA it is possible to address the entire solid waste hierarchy. It can be used to identify sources for minimizing waste or reveal internal material flows and potential opportunities for recycling or further material reuse. MFA characterizes existing disposal practices and treatment mechanisms such that they may be reformed in a more environmentally sound manner. It can also point to holes or potential efficiency-improvement links in solid waste service coverage.

The Board on Earth Sciences and Resources (BESR) explored the material flows analysis approach as it has been implemented in applications from tracing chemicals through an industrial processing plant to assessing resource limitations and availability on a national economic scale (BESR, 2004). They define MFA as “a method for tracking the movement of matter into and out of a system of interest from and to the environment, using methodically organized accounts, and denoting the total amounts that remain in the system to create a stock” (p. 17).

The guiding principle behind an MFA is based on a model in which the system being analyzed is linked to its surrounding environment by the flow of materials and energy. The model can be further expanded to account for this flow of materials and energy on the basis of the first law of thermodynamics on the conservation of matter (Eurostat, 2001). In other words, everything that goes into a defined system must be accounted for in output or accumulation. MFA has the capacity to characterize the flow patterns of a material of interest on any scale, so long as there is a fixed boundary that is defined by the user.

The BESR stresses the importance of clearly delineating a system boundary for a MFA, as there is no universally accepted boundary for this accounting method. The strength of this loose definition is the potential for using MFA in a broad range of applications. According to the BESR (2004), MFA can be used to integrate natural and social science data for characterizing the connections among the global economy, the environment, and human impacts. It thus carries enormous potential for deriving indicators, calculating mass balances within a system, or framing public policy decisions.

MFA has been implemented by the private sector to serve a number of purposes. For example, DuPont was able to cut costs and improve efficiency in its operations by using MFA to assess mass and energy inputs compared with functionality and effective use of materials. The company then utilized the detailed accounting information afforded to them by MFA to identify critical limiting factors within their production cycles and develop contingency plans for these potential shortcomings. An alternative approach to MFA has been taken by the Institute of Scrap Recycling Industries as they are compiling existing landfill data in order to track the composition and quantity of materials in landfills. By establishing such a comprehensive account of landfill items, this information could be used to appropriately assess the potential for future resource recovery from landfills, which in turn could generate income, reduce volume in existing landfills, and offset energy use from the production of virgin materials (BESR, 2004).

Innovative applications of MFA such as these on the part of private organizations have facilitated fulfillment of all steps on the solid waste management hierarchy established by Agenda 21. These successes can be more widespread by synthesizing economy-wide material flow data as a basis for establishing public policy in material and energy use. Using statistical approaches for MFA is not a new concept. This method of synthesizing economy-wide accounts and balances was first implemented in Europe during the 1970s, and later applied to the production of statistical information during the 1990s in Austria, Germany, Japan, and the USA (Eurostat, 2001). The first application of material flow balance on a national scale was conducted by the German Federal Statistical Office in 1995 (Eurostat, 2001).

The European Union (EU) has initiated the effort in developing a standard methodology for performing economy-wide material flow analyses based on comprehensive compilation of material accounts. This was done in an attempt to streamline the process so that resulting information can be used to establish indicators and compare resulting information among countries or across economic lines. The publication of Eurostat's *Economy-Wide Material Flow Accounts and Derived Indicators: A Methodological Guide* (2001) aims to establish definitions, terminology, and classification schema in an effort to eventually standardize the MFA process, although the guide does not yet function as a "fully operational compilation guide" (Eurostat, 2001, p.9). Instead, it serves to establish a starting point, from which it invites the contributions and input of other compilers and users alike.

In terms of applications of MFA in the developing world, Belevi (2002) implemented MFA in Ghana to assess nitrogen and phosphorous emissions and optimize resource recovery. After establishing the MFA, Belevi was able to explore the possibility of meeting nitrogen and phosphorous demands in agriculture by co-composting fecal sludge and solid waste diverted from local landfills. In this way, nitrogen and phosphorous were maximized on a local level, thereby limiting pollution from fecal sludge and solid waste emissions and simultaneously improving soil quality for agriculture.

1.3.3 Argument for MFA approach

The detailed accounting offered by an MFA provides a more complete lens from which it is possible to identify potential hidden solid waste sources and sinks that may be important in more appropriately characterizing the solid waste scenario for the community. This approach, in turn, could provide better information for use in developing community-scale comprehensive solid waste management plans, as in the case of Kayangel Island. An additional enhancement of this approach, suggested by the

BESR (2004), would be to link spatial information to the material flows analysis. A spatially discrete MFA could classify and quantify material production and consumption, while tying the stocks and sinks to specific geographic locations. This could prove invaluable in developing more efficient solid waste management procedures. For example, it would be possible to identify ideal distribution locations for household-cluster solid waste segregation receptacles, based on spatial information about local waste generation.

MFA is one of the many specific strategies that have been defined to address the mandates established by the Brundtland Commission more than 20 years ago. The EU has emerged as a leader in coordinating efforts to define distinct methodologies for implementing sustainable development agendas; however, there remains a "need for effective international cooperation to manage ecological and economic interdependence… The ability to anticipate and prevent environmental damage requires that the ecological dimensions of policy be considered at the same time as the economic, trade, energy, agricultural, and other dimensions. They should be considered on the same agendas and in the same national and international institutions" (UN, 1987, p. 25).

Applying MFA for enhancing a small-scale, economy-wide solid waste management plan is a logical extension of the international mandate for sustainable development. While in broad context, MFA has been applied to improve energy efficiencies, conservation of materials, and general resource management by providing a "big picture" perspective (BESR, 2004; Belevi, H., 2002; Eurostat, 2001), it has not been widely used to assess solid waste management practices outside of individual elemental recovery (BESR, 2004; Belevi, H., 2002). To the author's knowledge, MFA has not been applied in the context of solid waste management for SIDS. Consequently, this report will serve to connect the concepts of MFA with solid waste management, using the community of Kayangel in the Republic of Palau as a case study.

In the context of SIDS such as the community of Kayangel in the Republic of Palau, MFA is a valuable tool for streamlining solid waste management practices when utilized to spatially pinpoint the patterns of production and consumption of the nonorganic fraction of solid waste generation. This case will be further developed in later sections of this report.

2 BACKGROUND ON REPUBLIC OF PALAU

2.1 Geography, Geology

The Republic of Palau (ROP) is the westernmost cluster within the Caroline Islands, a tropical archipelago in the western Pacific Ocean. The 300+ islands within the ROP have a combined land area of only 458 sq km, and are centered around 7 30 N, 134 30 E (CIA, 2008c). The islands vary tremendously, from the volcanic mountains of Micronesia's second-largest island of Babeldaob to the curiously mushroom-shaped limestone caps of Palau's famous Rock Islands, and even the coral atolls of Kayangel State and Helen Reef, with fringing barrier reefs.

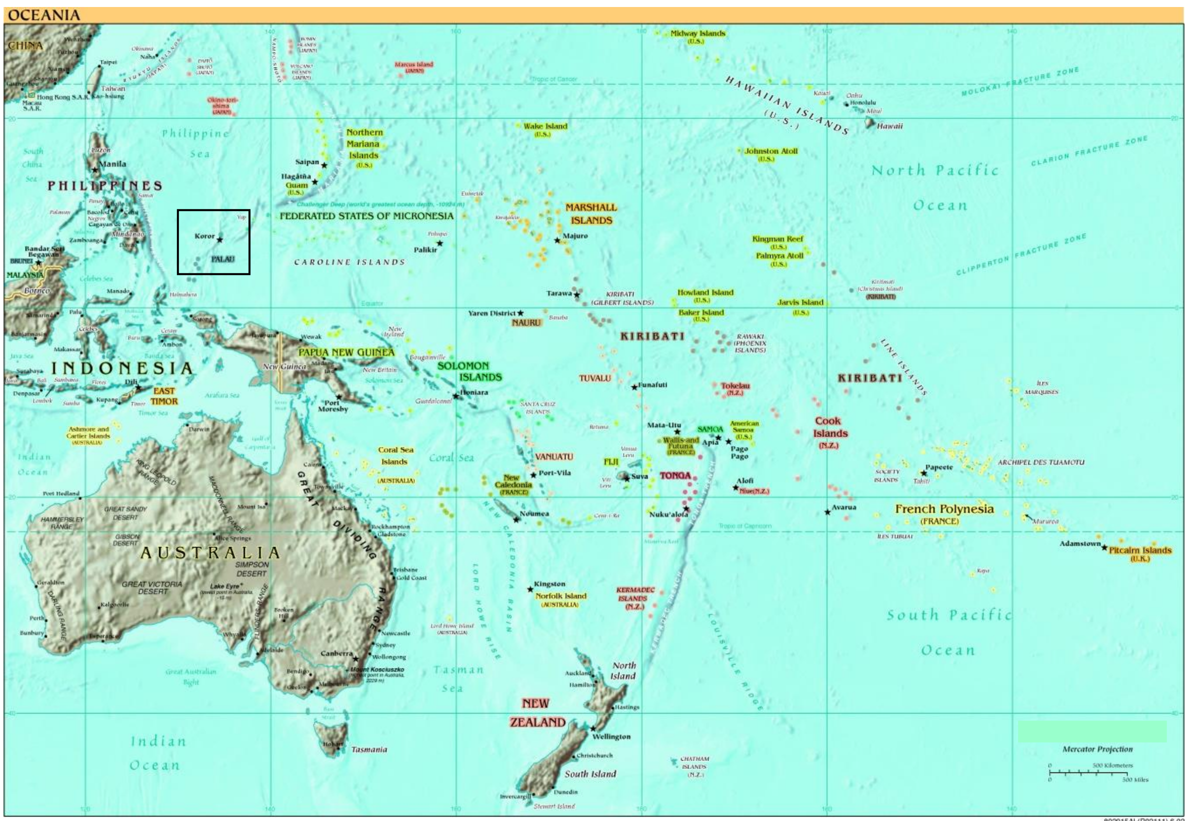


Figure 1: Map of Western Pacific Ocean region, showing Republic of Palau

From: http://en.wikipedia.org/wiki/Image:Oceania.jpg. Licensed under the public domain, as a work of the United States Federal Government.

The islands within the Republic of Palau are the exposed portion of the extinct Belau volcanic arc, which was volcanically active between 40 and 20 million years ago. Plate convergence resulting in subduction of the Pacific Plate under the Philippine Plate pushed up a volcanic island arc, the remains of which are known as the Kyushu-Palau Ridge, and form the oldest rocks of the ROP (Hawkins, J. and Castillo, P., 1998). As subduction continued, sea-floor spreading between the Belau volcanic arc and the converging plates created a back-arc basin that is now considered the Philippine Sea (PacIOOS, 2008). A deep ocean trough formed along the convergent plate boundary and the now inactive southeastern portion with maximum depths of greater than 7500 m. This trough is called the Palau Trench (Hawkins, J. and Castillo, P., 1998).

Since active subduction ended around 20 million years ago in this region, sedimentation has dominated, including the formation of carbonate reef limestones (PacIOOS, 2008). Kayangel Atoll, located in the northernmost part of the country, is one of Palau's two true coral atolls. Atolls are coral islands that are established from the build-up of barrier reefs which form around a subsided volcanic sea mount (Encyclopædia Britannica, 2008).

2.2 Government, Economy

The Republic of Palau became an independent nation on October 1, 1994, and a member state of the United Nations on December 4, 1994 (MRD, 2004). Prior to independence, the islands comprising the ROP had been governed under the United States-administered United Nations Trusteeship (World Bank, 2005). Coincident to its nationhood, Palau entered a 50-year treaty, called the Compact of Free Association (COFA), with the United States (MRD, 2004). Under the Compact accords, Palau receives security and military protection by the United States, $410 million in direct payments as well as disbursement of an average 20% of GDP to establish a Compact Trust Fund (CTF) for future self-reliance and government financing, all given over a 15-year time period (World Bank, 2005).

In exchange for military protection and a combined grant assistance package of over $600 million, the U.S. has the right to maintain military facilities in Palau and withholds exclusive strategic access to Palau's waterways for this same 50-year period. The grant assistance, both direct payments and funding directed to the CTF, is focused on infrastructure development and transitioning into autonomous financial management by the Palauan government. The CTF includes deposits of $5 million per year from 1999–2009 and $15 million inflation-adjusted annual deposits from 2010-2044, following the cessation of the direct annual payments (IMF, 2006).

The grant assistance from the U.S. Compact, combined with merit-based US federal grants (administered outside of the U.S. Compact), as well as large-scale grants from Japan, Taiwan, and other international donors translates into inflated GDP for Palau. Regionally, Palauans have one of the highest standards of living, with average annual per capita GDP of $7,600 in 2005 (CIA Factbook, 2008c). In fact, based on statistics from 2003, among Pacific Islanders, Palau not only enjoyed the highest per capita income of $7,500, but also the highest per capita aid with an average of $1,712 from 1999-2002 (World Bank, 2005).

Much of the COFA money is specifically earmarked for infrastructure development; hence Palau has recently experienced some rapid large-scale development. The most significant of these projects, considered the most major development project in Micronesian history (MRD, 2004), has been construction of the 53-mile "Compact Road", which circumnavigates Palau's main island of Babeldaob. This road connects the 10 formerly isolated states of Babeldaob, providing easy access to Koror State, Palau's commercial capital.

The improvement in ease of access to goods and products, as well as the wealth from the COFA and other aid money has resulted in a high level of foreign imported goods, despite Palau's limited exports. Economic diversification efforts resulting from foreign grants have been limited mainly to tourism, with some fisheries development to a lesser degree (MRD, 2004).

In 2006, more than 82,000 visitors spent $62 million in Palau (USDOSBEAPA, 2008). This accounts for 43% of Palau's $145 million GDP from 2005 (CIA factbook, 2008c) Tourism is specifically centered on the marine environment, as Palau hosts the world's highest density of tropical marine habitats, as well as Micronesia's most diverse coral fauna (Golbuu et al., 2008). More than 75% of tourists come from Japan, Taiwan, and the U.S. (USDOSBEAPA, 2008).

Palau's only real exports, fishing and handicrafts, generated revenues of $6 million in 2004. With a combined GDP of $133.6 million that year, exports only contributed 4.5% to the nation's economy (IMF, 2006). Palau's dependence on aid is further compounded by its overwhelmingly negative trade balance. During fiscal year 2005/6, Palau was projected to have a trade balance of -$101.9 million, with only $13.5 million in exports, compared to $115.5 million in imports (IMF, 2006).

Palau's imbalanced trade statistics are a product of not only limited exports, but also a disproportionately high employment rate within the service sector. In fact, the service sector in Palau accounts for more than 50% of the nation's GDP (USDOSBEAPA, 2008). The government, fueled with funds from the COFA, accounts for almost 25% of Palau's employment and 23% of the GDP (USDOSBEAPA, 2008). As the annual COFA funds expire in 2009, many are beginning to wonder about the resulting effects on employment, consumption patterns, trade balance, and ultimately Palau's high per capita GDP.

Table 1: General statistics for the Republic of Palau and Kayangel State

Palau by the Numbers		
Population		**(Source)**
Palau	19,907	(OPS, 2006a)
Kayangel (voters)	188	(OPS, 2006a)
Kayangel (avg. year-round residents)	98	(Owens, 2008)
Socio-Economic Conditions		
Gross Domestic Product per capita	$7,600 (in 2005)	(CIA Factbook, 2008c)
Median annual household income		
Palau	$19,759	(OPS, 2006b)
Kayangel	$8,099	(OPS, 2006b)
Geography		
Palau		
Total number of islands	586	(MRD, 2004)
Total reef area	525 km^2	(MRD, 2004)
Total lagoon area	1,137 km^2	(MRD, 2004)
Total land area	535 km^2	(MRD, 2004)
Total coastline	1,519 km	(UNDESA, 2007)
Kayangel State		
Total number of islands	4	(PALARIS, 2008b)
Total reef area	8.04 km^2	(PALARIS, 2008b)
Perimeter of reef	41.52 km	(PALARIS, 2008b)
Land area of Kayangel Island	1.61 km^2	(PALARIS, 2008b)
Coastline of Kayangel State	11.3 km	(PALARIS, 2008b)
Coastline of Kayangel Island	6.3 km	(JFK students, 2008)
Climate		
Average annual temperature	27ºC (81ºF)	(MRD, 2004)
Average annual rainfall	373 cm	(MRD, 2004)

2.2.1 Economic and social factors contributing to waste scenario

Palau's current wealth from COFA funds and aid money puts it in a unique development category. According to Troschinetz (2005) a nation with a per capita GDP of less than $5,000 is given a designation of "less developed" or "least developed", while a nation who's per capita GDP is more than $10,000 is considered to be "economically developed". Palau fits into a more ambiguous intermediate category, and the implications of this contribute to explaining its unique development problems.

Like many Pacific Islands, Palau has become dependent upon the imported goods made available by the US military in the wake of World War II destruction. Following the war, remnant unexploded ordnance made it dangerous to resume fishing, seafood harvesting, farming, and other subsistence activities. To combat this tenuous food security issue, canned goods were introduced by administrators during the U.S. Trust Territory administration. People developed a taste for these foreign imports, and a demand for these products was created that outlasted the removal of unexploded ordnance and safe return to fishing and other food gathering.

3 METHODOLOGY

3.1 Case Study: Kayangel State, Republic of Palau

3.1.1 Location Maps

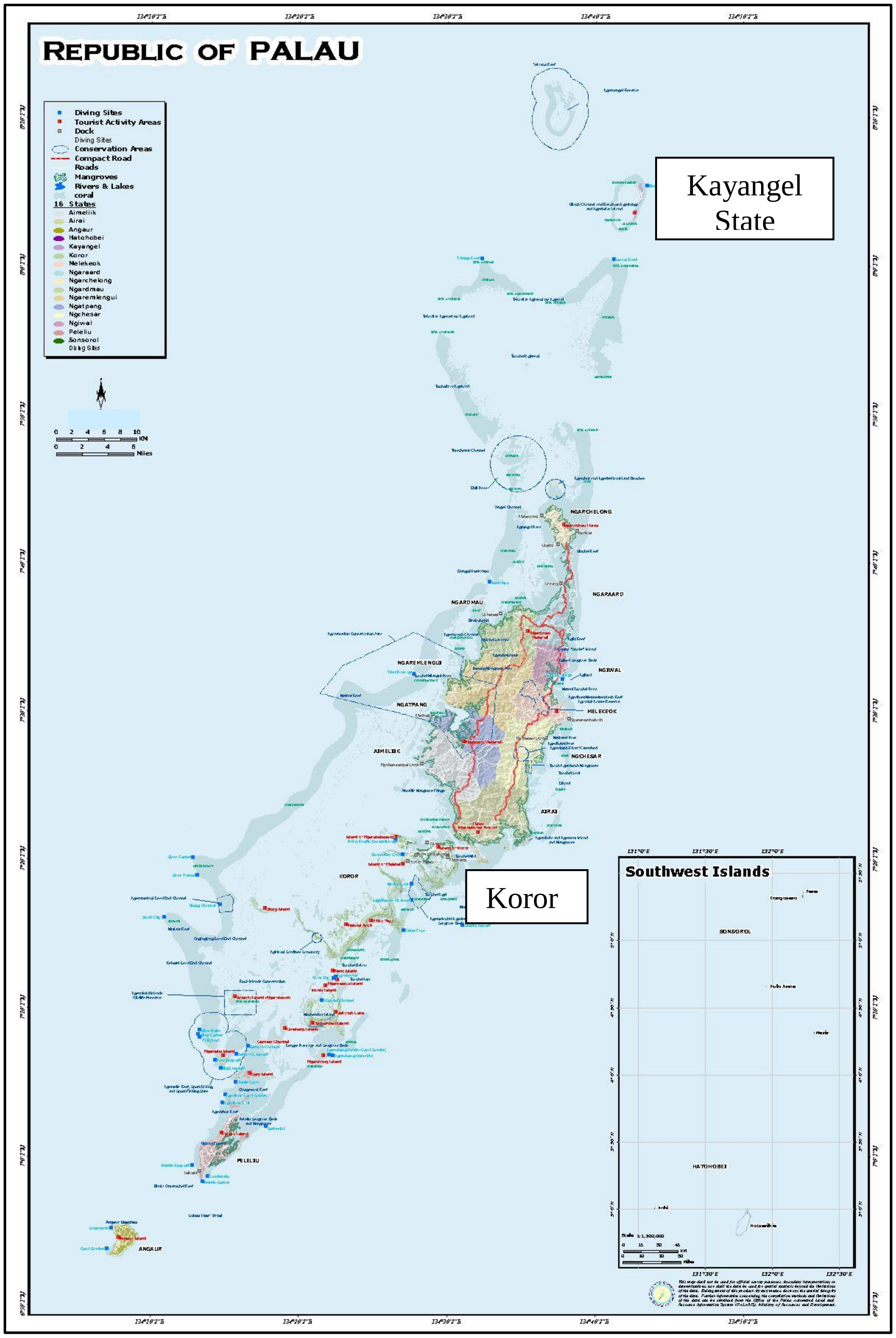


Figure 2: Map of Republic of Palau showing locations for Kayangel State and Koror (modified with permission from PALARIS, 2008c)

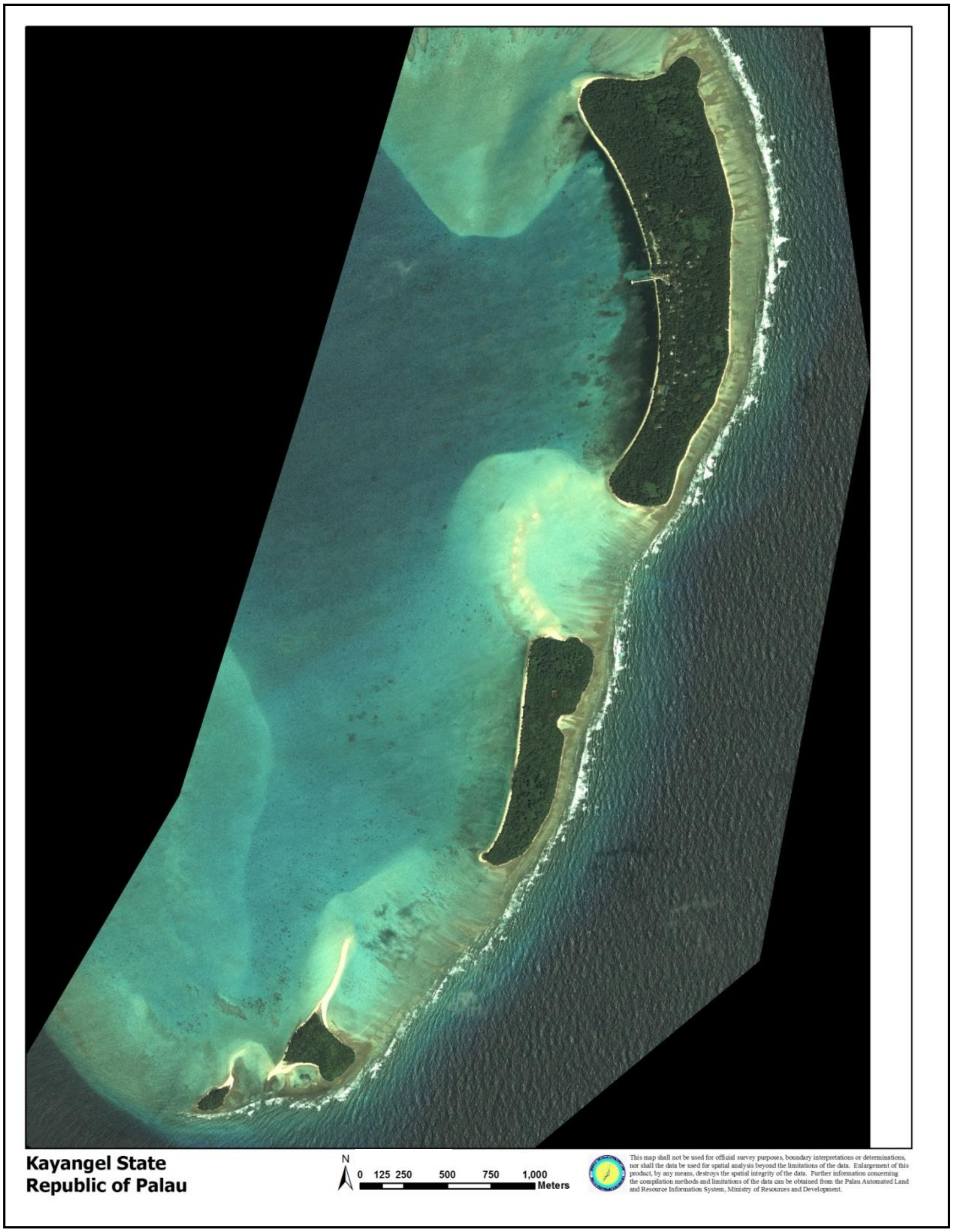


Figure 3: Satellite image of Kayangel State atoll.

(modified with permission from PALARIS, Ministry of Resources and Development, Republic of Palau, 2004)

3.1.2 Site-specific context

Kayangel State is the northernmost of the 16 states within the Republic of Palau, and includes an atoll with 4 islands. The area within the Kayangel Atoll is 8.04 km^2, of which only 1.61 km^2 constitute the one inhabited island of Kayangel (PALARIS, 2008). Kayangel Island is located approximately 40km north of Palau's main island of Babeldaob, and approximately 90km north of Koror, the main business center for the Republic of Palau (PALARIS, 2008c). It is accessible by speedboat and travel takes between 2 and 3 hours with calm seas.

The geographic isolation of Kayangel State's reef and island atoll are constraints to extensive development there. The voting population of Kayangel State is split between those who reside on Kayangel Island and those who live in Koror and elsewhere. This is not evident in the most recent census data from 2005, however, in which Palau's Office of Planning and Statistics (OPS) lists a population of 188 for Kayangel State (OPS, 2006a). The 2005 census represents a "modified *de jure"* technique, "counting people and recording selected characteristics… according to his or her usual place of residence as of census day" (OPS, 2006a, p. 23). As a resident of the Kayangel community from November 2006-August 2008, the author conducted frequent informal population counts for those residing on the island, and the school-year results were consistently less than the "usual place of residence" cited by the 2005 Palau Census data. These population counts were conducted based on personal knowledge of the island and its residents at any given time. The population counts made in association with data collection during the school and non-school periods resulted in an average year-round population of 98 for Kayangel (see APPENDIX G: Kayangel Average Annual Solid Waste Generation by Household Employment (weight in lbs.). In addition to the population count for Kayangel, the 2005 census for Palau also provides population statistics by age category (OPS, 2006a) as shown in Table 2.

Table 2: Republic of Palau population statistics by sex, age, and state (OPS, 2006a).

Kayangel State Populations Statistics (OPS, 2006a)	
Males	106
Females	82
Total	188

Age	Koror State	Kayangel State	Republic of Palau
0-14 years	23.4%	30.9%	24.1%
15-24 years	15.2%	5.3%	13.7%
25-44 years	36.8%	34.0%	36.6%
45-64 years	19.8%	19.1%	19.9%
65+ years	4.8%	10.6%	5.7%

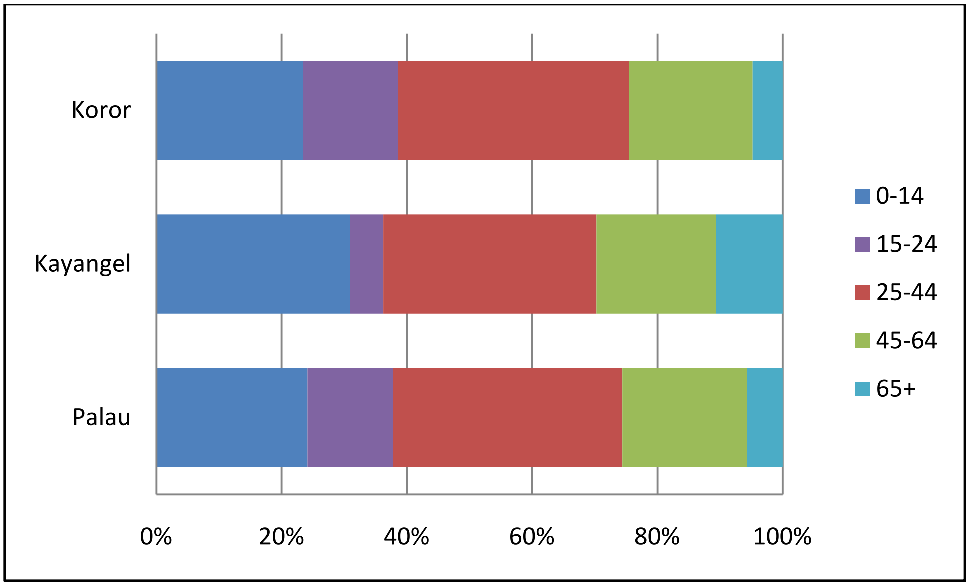


Figure 4: Population demographics by age and state (OPS, 2006a)

Kayangel State has unusual population demographics, 30.9% of residents are aged 0-14, yet only 5.3% of residents are in the next age category of 15-24 (Table 2 and Figure 4). This phenomenon is largely based on school availability. While Kayangel State has an elementary school, it does not have a high school. The high school-aged population is thus largely absent; those individuals must attend public or private high schools located off-island. After completing school, many young adults (ages 15-24) from Kayangel remain in Koror, Palau's commercial capital, for employment or further education at

Palau Community College. This is apparent in comparing the population age distribution for Koror (which as the population center of Palau closely mirrors the distribution for all of Palau) with that of Kayangel in Figure 4. Kayangel State also has a relatively older population, with 10.6% of Kayangel residents aged 65 or older, compared with only 5.7% for Palau as a whole.

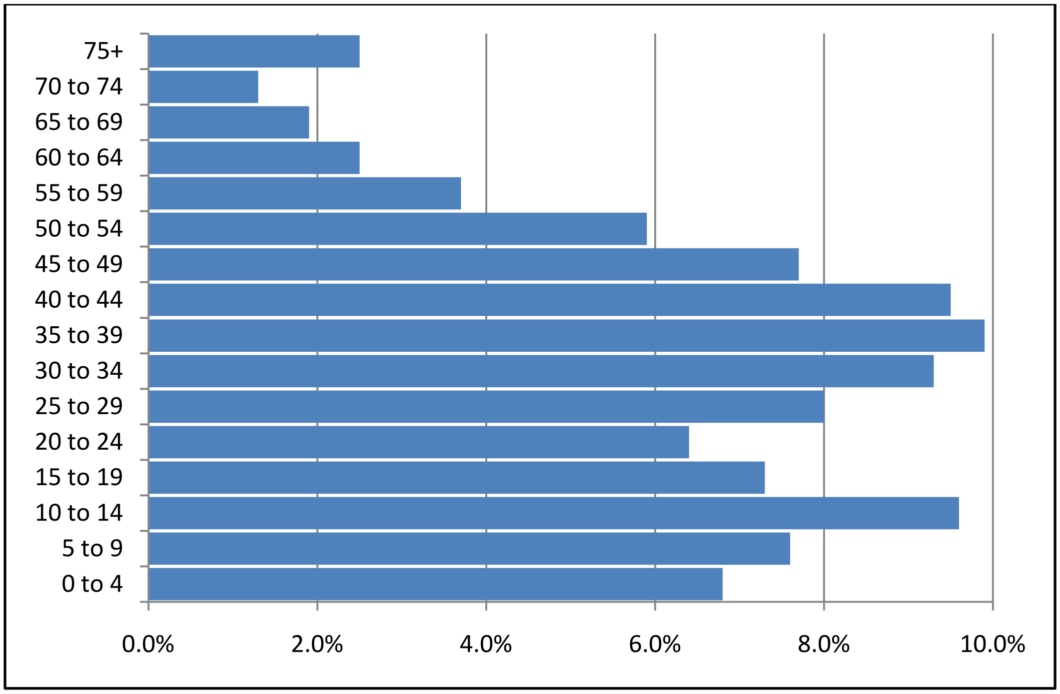


Figure 5: Palau population statistics by age (OPS, 2006a).

Migration is identified as a huge factor which shapes Palau's demographics. Figure 5 shows population distribution divided into 5 year increments. It shows a significant drop in population for the 15-29 year age ranges. The migration patterns are two-fold, with emigration of many Palau-born young adults, combined with immigration of non-Palau born workers (OPS, 2006a). Palau's OPS conducted a *de jure* census in 2005, which lacks emigration data but includes explanations for migration patterns based on the work of others. They suggest that Palau-born young adults are predominantly emigrating to Guam, the Commonwealth of Northern Marianas Islands, and the United States for employment, education, and marriage. Figure 6 correlates age distribution and birthplace for Palau's population based on the 2005 census data (OPS, 2006a). For the population aged 25-44 years, there is a higher percentage of non-Palau born/lower percentage of Palau-born compared with the birthplace distribution for the total population.

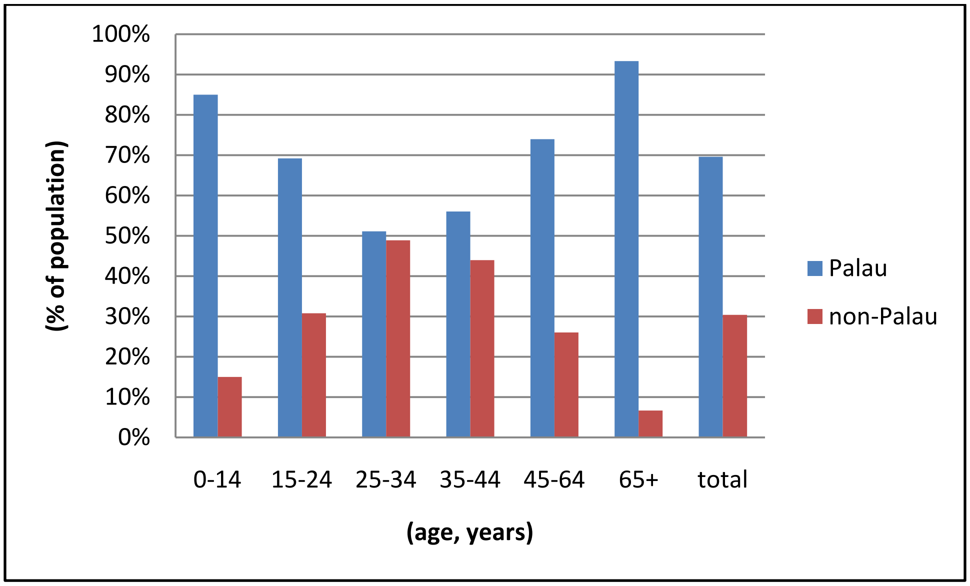


Figure 6: Palau population demographics by age and birthplace (OPS, 2006a).

The demographics of Kayangel State, particularly the skewed age distribution of its population, and the island's geographic isolation have a profound influence on local consumption patterns. According to Franco Modigliani's Life Cycle Hypothesis (Kungl Vetenskapsakademien, 1985), the income stream of an individual is relatively highest in the middle of his/her lifespan, while consumption levels generally mark a gradual but continuous rise through life. In Kayangel, the lack of young adults thus translates in a reduced income stream for the community. Less available income combined with reduced availability of imported goods due to geographic isolation of the island result in lower consumption rates.

3.1.3 Employment and Income

Another factor influencing consumption rates and material flows for Kayangel State is income generation. The Office of Planning and Statistics released the *Republic of Palau Household Income and Expenditure Survey* (2006b) and cited average annual household income for the two outer islands of Kayangel and Angaur as $8,099 compared with

$19,759 for all of Palau (Figure 7). The discrepancy between these statistics points out the difference in scale of the economy of Kayangel State versus the entire Republic of Palau. Average annual household expenditure figures are equally divergent, with $8,902 for Kayangel and Angaur compared with $19,330 for Palau. The difference in average annual household income and expenditure gives a sense of consumption vs. income for both Kayangel/Angaur and Palau as a whole. In this case, average households in Palau maintain a positive average net balance of $429 per year, while Kayangel/Angaur residents have a negative average net balance of $803 per year. This information can be interpreted to suggest that residents of Kayangel/Angaur spend less than residents of Palau as a whole; however with a negative annual net balance, they are living outside of their means or have unreported income.

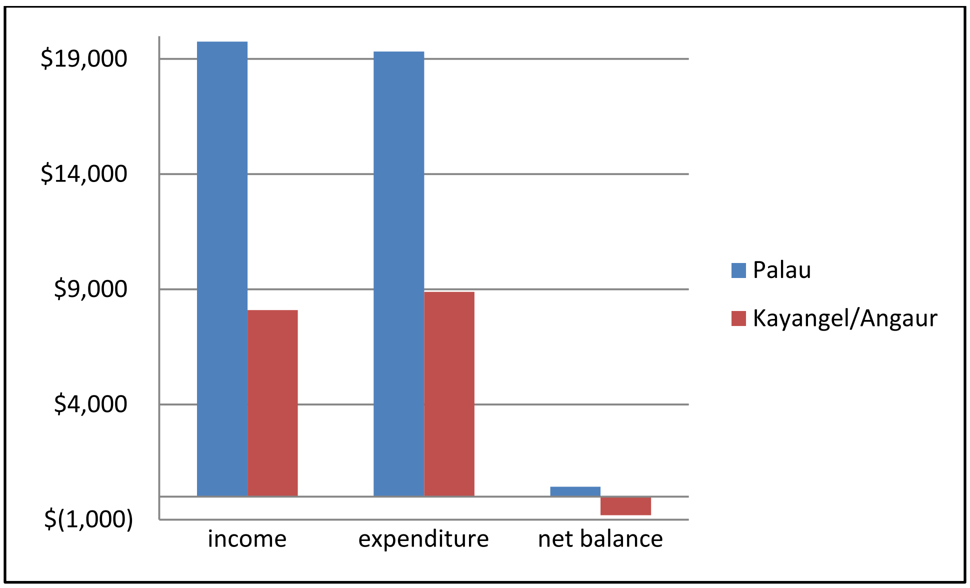


Figure 7: Average annual household income and expenditure information for Kayangel/Angaur and Palau (OPS, 2006b).

3.2 KHSWGS Survey Methods

3.2.1 Seasonality

Data collection for the KHSWGS was conducted during two phases, representing school-year and non-school-year periods. The population of Kayangel State varies seasonally, as marked by the school calendar. This seasonality impacts consumption and waste generation patterns, and was thus factored into the study.

A number of Kayangel residents have homes both on the island and in Koror or other states of Palau with extended family members. Retired and elderly residents often maintain a rather transient status, with frequent trips back and forth for access to family, customary obligations, and health care. During the non-school period of the year, the population fluctuation patterns are more pronounced, as there is much more transportation between Kayangel and the rest of Palau. Some local residents with children take advantage of school vacation time to go shopping and visit family-members off-island. Likewise, many extended family members, especially school children, stay on Kayangel for extended visits during non-school times. Kayangel has many homes that are vacant for the majority of the year, and used exclusively during seasonal visits by family members living off-island.

At the time of data collection for both survey phases of the KHSWGS, 30 Kayangel houses were occupied and included in the study, however individual residents of some of the included 30 households were absent due to travel off-island. Since travel between Kayangel and the rest of Palau is a regular occurrence, the individuals who were temporarily absent as part of routine off-island travels were factored into the resident population used for statistical calculations. Solid waste from the local elementary school was included for the school-year survey, but not the non-school-year survey.

3.2.2 Sampling Scope

Due to the small size of the Kayangel State community, the KHSWGS was designed as a comprehensive survey for the island. With only 1.61km² of land area (PALARIS, 2008a) and an average of 98 year-round residents, all of the island's 30 occupied households and the school were invited to participate. The residents from two of the 30 households were off-island for several months during the school-year, and were thus not included during that phase of the surveying (they are an example of the transient population for the island). Furthermore, no data was collected from three of the 28 occupied households during the school-year surveying due to difficulties in cooperation and miscommunication or misinterpretation of instructions. For similar reasons, the nonschool-year phase of the survey sampling included data from 8 of the 30 occupied households, as presented later in Table 3.

Public and private areas that were omitted from the study included the power plant (the generator facility that powers the community with electricity), and the dock and adjoining public waiting house. The latter serves as the main entry port for the island, as well as the hub for employees of the Kayangel State government, and social meeting place for the remainder of the community. The state employees are responsible for solid waste management in the port area, and periodically burn the garbage that accumulates in two steel drums that serve as waste receptacles there.

3.2.3 Survey time period

A survey time period of 14 days was selected to represent the standard time cycle of material production and consumption on Kayangel Island. This cycle is time-dependent based on public transportation frequency, since all non-organic solid waste generated on the island comes from off-island. Boat traffic provides access to goods, thus the bi-weekly state boat trips dictate local consumption patterns on a 14-day cycle. For the KHSWGS, household solid waste data was compiled based on 14-day collection periods from March-June 2008.

The Kayangel State community is isolated from the rest of the Republic of Palau by approximately 40km of open ocean and shallow coral reefs (PALARIS, 2008c). Several residents of the island own private boats, but the only state government-subsidized transportation is a biweekly boat trip to Koror, the commercial capital of Palau. Currently, the state sends a speedboat from Koror to Kayangel with a return trip back to Koror on Friday and Sunday, every-other week, in conjunction with government pay day weekends. These trips not only provide Kayangel residents with access to goods from off-island, but they can also serve to change the population of the island. Depending on the time of year and busy schedule of customary obligations (first-birth ceremonies, house fundraising parties, funerals, etc.), the state boat may either bring visitors (family members, guests, representatives of agencies working in Palau, tourists) to stay for the weekend or take several local residents away from the island.

3.2.4 Dates

Table 3: KHSWGS survey dates, school-year and nonschool-year

School-year Survey Dates	Number of Households
March 15-29, 2008	13
March 30-April 13, 2008	5
April 1-15, 2008	2
April 2-16, 2008	1
April 13-27, 2008	1
April 14-28, 2008	1
April 25-May 9, 2008	1
April 27-May 11, 2008	1
off-island	2
no data collected	3
TOTAL	30
April 23-May 7, 2008	*JFK Elementary School*

Nonschool-year Survey Dates	Number of Households
May 30-June 13, 2008	1
June 1-15, 2008	7
no data collected	22
TOTAL	30

3.2.5 Eco Map of Kayangel

Figure 8: Kayangel community eco-map with KHSWGS survey locations

(Modified with permission from PALARIS, 2004).
Red numbers correspond to household survey data in APPENDIX A.

3.2.6 Community Participation

The limited size of the island and community of Kayangel, combined with the scope of a study to characterize local solid waste generation by type and quantity, made it possible to include all Kayangel State households in a comprehensive analysis. Accordingly, all households on the island were invited to participate in the KHSWGS. There were however varying levels of cooperation and interpretation of the instructions. As a resident of the island, the author benefitted from close personal contact with all residents of Kayangel State, and community members were generally willing to participate in the study. Residents were asked to assist in collecting and consolidating all solid waste generated by each house within a two-week period. They were told that this information would be used to better assess the quantity and type of solid waste generated by the entire island on a bi-weekly basis, in order to design the community's first ever solid waste management plan. Previously, solid waste was managed on a household basis, with no coordinated collection efforts for the island aside from aluminum recycling conducted by the local elementary school. In general, community members were enthusiastic about the prospect of a formal island-wide solid waste management scheme.

3.2.7 Waste Categories

Twelve categories of solid waste were used for segregating and characterizing waste generation as part of the KHSWGS. Table 4: Waste segregation categories for KHSWGS.Table 4 lists these categories. They were selected based on solid waste classifications from studies conducted by the South Pacific Regional Environment Programme (SPREP) (Sinclair Knight Merz, 2000a-h) and the United States Environmental Protection Agency (USEPA, 2007). Additionally, the author worked in association with Palau's Division of Environmental Health to further divide waste categories for the purposed of potential material recovery, reuse, and recycling efforts within the community of Kayangel or the Republic of Palau. Transportation availability, prohibitive fuel costs, and access to recycling facilities are factors which influence material recovery, reuse, and recycling potential in Palau. Currently, coordination of transportation to and from Kayangel Island and cooperation between public and private carriers is ad hoc, and prevents routine solid waste removal.

Table 4: Waste segregation categories for KHSWGS.

Waste Segregation Categories
Mixed metals
Aluminum
PET plastic bottles
Hazardous waste (e.g., batteries, chemicals, paint cans, fuel containers)
Non-recyclable plastic
Styrofoam
Textiles
Ceramics
Glass
Paper/cardboard
Rubber
Other/mixed material (e.g., foil-lined milk boxes, cigarette packets, diapers)

As mentioned in SPREP's *Guidelines for Municipal Solid Waste Planning in Small Island Developing States in the Pacific Region* (1999), island economies were traditionally characterized by agriculture, agroforestry, and marine harvesting; the resulting wastes from these activities were biodegradable and formal community-wide waste management schemes were thus unnecessary. A study by Troschinetz (2005 and 2008) compared composition of municipal solid waste (MSW) by weight, and cited an average of 55% organic material for the 19 developing countries included in the study.

Problems in waste management on small islands, particularly atolls, have arisen in response to the introduction of imported materials. Ironically, despite the traditional dominance of organic waste in island communities, waste surveys conducted by SPREP are often low in organics. This can largely be explained by another island inhabitant, pigs (SPREP, 1999). Most households feed kitchen and food scraps to pigs, dogs, cats, and other animals; thus, these organic wastes do not appear in waste generation survey statistics. Another component to the organic wastes which typically dominate solid waste generation in developing nations, but is largely unaccounted for in island waste generation surveys is yard waste. The preponderance of subsistence agriculture, marine harvesting, and handicraft production using local materials within most islands households results in little net green waste (SPREP, 1999). These biodegradable materials are composted or burned at the household level; hence quantifying their production is problematic.

For these reasons, the author was unable to quantify organic solid waste generation as part of the KHSWGS, and thus eliminated this category from waste segregation and data collection. Organic materials (e.g., chewed and/or rotten betel nuts, leaf litter, and food residue remaining in cans) were occasionally present in household solid waste, but generally not in significant quantity to merit distinct categorization. If present and able to be separated, these small amounts of organics were included as part of the "other" category in this study.

3.3 Instructions

Households were clustered, in order to facilitate surveying based on 14-day collection increments. At the beginning of each survey period, the author went house-to-house and spoke with at least one, and frequently all, adults/heads of household for each residence being surveyed. The KHSWGS was explained to household residents, complete with detailed oral instructions in both Palauan (local language) and English, as well as a paper copy of these instructions with a list of the waste segregation categories. (see APPENDIX A: Palauan Language KHSWGS Survey and Table 4 which lists the waste segregation categories).

At each household, residents were asked for assistance in collecting all household solid waste generated within the two-week survey period. They were requested to keep all solid waste in a container of their choosing (plastic garbage bags were provided if needed). Each individual was reminded of the objectives of the study, using the 2-week survey period as a representative sample for quantifying annual solid waste generation for the island and ultimately devising a community-wide solid waste management plan. Emphasis was placed on the importance of including only waste generated within the confines of the 14-day study period. Residents were informed that the author would return to the household at the end of the collection period in order to sort the waste into the categories listed in Table 4 and weigh the waste within each category.

In addition to individual household visits, a local announcer explained the KHSWGS in Palauan to the crowd at an all-community softball tournament and lunch gathering in celebration of Youth Day using a microphone and public address system. Local schoolchildren were also a valuable resource in explaining and implementing the study. The author conducted a two-week data collection survey at the local school, John F. Kennedy Elementary School (JFK), with the help of the $7^{th}/8^{th}$ grade class. Students from grades 5-8 painted empty oil drums that had been split in two and donated by the state government employees, decorating and labeling each waste receptacle according to the categories in Table 4. The four students in the $7^{th}/8^{th}$ grade class went classroom-to-classroom, explaining the waste segregation categories, survey procedures, and overall solid waste scenario for the island. This exercise was a valuable educational experience for the students, as it reinforced concepts from the waste management hierarchy, particularly waste minimization and segregation. Based on this experience, students were invaluable in assisting with the study by explaining procedures and collecting solid waste generation data at individual households.

At the end of each collection period, residents of the households included within the KHSWGS (households numbered 25 for the school-year survey and 8 during the nonschool-year survey) were asked to amass the solid waste generated within the 14 days. The author then segregated the waste into the twelve categories listed in Table 4**Error! Reference source not found.**. In some cases, local students assisted in segregating and weighing the household solid waste. In other instances, household residents did some segregation, either out of normal practice or in an attempt to assist with data collection. For the most part, residents of Kayangel have traditionally practiced some degree of waste segregation. As mentioned in the above explanation of waste category selection, every household collects kitchen scraps and food waste for animal feed (pigs, dogs, cats, chickens, etc.). Additionally, organics that elsewhere may be considered “yard waste” are treated separately from other household waste on Kayangel Island (composted or burned), and consequently absent from this KHSWGS. Many households already practice some waste segregation, and separate plastic and metal containers as part of their normal household waste management routines.

Following mechanical segregation, the waste from each category was weighed using a spring scale and immediately recorded. Since there are already alternative community-wide disposal options for aluminum cans and batteries on Kayangel Island, any of these items were transferred to the appropriate collection receptacles for recycling after completing household data collection. The segregated waste was then returned to the household residents for them to manage according to their standard routine. Residents of each household were then thanked for their participation in the KHSWGS, and reminded that their cooperation would contribute to improved solid waste management plans for the entire community.

3.4 Material Flow Analysis

Establishing an MFA for Kayangel Island will provide an important perspective for evaluating the results of the KHSWGS, and more objectively assessing local solid waste management practices. The most critical component of an MFA is the establishment of system boundaries. This MFA will be geographically constrained, and defined as the Kayangel Island. In this way, it will be possible to trace all material flows and fluxes coming to or leaving from the island, as well as internal cycling for accumulated materials.

The author lived and worked on Kayangel Island as a United States Peace Corps volunteer from November 2006-August 2008. The nature of her work and living experience as one of approximately 100 year-round residents on the island provided her first-hand knowledge of the ins and outs of daily life in the Kayangel community. She worked in association with Palau's Division of Environmental Health as a rural environmental health extension agent, focusing on rodent control, household environmental health assessments, and solid waste management. These projects provided her an intimate perspective on local environmental conditions (e.g., infrastructure, waste pits, flora, and fauna). Another aspect of her work included teaching at the JFK Elementary School, where she benefitted from daily interactions with all of the school children and staff. Finally, the family she lived with owned and operated the larger of the two stores on the island, so she was personally involved with its operations (e.g., knowledge of types of goods available for purchase, trends in purchasing by individuals and households, inventories, frequency of restocking, boat schedules, waste disposal, etc.). These combined responsibilities and relationships offered a unique familiarity with the community which was invaluable in developing an MFA to characterize the local solid waste scenario. This should serve to qualify the assumptions made in defining the Kayangel MFA.

Material contributions to the MFA (influx) come from boats or tides, as goods imported from the mainland of Palau or elsewhere as well as flotsam and jetsam from the sea. Considering that the objective of this MFA is to improve the analysis of solid waste and local management practices for Kayangel Island, the material influxes will be quantified in terms of their net solid waste accumulation. In this way, the MFA is framed for the specific purpose of assessing materials based on their eventual fate. The three general material fate categories used in this analysis and the assumptions made in their characterization are defined in Table 5. They are discussed in more detail in the following sections.

Table 5: Material fate categories and assumptions for Kayangel MFA.

Material Fate	Materials Included	Assumptions
Removal from island	• Aluminum • PET plastics, primarily bottles • Hazardous waste, primarily batteries • Cardboard	• On average, one case (24 bottles) of coconut oil is removed from the island per state boat trip. With 26 annual trips, this translates to the removal of 624 PET plastic bottles per year or approximately 80 lbs. (based on measured avg. wt. of 2oz./bottle) • All hazardous waste is characterized by mass of batteries from KHSWGS that are collected via existing battery collection programs and subsequently removed. • On average, 10 cardboard boxes are removed from the island per state boat trip. With 26 annual trips, this translates to the removal of 260 cardboard boxes per year or 130 lbs. (based on measured avg. wt. of 8oz/box).
Accumulation	• Mixed metals • PET plastics, primarily bottles • Non-recyclable plastic • Styrofoam • Textiles • Ceramics • Glass • Paper/cardboard • Rubber • Other/mixed material	• Organics are not included due to scope of MFA, their rapid rate of decomposition, and difficulty in quantification • Other material quantities equal to corresponding mass values from the KHSWGS • Solid waste from tidal deposition (flotsam and jetsam) is deposited as modeled from May 2008 Kayangel coastal clean-up and data projections.
Burning	• Non-recyclable plastic • Paper/cardboard	• The non-recyclable plastics that are burned on Kayangel are predominantly plastic bags and plastic wrappers/packaging. These items are less dense than the mass of the non-recyclable plastic waste accounted for in the accumulation category (as represented by the KHSWGS). It was assumed that the mass of non-recyclable plastics that were burned was a value equivalent to 40% of the annual mass of the non-recyclable plastics that are not burned as determined from the KHSWGS (approximately 730 lbs.). • Most paper and some cardboard are burned as part of normal household solid waste management practices on Kayangel. This is difficult to quantify, especially considering the limited use of paper on Kayangel outside of the school. It was assumed that the mass of paper and cardboard that was burned at the household level was an equivalent value to approximately 10% of the total annual mass of paper and cardboard produced by the school that are not burned as determined from the KHSWGS (80 lbs.).

3.4.1 Material Flow Diagram for Kayangel Island

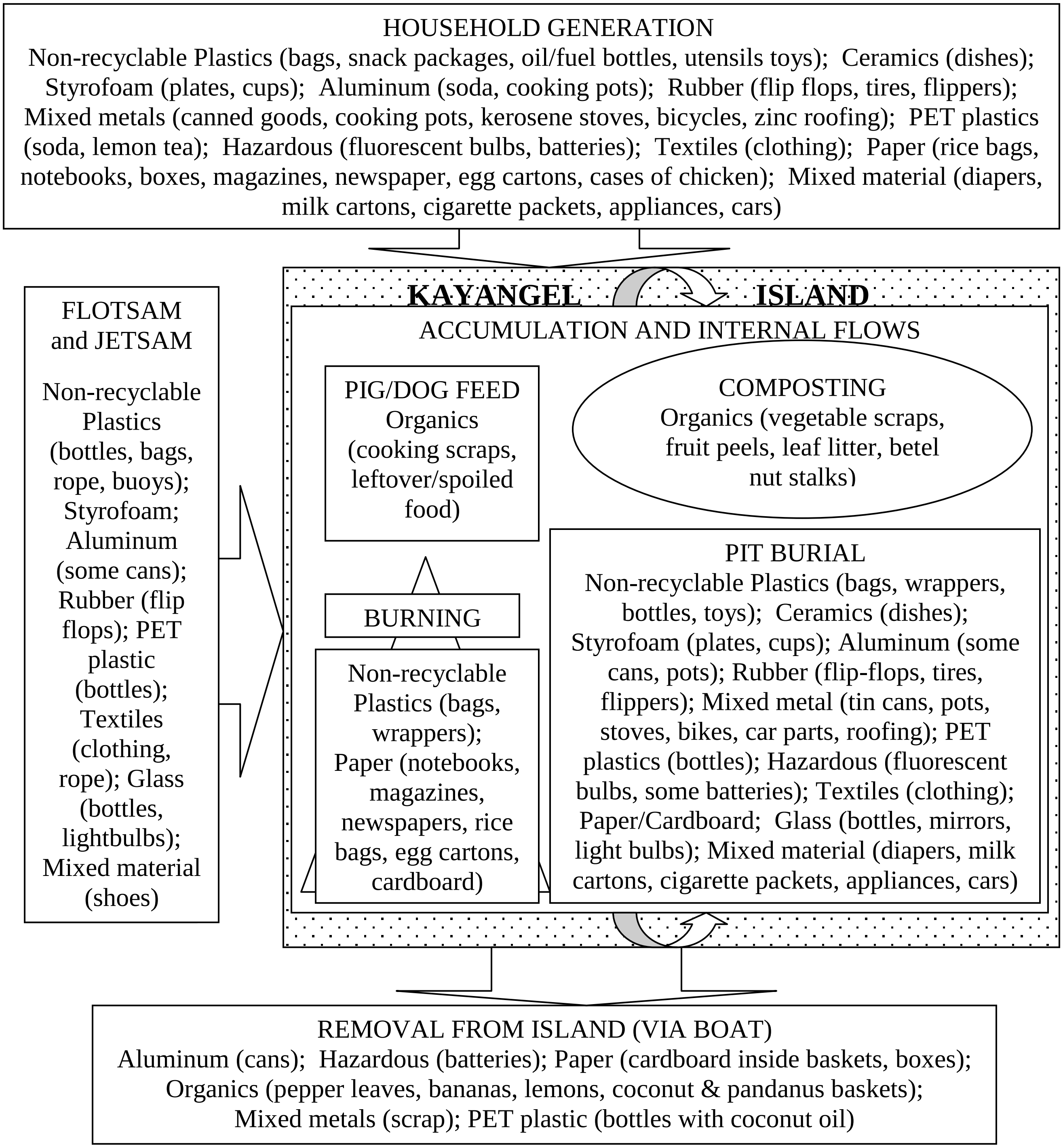


Figure 9: Materials flow diagram for Kayangel State, Republic of Palau.

3.4.2 Comparison of KHSWGS survey and MFA

Figure 9 outlined the material inputs, internal flows, and outputs for Kayangel Island offered by a MFA. This MFA builds upon solid waste generation and composition data provided by the KHSWGS survey, and provides missing details regarding sources of solid waste and sinks masked by internal flows. These differences are listed in Figure 10. The additional information supplied by combining a solid waste generation survey with a MFA is especially beneficial for linking materials and processes to streamline management practices. For Kayangel, KHSWGS survey data combined with an MFA defined by material fate (accumulation, removal from island, and burning) provides an objective perspective for evaluating and improving current solid waste management practices.

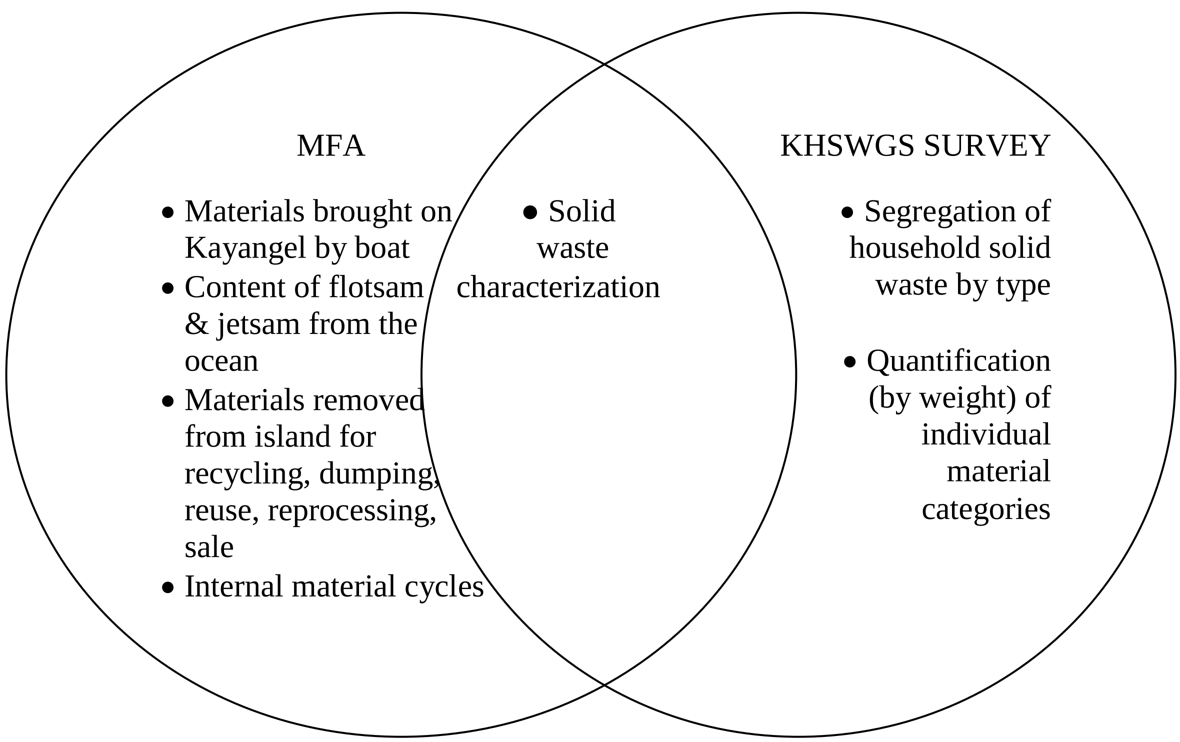


Figure 10: Venn diagram comparison of MFA and solid waste generation survey.

3.4.3 Material fate categories

Materials within the *removal from island* fate category (see Table 5) include: aluminum, hazardous waste, PET plastics, and cardboard. Mass values for aluminum and batteries/hazardous waste are assumed from the KHSWGS results. This is because these materials were segregated and collected separately from individual households as part of pre-existing local recycling and resource recovery efforts. In addition to the household segregation and collection efforts, there are significant quantities of old batteries that can be found littering the island and near-shore environment. While these could be included as part of the accumulation term, it is more instructive to omit them considering the goals of this analysis involve defining an MFA to depict current material flows in order to assess and improve future solid waste management practices. As listed in Table 5, it is assumed that all hazardous items are removed from the island as represented by the KHSWGS.

Every two weeks, a state-run boat makes trips back and forth between Kayangel and Koror (Palau's commercial center), transporting people and goods. Approximately one case (24 bottles) of coconut oil is removed from the island on each of the 26 annual state boat trip weekends, thus it is also assumed that 624 PET plastic bottles per year are removed from the island. Assuming an average mass of 2 oz. per bottle (based on measurements made by the author for the KHSWGS), approximately 80 lbs. of PET plastics are removed from the island annually. In addition to bottles of coconut oil, cardboard boxes are also removed on these state boat trips. An average of 10 cardboard boxes are removed from the island per state boat trip weekend, totaling 260 boxes annually or 130 lbs. (based on measurements made by the author for the KHSWGS).

The *accumulation* category (see Table 5) consists of all materials that remain on the island indefinitely. The following waste categories quantified within the KHSWGS are included: mixed metals, PET bottles, non-recyclable plastic, Styrofoam, textiles, ceramics, glass, paper/cardboard, rubber, and other/mixed material. Additionally, organics (e.g., leaf litter, food scraps, fruit and vegetable peels, etc.) could be included as part of a material accumulation term for a comprehensive Kayangel MFA. However for the purposes of this analysis, organics were omitted. This was because the majority of organics that could become accumulated solid waste represent internal cycling within the MFA system boundaries as seen in Figure 9 (e.g., food for pigs and dogs, composting). Moreover, the rapid decomposition of most organics renders their presence inconsequential in the grand scheme of solid waste management for SIDS like Kayangel.

Non-recyclable plastics and paper/cardboard make up the *burning* material fate category (see Table 5). Material is burned to generate fires for cooking and heating and is also performed to reduce the volume of waste material. Because burning material can be viewed as a processing step in solid waste management, it effectively reduces the volume, or in this case, removes these items from the waste stream. The KHSWGS accounted only for items that either accumulate or are removed from the island for recycling/recovery (e.g., aluminum and batteries). This material fate category is consequently difficult to quantify. It is, however, significant to include as an internal flow/material sink.

From Table 5 and Figure 9, it can be seen that the non-recyclable plastics that are burned on Kayangel are predominantly plastic bags and plastic wrappers/packaging. These plastics are light-weight compared with the more dense chemical plastics (e.g., HDPE and PETE plastics, oil containers, shampoo bottles, etc.) that account for most of the non-recyclable plastic mass within the accumulation term. It was assumed that the mass of non-recyclable plastic that was burned was a value equivalent to approximately 40% of the annual mass of accumulated (not burned) non-recyclable plastics as determined from the KHSWGS survey (Table 5), or 730 lbs.

As described in Table 5, most paper and some cardboard are burned as part of normal household solid waste management practices on Kayangel. While burning is the dominant processing mechanism for paper at the household level, it is important to consider the fact that the majority of the paper waste generated on Kayangel comes from JFK Elementary School. During the school-year survey of the KHSWGS, JFK generated 15.9 lbs. in 14-days. The cumulative total of the remainder of the community household generation for that time period was 6.9 lbs, or approximately 40% of the school generation (see APPENDIX B: Results of KHSWGS). Clearly, the mass of paper generated as solid waste by the school is significantly more than that generated at the household level in the KHSWGS.

At the household level, the majority of paper waste is burned, and consequently is not included in the accumulation term that was determined from the KHSWGS. Based on the distribution of paper use at the household level compared with the paper used by the school (both of which were included in the KHSWGS), as well as the prevalence of burning as a treatment mechanism for household paper waste, it was assumed that the mass of paper (including some cardboard) burned by the community annually was an equivalent value to approximately 10% of the projected annual paper waste generated by the school, or approximately 80 lbs.

3.4.4 Flotsam and Jetsam

Another potential influx for the Kayangel MFA is contributed from floating material deposited along the island's 6,280-m coastline (coastline measurement made by JFK 5th-8th graders, 2008). This flotsam and jetsam, accounted for in Figure 9, consists of non-recyclable and PET plastics (e.g., bottles, bags, rope, buoys), glass (e.g., bottles and lightbulbs), Styrofoam, aluminum (e.g., some cans), rubber (e.g., flip flops), textiles (e.g., clothing, rope), and mixed material (e.g., shoes). These items are deposited by the sea on the beach and backshore environments of Kayangel as a function of natural variables (e.g., tides, wind, and storm events) and human intervention (Barbosa de Araújo and Ferreira da Costa, 2007).

The author participated in multiple coastal clean-up efforts on Kayangel Island between November 2006 and August 2008, however she was unable to establish a local rate of deposition for the flotsam and jetsam based on experimentation. An estimation of this rate is assumed based on two solid waste cleaning efforts involving the entire Kayangel community that were made on the south and southeastern sides of the island (representing approximately one-quarter of the coastline of Kayangel Island, an estimated area of 31,400 m^2) in both August 2007 and May 2008. The latter of these cleaning efforts was conducted in association with a grant secured by Palau's Council of Chiefs (personal communication, Blekuu Sebal, 2008). The grant was aimed at cleaning the entire coastline of the ROP. In addition to picking up all of the solid waste from the beach and backshore environments, this waste was segregated and weighed. The data from the May 2008 clean-up is assumed to represent 9 months of accumulation, due to the previous clean-up effort on the same part of the island; however, the May 2008 effort was comprehensive in scope, and large items (e.g., metal buoys, anchors, thick ropes, etc.) were removed that had been skipped during the August 2007 clean-up. The area covered in the May 2008 clean-up also exceeded the August 2007 effort by approximately 1,500 m^2 (assuming an additional 300 m of coastline were covered with an average 5 m beach and backshore depth).

According to Barbosa de Araújo and Ferreira da Costa (2007) the highest concentration of coastal solid waste accumulation occurs in vegetated areas and dunes. As visible in Figure 3, the long, linear coastline of Kayangel is bordered by reef and open ocean to the east and the inner lagoon of Kayangel Atoll to the west. The northern and southern ends of the island are subject to seasonal changes in deposition and erosion processes, based on currents and tidal fluctuations. The entire backshore of Kayangel is densely vegetated apart from an approximately 50-m stretch of sand on the eastern side of the island and 10 private boat-launch paths covering an additional approximately 150 m of backshore void of vegetation on the lagoon side. The dense vegetation surrounding the entire island would therefore trap solid waste originating from the ocean, with a slightly higher concentration on the eastern coast than the western coast.

Another factor cited by Barbosa de Araújo and Ferreira da Costa (2007) as influencing deposition of solid waste is the ocean environment adjacent to the beach. Open ocean tends to contribute more solid waste than a bay or shallow lagoon. Hence, for Kayangel Island, the eastern side would be expected to contribute more solid waste than the western, lagoon side. Because community solid waste is managed at the household level (typically in shallow pits adjacent to the houses), and there are no rivers to carry locally-generated solid waste to the beach, it is assumed that all solid waste on the beach and backshore environments is of ocean, rather than terrestrial provenance.

The most complicating factor in developing a viable model for flotsam and jetsam deposition on Kayangel Island is the dominating influence of the natural variables. Barbosa de Araújo and Ferreira da Costa (2007) summarize these phenomena with the explanation:

> "Near the coast, the synergism among various factors as wind, tides, currents, [and] beach morphodynamics… discharge promotes water circulation patterns that condition the distribution of the solid wastes" (Barbosa de Araújo and Ferreira da Costa, 2007, p. 837).

In summary, developing an accurate rate of deposition for solid waste of ocean provenance on Kayangel beaches is difficult and would require further study. For the purposes of this analysis, it was assumed that 75% (reduced due to presence of persistent bulky items and data collection representing the open ocean/reef side of the island) of the mass of solid waste collected and weighed along the Kayangel coastline in May 2008 is representative of one-quarter of the total 9-month accumulation of solid waste from the ocean, or approximately 12,000 lbs. All of the flotsam and jetsam that are deposited on the upper beach and backshore environment are also assumed as solid waste accumulation.

4 RESULTS AND DISCUSSION

4.1 KHSWGS Survey Results

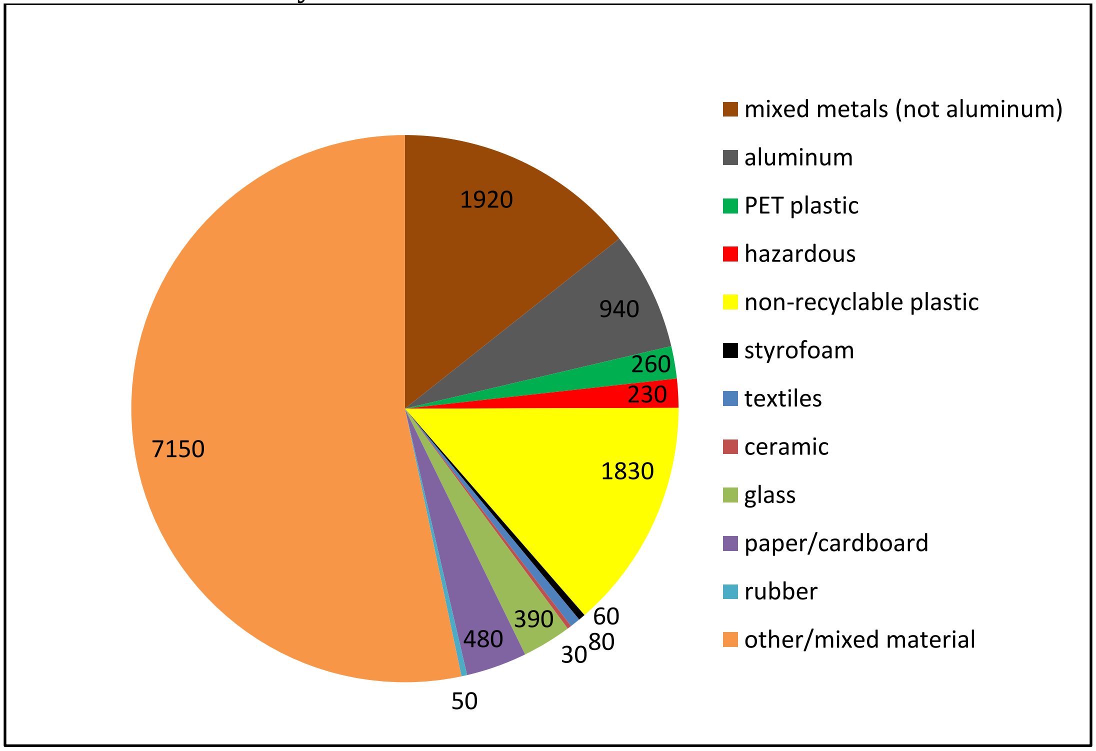


Figure 11: Kayangel annual household solid waste generation (lbs/yr).

The results of the KHSWGS survey were used to develop annual solid waste generation rates presented in Figure 11 and APPENDIX B: Results of KHSWGS. Of particular significance are the categories of waste which are slow to decompose and remain on the island indefinitely due to current waste management practices. These include mixed metals, PET plastic, non-recyclable plastic, Styrofoam, ceramics, glass, rubber, and mixed material. These waste categories are collectively be referred to as the *accumulation term* (refer to Section 3.4 Material Flow Analysis for discussion of this term). Based on the data collection from the KHSWGS, 91% of items found in household solid waste on Kayangel are being accumulated.

The remaining 9% of household solid waste from the survey is currently being diverted from the local solid waste stream at the household level. These materials include aluminum and hazardous waste (batteries), and are referred to as the *removal term* (refer to Section discussion of this term).

In terms of generation, assuming a year-round average of 98 local residents (based on averaging population counts conducted by the author during school-year and non-school-year studies) Kayangel residents on average produce 0.37 lbs. of waste per capita per day. By material fate, each day 0.34 lbs. of waste per capita (91%) accumulate on the island, while 0.03 lbs. of waste per capita (9%) are removed for recycling and reprocessing.

4.2 Results in Context of Global Solid Waste Composition and Generation Rates

As discussed in the previous chapter, the solid waste generation study for Kayangel Island excluded organics based on local solid waste management practices. Many similar solid waste generation and composition studies have been conducted throughout the world. Troschinetz (2008 and 2005) synthesized related work of others in order to analyze indicators for sustainable recycling habits, comparing data from the United States (US), European Union (EU), and many developing countries throughout the world. For the purposes of comparison, the organic portion of the solid waste composition data from Troschinetz was removed and composition percentages were re-calculated to reflect the non-organic solid waste content.

The waste categories for the Kayangel household solid waste generation study were consolidated in order to reflect those from Troschinetz (2005). Figure 12 displays the municipal solid waste (MSW) compositions excluding organics for Kayangel, the US, the Western EU, 13 candidate countries for the EU, and 19 developing countries (based on criteria established by Troschinetz, 2005).

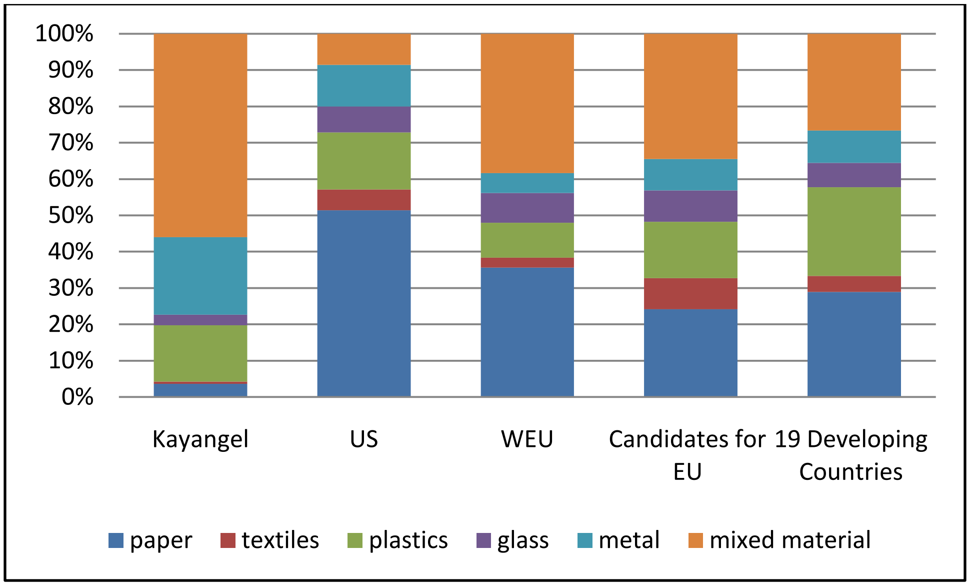


Figure 12: Global municipal solid waste compositions, excluding organics, compared with Kayangel.
(global data from Troschinetz, 2005)

The information from Figure 12 is presented for the individual nations and development categories in APPENDIX D: Global MSW Comparisons Excluding Organics. The Kayangel municipal solid waste (MSW) profile is noticeably different from the other nation groups. The marked differences occur in the relative percentages of paper, metal, and mixed materials. As seen in Figure 12, paper waste in Kayangel is a far smaller percentage of the overall solid waste scenario relative to the other nation groups by 20-45%, but metals (10-15%) and mixed material waste (18-47%) are present in greater relative percentages. Paper has a rapid degradation rate of 2-5 months (Mihelcic and Zimmerman, 2009). Recall from the discussion in Section 3.4 that it is also typically burned on Kayangel, which explains its limited contribution to the island's MSW composition. Metal and mixed material waste are the by-products of goods imported to the island, and have a much longer lifespan (refer to Section 4.6 for further discussion of waste accumulation and material degradation). These solid waste categories are included in the accumulation term.

In terms of generation of paper waste at the household level, Kayangel is more similar to the less developed countries in the global categories of European Union candidate countries or developing countries from Troschinetz (2005). However, by metal and mixed material waste generation, Kayangel more closely matches the compositions of MSW from the European Union and the United States.

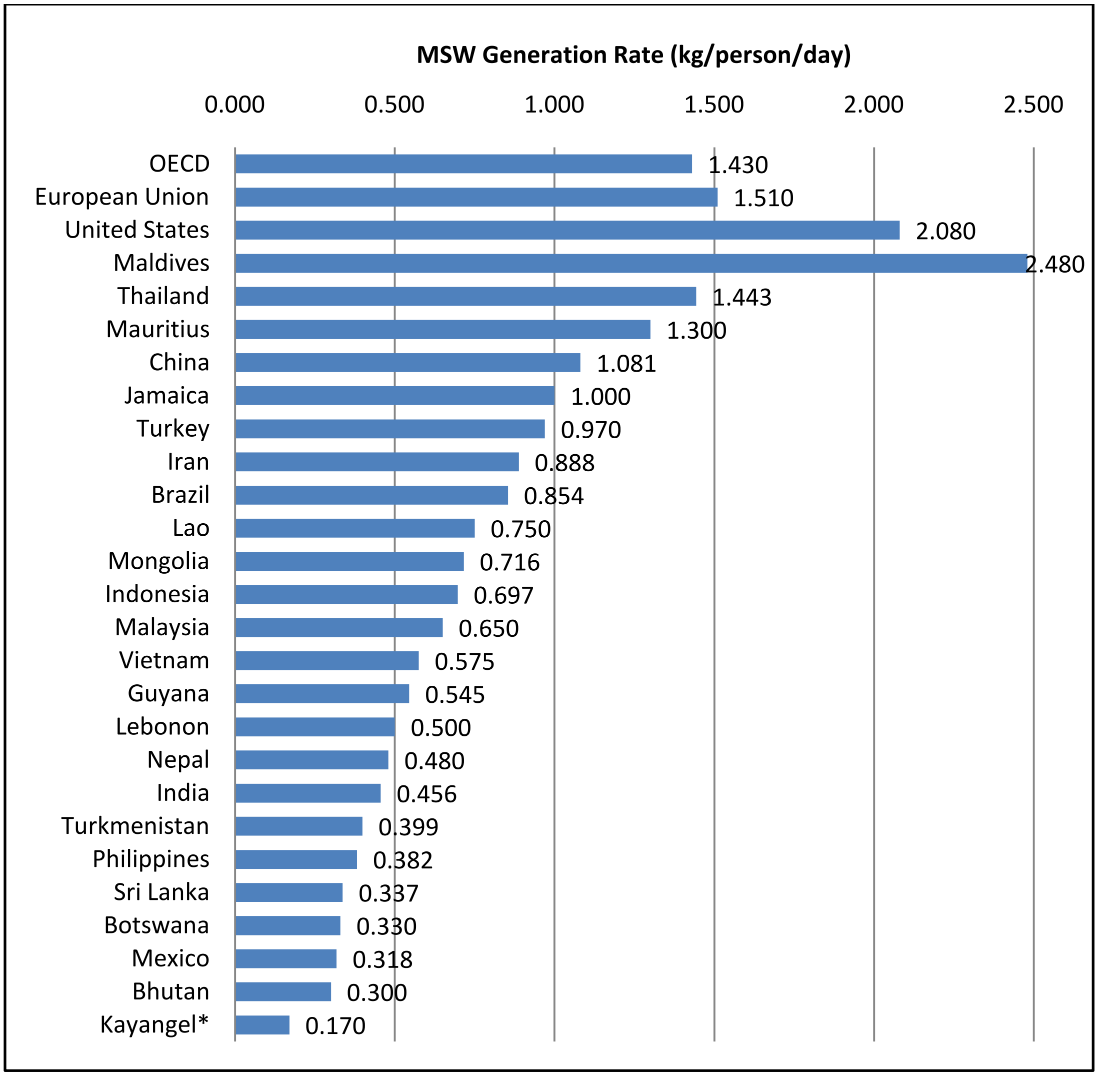


Figure 13: Global MSW Generation Rates (global data from Troschinetz, 2008).
*** Kayangel generation rate based on household MSW data that excludes organics and is converted from lbs/capita/day.**

While it is clear from Figure 12 that the composition profile of solid waste on Kayangel is different from other nations, a more qualitative global comparison of solid waste is provided in Figure 13, with comparative MSW generation rates. Kayangel's average daily per capita solid waste generation rate of 0.170 kg/capita/day is far less than all other nations listed. This seems surprising, considering the composition profiles for the community provided in Figure 11 and Figure 12. However it is important to point out that the daily per capita waste generation rate for Kayangel is based on only household generation for a small, isolated island community (no industry). The other marked difference between the global rates and that from Kayangel is the absence of organic waste in the latter MSW generation. Organics are water-rich and tend to be greater in mass than the waste materials from the Kayangel profile (predominantly mixed materials, metals, and plastics). While organics account for greater mass (as reflected in more elevated MSW generation rates found in Figure 13), they are typically far less persistent in the environment. This can be seen by comparing the 6-month degradation rate for an orange peel with the 50-100 year rate of a tin can, or >1 million year rate of degradation for a plastic bottle. More discussion of material degradation rates follows in Section 4.7.

In the case of Kayangel Island, a low per capita daily MSW generation rate of 0.170 kg per capita per day at the household level does not represent the full local solid waste scenario. In fact, the contribution of solid waste deposited by the ocean is far more significant, as it represents the majority of the solid waste generated on the island on an annual basis. This will be discussed in greater detail in Section 4.6. If all sources and sinks of solid waste on Kayangel Island are included, as represented by the MFA assessment, 0.420 kg of solid waste per capita per day are generated. From a global MSW perspective (Figure 13), Kayangel would fit between Turkmenistan and India for overall solid waste generation on the island. The total island solid waste generation rates for Kayangel is more than twice the household MSW generation rate, solely due to the deposition of solid waste from the world at large. Thus, the majority of the solid waste materials on Kayangel are the products of the consumption and disposal practices of the larger global community, rather than the local residents.

4.3 Regional Solid Waste Comparison

On a regional scale, Palau is one of the 25 member countries within the South Pacific Regional Environmental Programme (SPREP, 2007). In 1999, the European Communities financed the Solid Waste Characterization and Management Plans Project for eight Pacific Countries. Sinclair Knight Merz Ltd. conducted these studies for landfills and households in Fiji, Tonga, Vanuatu, Papua New Guinea, Kiribati, Tuvalu, Solomon Islands and Western Samoa (2000a-h). Using the data from these studies, and removing the organic content, it is possible to compare the solid waste composition of Kayangel with regional population centers throughout the Pacific. Country and study-specific information details are provided in APPENDIX E: Pacific Region Solid Waste Composition Comparison.

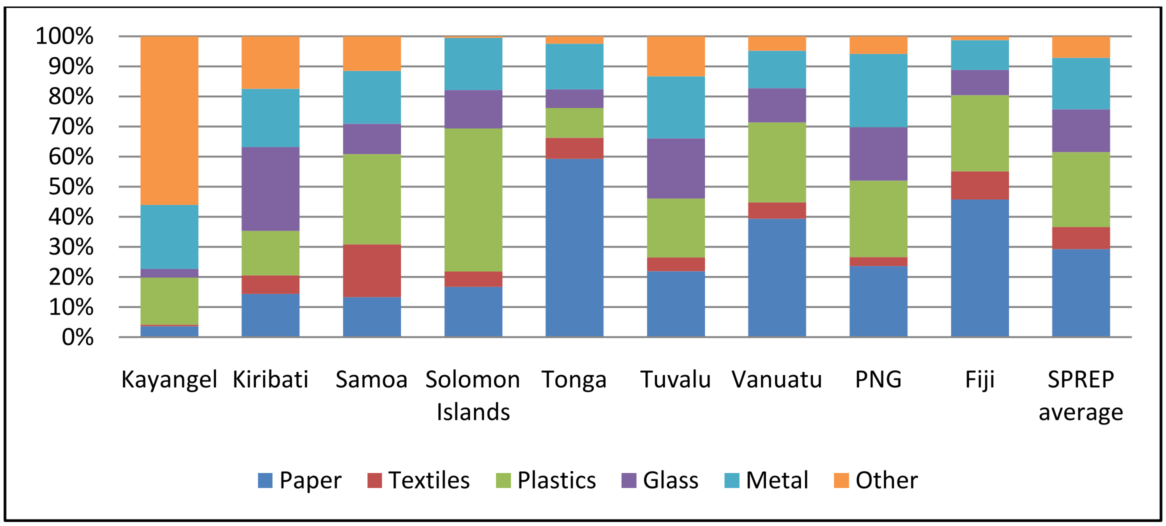


Figure 14: MSW composition for Kayangel & SPREP countries, organics excluded.
(data from Sinclair Knight Merz, 2000a-h)

The Kayangel MSW composition profile is markedly different from the other SPREP countries with regards to its relatively high incidence of “other” (i.e., mixed material waste) and lower relative incidence of paper and glass. Plastics and textiles are more varied in their relative concentrations within the solid waste composition for the Pacific SIDS from Figure 14. As suggested in the global analysis, Kayangel’s lower relative incidence of paper compared with the other SPREP countries studied. This might be explained by setting and composition of the study communities. The Kayangel community is a relatively isolated, rural population compared with the larger, more urban communities represented in the SPREP data collection. In absence of businesses and industry, the Kayangel population likely produces less paper and glass waste compared to the more urban wastes from the SPREP data. Population and additional country-specific information are shown in APPENDIX E: Pacific Region Solid Waste Composition Comparison.

Overall, the Kayangel waste profile is more similar to the other SIDS than to the global data when incomes to metals (see Figure 12 and Figure 14). As characterized by this data, Pacific Islands have a lot of canned goods. These items were largely introduced as a result of World War II. Many of the Pacific Islands, including the ROP, were battlegrounds during World War II. Following the war, many of these islands were annexed by the United States and other nations. Unexploded ordinance was widespread, thus traditional subsistence activities (e.g., marine harvesting, agriculture, etc.) was dangerous. Canned foods were introduced to provide temporary food security, but were gradually incorporated into local diets as a taste for these items was developed. The continued widespread availability of these items (as represented by the high incidence of metal waste) attests to the legacy of American influence and global shipping routes throughout the Pacific.

Much like the global analysis from Figure 12, comparing relative composition percentages for Kayangel and other SPREP countries provides an incomplete analysis. Unfortunately, the solid waste generation rates were not published within the SPREP solid waste data from Sinclair Knight Merz Ltd. (2000a-h). It is important to note that the sites selected as part of these SPREP studies were regional population centers, while Kayangel is considered a rural, outer island within the Republic of Palau. Additionally, the Republic of Palau has the highest per capita Gross Domestic Product (GDP) of the SPREP countries from the study (CIA Factbook, 2008a-i). Recall from Section 3.1.3 and Figure 7, however, that annual average income and expenditures for Kayangel residents are less than half of those for the nation of Palau. For a more equivalent comparison, the solid waste composition profile and generation rate from Kayangel should be compared with those from a similar small community within one of the SPREP countries. Refer to

APPENDIX E: Pacific Region Solid Waste Composition Comparison for more country-specific information for the SPREP countries compared in this analysis.

4.4 Analysis of results on local level

The KHSWGS data can be analyzed in many different ways in order to pick out trends and information of significance.

4.4.1 Kayangel Solid Waste Generation by Season

Solid waste generation rates can be compared on a seasonal basis for Kayangel Island. To facilitate this analysis, the solid waste compositions and generation rates from both the school-year and nonschool-year data were projected on an annual basis, using an average 98 year-round residents. These results are presented in Table 6.

Table 6: Seasonal solid waste generation projections based on school-year (SY) and nonschool-year (NSY) data from KHSWGS.

Waste Category	Avg. SY data (lbs/capita/14 days)*	Annual projection from SY data (lbs)**	Avg. NSY data (lbs/capita/14 days)*	Annual projection from NSY data (lbs)**
Mixed metals (not aluminum)	0.64	1,631	0.78	1,980
Aluminum	0.33	829	0.36	910
PET bottles	0.11	276	0.06	160
Hazardous	0.13	326	0.00	0
Plastic (non recyclable)	0.68	1,738	0.61	1,550
Styrofoam	0.03	71	0.01	10
Textiles	0.03	74	0.03	70
Ceramic	0.01	31	0.01	30
Glass	0.20	521	0.02	60
Paper/cardboard	0.26	661	0.02	40
Rubber	0.00	7	0.04	100
Other (mixed material waste)	1.92	4,887	3.72	9,480
TOTAL	4.34	11,050	5.65	14,390

***SY data based on 88 individuals surveyed and NSY data based on 50 individuals surveyed.**
****Annual projections have been rounded due to accuracy of field measurements**

From Table 6, the nonschool-year projection of annual household solid waste generation by the Kayangel community is more than 3,000 lbs. greater than the school-year projection. The nonschool-year projection produced a greater incidence of mixed materials, aluminum, and mixed metal waste. All of the items accounted for within the

KHSWGS represent imported items that are introduced to Kayangel Island from outside; however the proportions of these materials change depending on the number of visitors or part-time residents vs. year-round residents staying on the island. This can be restated by asserting that based on the methodology of the KHSWGS, both the resulting solid waste composition and generation rates for Kayangel are completely dependent upon the available goods brought onto the island. Since the annual solid waste generation projections for the community are greater using the nonschool-year data as compared with the school-year data, it suggests that the nonschool-year population consumes more.

Hence, MFA results have shown that seasonal increases in population on Kayangel Island correspond with increased household solid waste generation. It is expected that this seasonal change has a profound effect on material flow patterns because the increased boat traffic during the nonschool-year provides increased access to imported goods. Furthermore, it is probable that visitors and part-time residents serve to alter consumption patterns towards goods which produce accumulation waste, since they come from more urban areas of Palau.

4.4.2 Kayangel Solid Waste Generation by Household Employment

In the Kayangel Household Solid Waste Generation Study (KHSWGS), households were classified by employment as part of the solid waste assessment survey for the island. The four household employment categories used were: 1) 2+ salaried or self-employed residents per household, 2) 1 salaried or self-employed resident per household, 3) casual or unemployed residents, and 4) retired residents. The resulting community household employment profile is reflected in Figure 15.

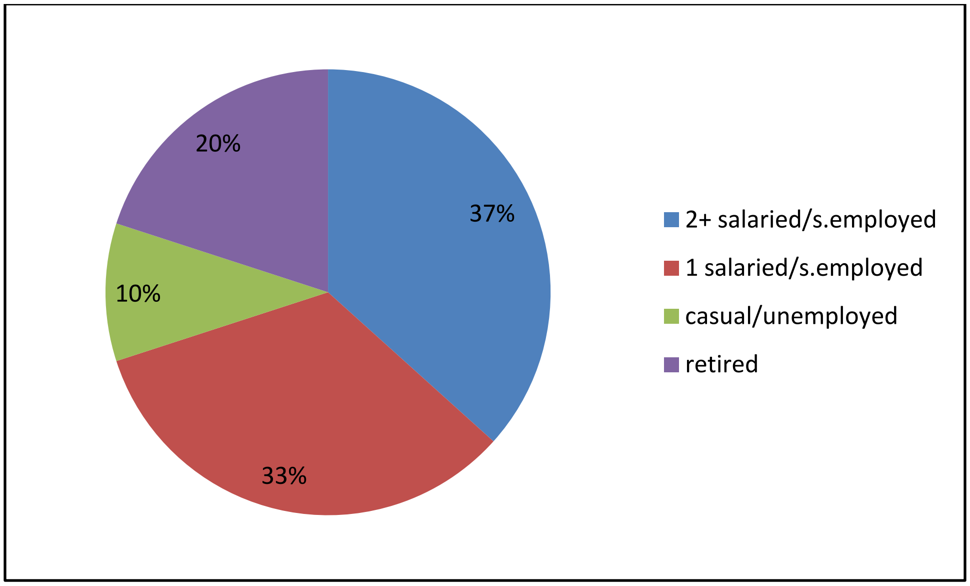


Figure 15: Kayangel State household employment statistics.

Because income and expenditures dictate consumption patterns, and Kayangel Island has significantly lower income and expenditures than the averages for Palau as a whole (refer back to Figure 7 in Section 3.1.3), the author wanted to correlate local employment with solid waste generation. This relationship is shown in Figure 16 and presented in more detail in APPENDIX F: Kayangel Average Annual Solid Waste Generation & Composition by Household Employment.

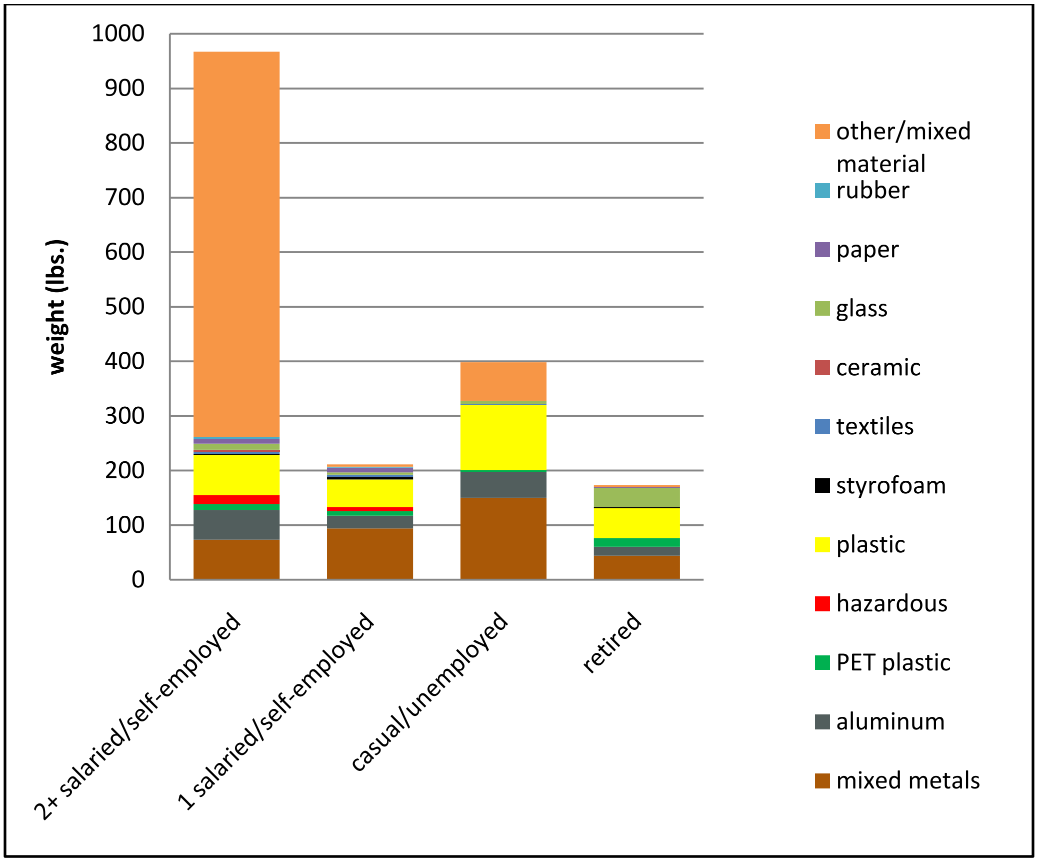


Figure 16: Kayangel average annual solid waste generation by household employment.

In general, it was surprising that the casual/unemployed category surpassed the 1 salaried/self-employed category in overall annual solid waste generation. This can be explained through knowledge of the local supply chains. As discussed in Section 3.2.3, the bi-weekly state-run boat trip is the main supply of goods and materials for the Kayangel community. The state boats transports the goods that are sold in the two island stores, as well as packages sent by family members from Palau's commercial center, Koror. The goods sold in the stores as well as those sent by family members serve to supplement foods harvested on the island (e.g., taro, tapioca, sweet potatoes, fish, crab, cultivated vegetables, etc.). In general, they can be characterized as imported goods which generate solid waste that accumulates on the island. The incidence of greater solid waste generation corresponds to the source of goods for a household. Because the KHSWGS serves to quantify solid waste that by definition originates from off island (the non-organic fraction of local solid waste), more solid waste generation for an individual household or household group means that more imported goods were consumed. This information could be used further to pinpoint dietary trends (local vs. canned or imported foods) and household spending habits.

One logical assumption that might be made would be to correlate steady or reliable household income sources from employment with higher waste generation rates. This would stem from the idea that households with more locally-generated money would consume more imported goods (vs. local foods from the island). As seen in Figure 16, this is true for the 2+ employed/self-employed category, as on average they produce over 500 lbs. more annual solid waste than the next highest employment group. The same chart also shows that the casual/unemployed households produce roughly twice as much as the households with one employed or self-employed resident. This unlikely result might be explained by households for which some family members reside in Koror or elsewhere in Palau for the purpose of employment. Kayangel is separated from the Palau's main island of Babeldaob and its commercial center in Koror by more than 40 km of open ocean. This isolation combined with limited employment options leads many Kayangel people to take up full- or part-time residency off-island. This phenomenon results in much sending of goods back and forth on the state boat trips, including imported goods that contribute to solid waste generation for Kayangel.

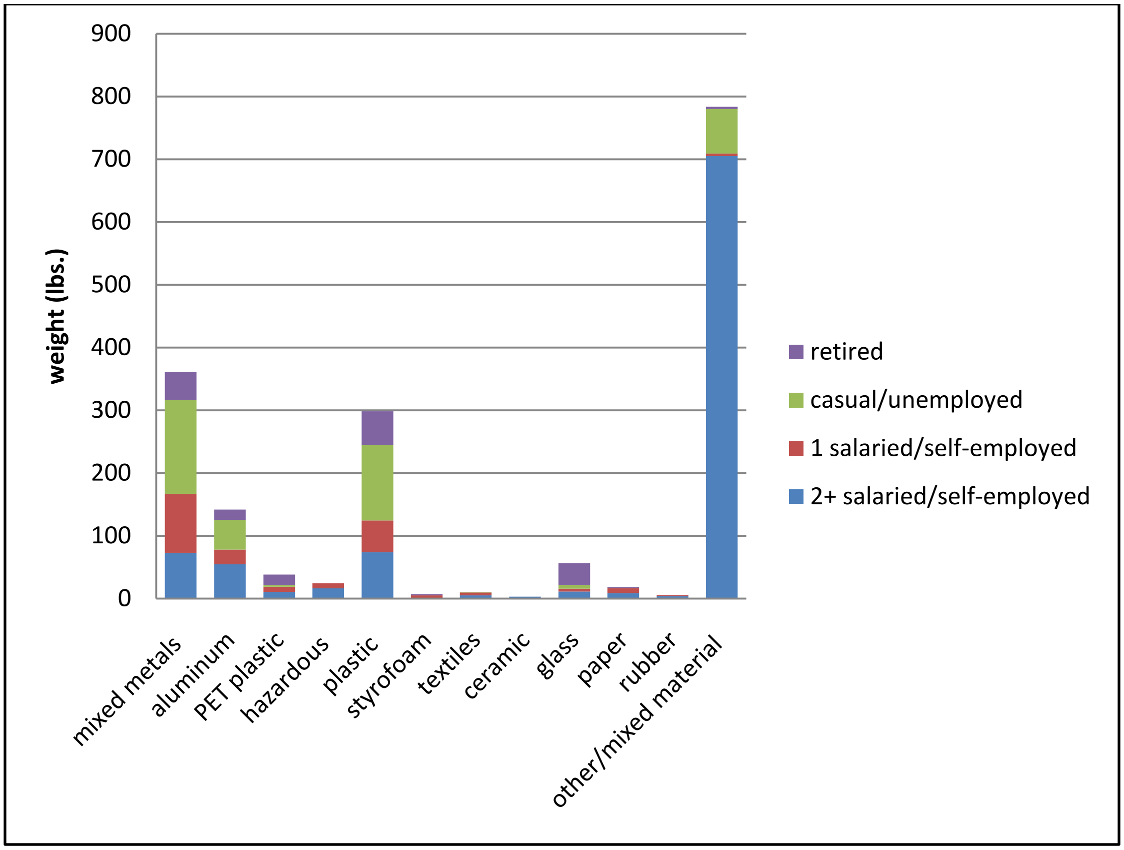


Figure 17: Kayangel average annual solid waste generation by composition and household employment.

Another observation from the solid waste generation data, organized by household employment, relates to the largest generation category, mixed material. The households with 2+ salaried/self-employed residents not only generated the most overall solid waste (Figure 16), but they also generate an average of more than 700 lbs. of mixed material waste per year, as seen in Figure 17. This can be explained by the largest single item contributor to the mixed material waste category: diapers. There are very few families with young children on Kayangel Island. In fact, at the time of the survey, only one full-time resident of the island was a toddler wearing diapers. It just so happens that the same household with this toddler also had a bed-ridden adult who wore diapers as well. Aside from this house, there was one more household with part-time resident diaper-wearing children. Coincidentally, both of the households which used diapers happened to be in the 2+ employed/self-employed category. While this doesn't serve to draw any parallels between household employment and solid waste generation or composition, it identifies a large source of mixed material waste for the community.

The KHSWGS survey quantified solid waste based on weight alone, which serves to explain the high proportion of mixed material waste presented in Figure 17. There is a large discrepancy between the weight of dry and wet diapers, therefore incorporating volume as part of the survey's quantitative analysis would serve to more fully characterize the solid waste on Kayangel.

The fact that there are very few diaper-wearers on the island, and yet these diapers constitute such a large portion of overall household solid waste generation on an annual basis underscores the importance of multi-pronged approach to data analysis. The significance of the contribution of diapers to the solid waste stream for Kayangel was not apparent to the author until the data was evaluated on a spatial scale. The subject of diapers also serves to preview the following discussion on one limitation of the KHSWGS, because diapers are one of the solid waste materials that are typically disposed of immediately, often in a manner different from the remainder of the household solid waste. These more personal or offensive waste items can thus be more difficult to quantify as part of a survey analysis such as the KHSWGS.

4.5 Limitations of KHSWGS Survey

The aforementioned example of a discrepancy in defining and dealing with solid waste as part of a survey to quantify generation rates for the Kayangel community lends support for a more comprehensive assessment of local solid waste dynamics. Despite Kayangel's limited population, isolated geographic location, and the author's intimate connection to the community, the cultural and logistical barriers to a more straightforward solid waste generation survey posed barriers that served to mask important internal flows. Though it could be appropriate to consider only net solid waste generation from this survey as a basis for comparing and contrasting solid waste generation information from Kayangel with other locations, developing a community solid waste management plan requires further scrutiny. The change from individual household solid waste management to a collective system has the potential to offer more convenience and ultimately change disposal patterns or even local definitions of solid waste. This degree of speculation is outside the scope of the solid waste generation survey, but could be gleaned from an alternative approach that offers more complete details of material flows.

4.5.1 Interpretation

The main problems that were observed in the survey of household solid waste generation were related to the individual interpretations of survey instructions. This could include personal definitions of solid waste and restriction on included items based on a limited survey period. Despite explanation of the study in both Palauan (see APPENDIX A for copy of survey in Palauan language) and English, household solid waste composition varied due to individual household solid waste management schemes. As mentioned in Chapter 3, yard waste and food scraps (organics) were mostly absent from the household solid waste collected from residents as part of the 14-day KHSWGS. However, there were occasional exceptions to this, especially food residues left in tin cans, betel nuts and the pepper leaves that are chewed with them (rotten or chewed and spat into a capped spittoon), some fish and vegetable scraps from food preparation, and leaf litter from basket-making. These were rare enough to be worth acknowledging as organic contamination of separate waste categories, rather than meriting a separate category of their own.

4.5.2 Time Scale Considerations

Limiting the scope of the KHSWGS to a 14-day time period also proved problematic for some residents. The fact that there had been no collection or schedule for emptying garbage receptacles prior to this study meant that people often included items that appeared to be suspiciously old. When possible, the author tried to clarify the limited time scope of the study, and asked household residents whether items were from the preceding 2-week period; however, this was not always successful. In these circumstances, the author thanked participants for their help in collecting solid waste for their household and recorded data for the given solid waste, but made notes when there were items of questionable age.

There is also possible error in defining the appropriate time frame for which items become solid waste. For food products, this transition is often clear because it occurs once the meal is prepared, and the can or vegetable peels or plastic bag are no longer used. Objects with a less-defined lifespan are discarded after the owner places them in a designated waste receptacle or disassembles, burns, or eliminates them in some other way. In a context where solid waste management has been purely conducted on an individual household level, the definition of solid waste and the time frame for items receiving this designation is more obscure. For the purposes of this study, the author was concerned with quantifying net solid waste as presented by locals. On Kayangel, this was a function of local perceptions of and definitions for "solid waste", as much as a measure of some kind of real value.

4.5.3 Population Variability

Changing population was also a barrier to data collection. A number of Kayangel residents have homes both on the island and in Koror or other states of Palau with extended family members. Retired and elderly residents often maintain a rather transient status, with frequent trips back and forth for access to family, customary obligations, and health care. During the non-school period of the year, the population fluctuation patterns are more pronounced, as there is much more transportation between Kayangel and the rest of Palau. Some local residents with children take advantage of school vacation time to go shopping and visit family-members off-island, while many extended family members, especially school children, stay on Kayangel for extended visits. With these continually changing population dynamics, it was much more difficult to coordinate solid waste collection and segregation studies with local residents during the non-school time period.

4.5.4 Disposal Mechanisms

The fact that solid waste management on Kayangel Island has always been conducted at the household level, has led to the development of diverse treatment schemes and schedules for individual households. This phenomenon consequently played a role in the manner in which solid waste was handled and presented to the author following each 14-day survey period. For example, many Kayangel residents are accustomed to tossing plastic bags and wrappers into their cooking fire (Figure 9). The same is often done for paper products (used paper, pasteboard packaging, and cardboard boxes). In terms of measuring net solid waste (household waste that needs to be treated as part of a community-wide collection and treatment system), it was not possible to include materials that were combusted or otherwise disposed of prior to data collection and solid waste quantification. This fact is seemingly obvious, yet it merits mention for addressing the limitations of this solid waste generation survey technique in adequately serving to characterize the consumption patterns for the Kayangel community.

4.6 Material Flow Analysis Results

Examining the KHSWGS results objectively, in terms of MFA, the waste categories have been highlighted in Figure 18 to reflect material fate: accumulation (light and dark blue), removed from island (red), burned (green). It is important to note that three of the original waste categories from Table 4 appear in more than one material fate category, according to the source of the waste, as well as existing local treatment practices. As discussed in Section 3.4, many assumptions were made in defining the MFA. The following results and analysis are limited by the scope of the KHSWGS survey data and the estimations provided by the Kayangel MFA.

4.6.1 Comprehensive Kayangel Annual Solid Waste Generation

Combining the KHSWGS data with the projected data characterizing flotsam and jetsam deposition rates, as well as estimates for items that are burned as a treatment mechanism, results in a comprehensive characterization of annual solid waste generation results. Individual waste materials are listed in Figure 18 with the annual mass generated of each according to its material fate: green for burning, red for removal from island, and blue (light and dark blue) for accumulation.

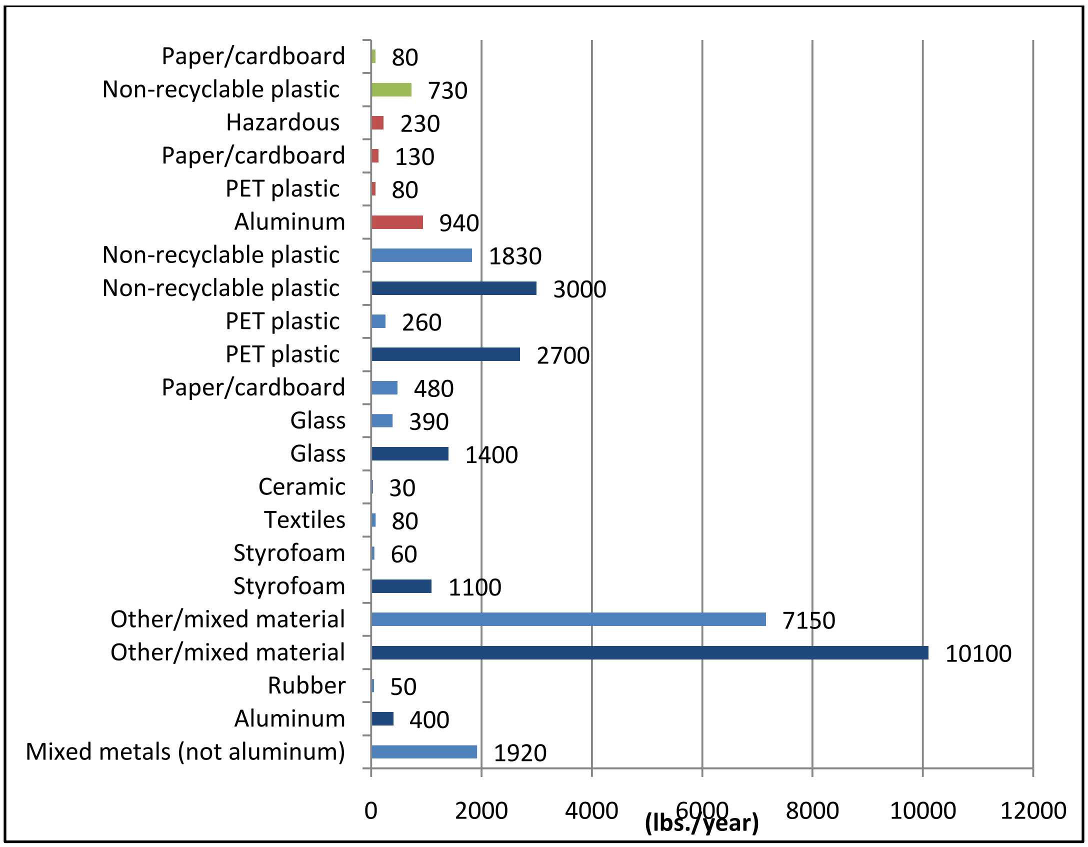


Figure 18: Kayangel annual solid waste generation organized by material fate.

(green=burning, red=removal from island, light blue=accumulation from household, dark blue=accumulation from tidal deposition).
Weight of solid waste from KHSWGS survey results and Kayangel MFA estimations.

4.6.2 Burning

The *burning term*, or total mass of solid waste that is annually removed from the Kayangel Island system by combustion, is an additional material fate category necessary for establishing a comprehensive characterization of local material movements with an MFA. It is the most difficult material fate category to quantify. As discussed in Section 3.4, burning is a common method of disposal at the household level on Kayangel. Land is obviously a limited resource for a small island community such as Kayangel, especially with solid waste management at the individual household level. The burning term as established for the Kayangel MFA characterizes the materials that are burned simultaneous to their transformation from good/material to solid waste. This can be illustrated by a food preparation example. Ramen noodles are sold in both of the local stores on Kayangel, and consumed on a regular basis. Most of the island's residents use a combination of fuels for food preparation (for humans or pigs), including propane and kerosene stoves, as well as wood or coconut husk fires. Often, after opening the cellophane wrapper from the ramen noodles, the plastic will be tossed in an active or dormant fire pit in the kitchen, effectively eliminating the waste as it is transformed from packaging to solid waste.

Although the solid waste characterized by the KHSWGS results (apart from the diverted aluminum and batteries) is deemed accumulation, in reality much of this is eventually burned. The solid waste is typically transferred from household waste containers to a shallow pit proximal to the residence, where it is covered with coconut branches. Periodically, these pits will be burned in order to reduce solid waste volume and/or deter vermin and breeding spots for mosquitoes. It is important to recognize that this secondary burning is a treatment mechanism that occurs for lack of alternative waste treatment option within the confines of the island.

If solid waste disposal was managed on the community level, the household solid waste included in the accumulation term (from the KHSWGS) would likely be transferred directly to a landfill or waste segregation facility for reprocessing and transfer off-island. This could be studied further by comparing solid waste generation and material fate within similar-sized island communities with collective solid waste management.

4.6.3 Flotsam and Jetsam

Aside from the three material fate categories, the other crucial information absent from the KHSWGS solid waste data is the contribution of solid waste from the ocean. As discussed in Section 3.4.4, the mass of this waste was calculated based on solid waste data from a coastal clean-up on the southeastern quarter of Kayangel in May 2008. Table 7 lists solid waste data as collected, segregated, and weighed by the Kayangel community during the May 2008 clean-up. It also provides the projected annual solid waste accumulation on the beach and backshore environment of Kayangel from flotsam and jetsam. When combined with the data from the KHSWGS and mass estimates for material that is burned at the household level (those not characterized within the KHSWGS survey), the projected mass of annual ocean provenance solid waste completes the material input information for establishing a Kayangel MFA. This is presented in Error! Reference source not found..

Table 7: Solid waste data and projections from Kayangel coastal clean-up, southeastern quarter of island, May 2008.
(personal communication, Blekuu Sbal, Palau Council of Chiefs)

Waste Category	9 months coastal accumulation data (lbs.)	75% of total from data (lbs.)	Annual projection for entire island* (lbs.)
Aluminum	101	76	400
PET plastic	667	500	2,700
Styrofoam	283	212	1,100
Non-recyclable plastic	760	570	3,000
Glass	360	270	1,400
Other (mixed metal, non-recyc. plastic, etc.)	2,530	1,898	10,100
TOTAL	4,701	3,526	18,700

***Annual projections have been rounded due to accuracy of field measurements**

4.6.4 Quantitative MFA for Kayangel Island

A quantitative MFA for Kayangel Island focused on spatially tracing the non-organic fraction of solid waste generation and material fate is provided in **Error! Reference source not found.**.

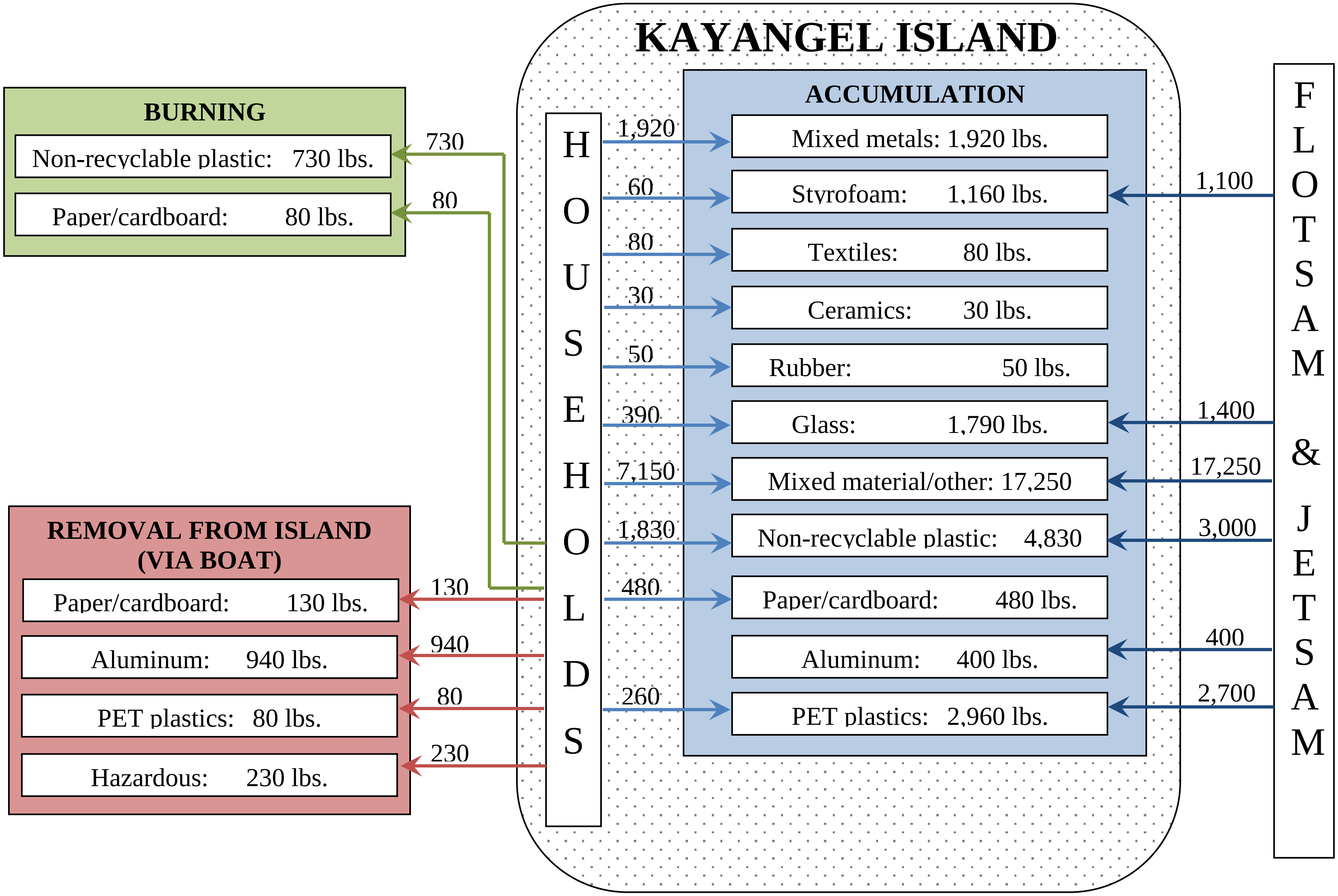


Figure 19: Graphical representation of Kayangel MFA on an Annual Basis.

As described in Section 3.4, solid waste materials on Kayangel are either: 1) removed from the island by boat (4%), 2) burned (3%), or 3) accumulate in household pits (93%). This information is depicted in more detail in APPENDIX C: Kayangel Solid Waste Generation in Terms of Material Fate. In Figure 19, the burning and removal from the island material fate categories are depicted on the left side of the diagram, with arrows indicating the net removal from both households and Kayangel Island of specified quantities of solid waste. The accumulation category is a combination of solid waste inputs from the household level (from the KHSWGS survey), as well as the solid waste deposited by the ocean (as represented by the coastal clean-up inventory), both of which remain in piles and pits around the island. A discussion of the degradation rates of the solid waste follows in Section 4.7.

In terms of generation, assuming a year-round average of 98 local residents (based on averaging population counts conducted by the author during school-year and non-school-year studies) the Kayangel community collectively produces an average 0.93 lbs. of solid waste per capita per day. This can be subdivided into daily per capita solid waste generation rates for the three material fate categories: 0.87 lbs. of accumulation, 0.04 lbs. removed from island, and 0.02 lbs. burned. Accordingly, the majority of the solid waste generated by the island residents is being accumulated, and thus requires improved or alternative management. Refer to Chapter 5 for specific recommendations.

4.7 Degradation Analysis

The waste categories of more significance within the accumulation term were those with the highest abundance within the Kayangel solid waste stream as well as those with the slowest break-down rates. As shown in Table 8, mixed material items (e.g., cigarette butts and plastic-coated paper milk cartons) break down on the order of years; plastic bags and tin cans break down on the order of 10s of years; and glass and plastic bottles can take approximately 1 million years to break down (Mihelcic and Zimmerman, 2009).

The other materials from the accumulation fate category were less abundant in the KHSWGS. Cotton textiles and paper biodegrade within several months (Mihelcic and Zimmerman, 2009), so they are also less important in this analysis. Styrofoam is the most persistent of the solid waste on Kayangel. Although it only contributes 60 lbs. annually at the household level, an additional 1,100 lbs. are accumulated as flotsam and jetsam (**Error! Reference source not found.** and Table 8). The MFA characterizes Styrofoam on Kayangel Island by its mass, but it is a problematic material because of its persistence and large volume.

Table 8: Degradation scales for common materials.

Material	Biodegradation Time	Source
Cotton rags	~1-5 months	Mihelcic & Zimmerman, 2009
Paper	~2-5 months	Mihelcic & Zimmerman, 2009
Orange peels	~6 months	Mihelcic & Zimmerman, 2009
Cigarette butts	~1 to 12 years	Mihelcic & Zimmerman, 2009
Plastic coated paper milk cartons	~5 years	Mihelcic & Zimmerman, 2009
Plastic bags	~10 to 20 years	Mihelcic & Zimmerman, 2009
Tin cans	~50 to 100 years	Mihelcic & Zimmerman, 2009
Disposable diaper	~75 years	Nemy, 2001
Aluminum cans	~80 to 100 years	Mihelcic & Zimmerman, 2009
Glass bottles	~1 million years	Mihelcic & Zimmerman, 2009
Plastic bottles	> 1 million years	Mihelcic & Zimmerman, 2009
Styrofoam	>> 1 million years	Nemy, 2001

Equally problematic is the 56% of the overall annual solid waste accumulation rate resulting from flotsam and jetsam deposition. Aside from periodic clean-up efforts by the school, community groups, and individual residents with beach-front property, there is no system of collection and management for solid waste accumulation from the ocean. This waste is predominantly inert; however it provides breeding sites for mosquitoes, particularly *Aedes Aegypti*, which transmit the Dengue fever virus (DEH, 2004). These mosquitoes are endemic in the ROP, and favor man-made containers for breeding sites.

5 CONCLUSIONS AND RECOMMENDATIONS

MFA has been proven as an effective tool for characterizing all of the inputs, outputs, and internal material cycling of a defined system. In the case of the SIDS of Kayangel, the holistic outlook of MFA was applied for the purpose of analyzing solid waste disposal practices. This was achieved by identifying and quantifying all of the material flows and internal cycling on the island at the household and community levels, and framing this in the context of material fate. Using the MFA model, annual generation rates (lbs/year) were defined for all twelve waste segregation categories according to whether they are burned, contribute to accumulation, or are removed from the island. The results of this analysis can be applied to link current solid waste generation rates and compositions on the island with household and community practices, in order to streamline future solid waste management efforts on Kayangel.

Waste Hierarchy

Based on the MFA model of Kayangel's solid waste scenario, it is possible to revisit the mandates from Agenda 21 and control measures from the Barbados Programme of Action, and evaluate both the specific case of Kayangel as well as the tool of MFA in terms of the hierarchy of environmentally sound solid waste management.

1) The first directive, waste minimization, can be addressed because the MFA approach identified all solid waste sources for Kayangel Island. Waste reduction strategies can be enacted in a more direct manner, by targeting specific waste categories from the MFA that contribute the most annual mass of solid waste. On Kayangel this is problematic, since the greatest single contributor to the annual solid waste generation of the island was solid waste deposited by the ocean. Minimizing this waste is a global issue, compounded by the fact that the source of this pollution is dispersed on a regional scale. Kayangel residents can only minimize solid waste generated at the household level, approximately 13,000 of

the more than 33,000 lbs. of solid waste that accumulate on the island each year. Of the household waste, mixed materials are present in the most mass (approximately 7,000 lbs). It would thus be logical for waste minimization efforts to begin with reducing the introduction of goods which produce mixed material waste, particularly diapers (see discussion from Section 4.4.2 for more details). Waste minimization efforts could focus on the community at large by correlating specific goods with local solid waste generation rates at a public forum. Waste minimization efforts could also be evaluated based on the criteria of mass and volume of annual generation, as well as material persistence (as discussed in Section 4.7). Priority waste categories for waste minimization efforts by these criteria would include plastics, glass, and Styrofoam (although the latter is mainly accumulated on the island via flotsam and jetsam deposition and is therefore outside of the scope of local waste minimization efforts).

2) Reuse and recycling are additional environmentally sound management strategies that can be optimized using the tool of MFA. The MFA model identifies and quantifies internal material flows and cycles that could potentially be redirected in order to maximize local material reuse and recycling. For example, according to the MFA model, mixed metals accounted for approximately 14% of annual household solid waste on Kayangel. The annual accumulation of solid waste could be reduced by almost 2,000 lbs. by diverting these mixed metals and other recyclable materials from the local waste stream and sending them to the recently renovated national recycling facilities in Koror. If the solid waste deposited by the ocean were collected and recycled, approximately 3,000 lbs. of PET plastics would be diverted each year from the accumulated solid waste on Kayangel. The ROP is in the process of expanding recycling facilities at the National Landfill to include mixed metals and PET plastics. Currently, there are a few private companies which buy aluminum, copper, and some hard and chemical plastics. As demand for these raw materials increases, it may become more profitable to recover some of these solid waste items accounted for in Kayangel’s MFA.

3) Promoting environmental disposal and treatment of solid waste is another priority action defined by Agenda 21. Atoll islands like Kayangel have sandy soil, a

shallow freshwater-lens, and limited available land, making them particularly ill-suited environments for the disposal of bulky solid waste which is slow to degrade. Not only is the ROP building national recycling facilities, but it has also upgraded the National Landfill by installing a sanitary liner. The MFA model itemizes the annual generation of each of these waste items, providing justification for their diversion from the local accumulation term. As discussed in Section 3.2.7, the remote location of Kayangel and the community's lack of coordinated solid waste management efforts are obstacles to promoting local environmental disposal and treatment. Based on the results of the MFA model, it is recommended that mixed metals, PET plastics, and other recyclable materials be removed from the island as part of community-managed solid waste efforts. This will require greater planning and coordination efforts in order to facilitate segregation, collection/consolidation, and transportation off-island for materials that can be recycled, reused, or disposed of in a more environmentally sound manner, but it will reduce the annual accumulation of solid waste on the island.

4) The final element in the waste hierarchy recommended by Agenda 21 involves extending waste service coverage and can be viewed as a limitation of the waste hierarchy analysis in the context of SIDS. From the MFA model, holes in waste service coverage are easily identified and quantified, yet this information serves to magnify the difficulties implicit in improving waste service coverage on a small island like Kayangel. The biggest hole in local waste service coverage comes from the most significant input, annual accumulation of ocean provenance solid waste on the beach and backshore environment of the island. This source contributes approximately 19,000 lbs. of Kayangel's 33,000 lbs. of annual solid waste generation (more than 55%), yet its widespread distribution, continuous deposition, and the global nature of its supply make it prohibitive for the community to adequately manage it. In the context of increasing populations and constraints placed on raw materials over a global scale, it may someday become cost-effective to extend waste coverage on Kayangel to the flotsam and jetsam that accumulates on its coastline. In the meantime, the priority will be

improvement of waste services at the household level, according to the MFA model.

The methodology of the combined KHSWGS and MFA serve to link solid waste generation and composition data with spatial information at the household level. This is particularly useful for a small community like Kayangel. By analyzing trends in data at the individual household level, solid waste management education and promotion efforts can target all four elements within the Agenda 21 hierarchy of environmentally sound solid waste management. SIDS like Kayangel can improve local waste management practices through the use of individual household solid waste improvement plans based on spatially-linked data.

Viable Local Solid Waste Options

As mentioned in the preceding section, collective community management of solid waste via household segregation, collection, consolidation, and transfer off-island would be the preferred recommended management plan. Spatial information from the analysis could be used to optimize the collection and transfer processes, though assistance is needed in organizing and funding these activities, with long-term commitment on the part of the Kayangel State government. In the meantime, solid waste continues to accumulate on Kayangel Island contributed by individual households and more significantly from the world at large.

The fact that more than 55% of the annual solid waste for Kayangel Island is generated by off-island sources puts the case of sustainable development as a global problem in point. Kayangel, like all of the SIDS, generates a miniscule fraction of the world's solid waste, yet each year almost 20,000 lbs. of this global solid waste accumulate along its coastline. The magnitude of this global solid waste contribution is made even more dramatic when contrasting the remote location and limited scale of Kayangel's 6,300 meter coastline with the scope of the endless waters of the Pacific Ocean that surround it. Sustainable development is clearly a global mandate, and the management of solid waste must be addressed universally before this waste can disappear from the smallest, most remote outcroppings of land encircled by the world's dynamic oceans.

The Kayangel MFA provides a characterization by type and annual mass of this solid waste accumulation. As mentioned in waste hierarchy assessment, this information could be used in the future to provide a long-term inventory of potential resources that could be recovered as raw materials, much like the comprehensive accounting of landfill materials on the part of the Institute of Scrap Recycling Industries (BESR, 2004). Additional applications of the MFA and potential related research are suggested below.

Potential topics for related research:

- Analysis of the solid waste scenario for Kayangel might be improved by including volume in addition to the mass quantification of solid waste in the KHSWGS survey and MFA.
- Improving the data collection and characterization of the dynamic processes of flotsam and jetsam deposition along the coastline.
- Remediation strategies for managing solid waste of ocean provenance.
- Analysis of solid waste disposal options for a small island (e.g., burning, transfer off-island for reprocessing/recycling, etc.), based on cost-benefit and environmental impacts.
- A comparison of product generation vs. solid waste generation rates for Pacific Islands or SIDS could be implemented to better evaluate imports and solid waste management on small islands.

6 REFERENCES

Atoll. (2008). In *Encyclopædia Britannica*. Retrieved Nov. 12, 2008, from Encyclopædia Britannica Online: http://www.britannica.com/EBchecked/topic/41543/atoll.

Barbosa de Araújo, M. & Ferreira da Costa, M. (2007). Visual diagnosis of solid waste contamination of a tourist beach: Permanbuco, Brazil. *Waste Management* 27 (2007) 833-839.

Belevi, H. (2002). *Material flow analysis as a strategic planning tool for regional waste water and solid waste management.* Duebendorf: Department of Water & Sanitation in Developing Countries (SANDEC), Swiss Federal Institute for Environmental Science and Technology (EAWAG). Retrieved November 6, 2008, from: http://www2.gtz.de/ecosan/download/IFAT2002-belevi.pdf.

Board on Earth Sciences and Resources. (2004). *Materials Count: The Case for Material Flows Analysis.* Washington, D.C.: The National Academies Press, 128 pp.

CIA Factbook. (2008a). *Country Profile: Fiji.* Retrieved November 11, 2008, from: https://www.cia.gov/library/publications/the-world-factbook/index.html.

CIA Factbook. (2008b). *Country Profile: Kiribati.* Retrieved November 11, 2008, from: https://www.cia.gov/library/publications/the-world-factbook/index.html.

CIA Factbook. (2008c). *Country Profile: Palau.* Retrieved November 11, 2008, from: https://www.cia.gov/library/publications/the-world-factbook/index.html.

CIA Factbook. (2008d). *Country Profile: Papua New Guinea.* Retrieved November 11, 2008, from: https://www.cia.gov/library/publications/the-world-factbook/index.html.

CIA Factbook. (2008e). *Country Profile: Samoa*. Retrieved November 11, 2008, from: https://www.cia.gov/library/publications/the-world-factbook/index.html.

CIA Factbook. (2008f). *Country Profile: Solomon Islands.* Retrieved November 11, 2008, from: https://www.cia.gov/library/publications/the-world-factbook/index.html.

CIA Factbook. (2008g). *Country Profile: Tonga.* Retrieved November 11, 2008, from: https://www.cia.gov/library/publications/the-world-factbook/index.html.

CIA Factbook. (2008h). *Country Profile: Tuvalu.* Retrieved November 11, 2008, from: https://www.cia.gov/library/publications/the-world-factbook/index.html.

CIA Factbook. (2008i). *Country Profile: Vanuatu.* Retrieved November 11, 2008, from: https://www.cia.gov/library/publications/the-world-factbook/index.html.

DEH. (2004). *Palau National Environmental Health Action Plan 2004-2007*. Republic of Palau: Division of Environmental Health, Bureau of Public Health, Ministry of Health.

Eurostat. (2001). *Economy-Wide Material Flow Accounts and Derived Indicators: A Methodological Guide.* Luxembourg: Office for Official Publications of the European Communities, 92pp.

Hawkins, J. and Castillo, P. (1998). Early History of the Izu-Bonin-Mariana arc system: Evidence from Belau and the Palau Trench. *The Island Arc* (1998) 7, 559±578, La Jolla, CA: Scripps Institution of Oceanography.

International Monetary Fund. (2006). *Republic of Palau: 2005 Article IV Consultation—Staff Report; Public Information Notice on the Executive Board Discussion; and Statement by the Executive Director for the Republic Palau*, IMF Country Report, No. 06/108. Washington, D.C.

JFK students. (2008). *Class project: Measurement of coastline of Kayangel Island.* Kayangel State, Republic of Palau: John F. Kennedy Elementary School.

Kungl Vetenskapsakademien. (1985). *The Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel 1985*, Press Release 15 October 1985. Retrieved on October 27, 2008, from: http://nobelprize.org/nobel_prizes/economics/laureates/1985/press.html.

Mihelcic, J. & Zimmerman, J. (2009). *Environmental Engineering: Fundamentals, Sustainability, Design*. John Wiley & Sons, 700 pages, publication in first half of 2009.

Ministry of Resources and Development. (2004). *Republic of Palau - National Assessment for the Barbados Programme of Action + 10 Review, January 2005, Mauritius*. Unpublished report, June 2004. Koror, Republic of Palau: Government of the Republic of Palau.

Nemy, E. (2001, October 1). Metropolitan Diary. *New York Times, October 1, 2001.* Retrieved November 16, 2008, from: http://query.nytimes.com/gst/fullpage.html?res=9A00E5DB153DF932A35753C1A9679C8B63&sec=&spon.

Office of Planning and Statistics. (2006a). *Republic of Palau 2005 Census Volume II: Census Monograph Population and Housing Profile.* Koror, Republic of Palau: Office of Planning and Statistics.

Office of Planning and Statistics. (2006b). *2006 Republic of Palau Household Income and Expenditure Survey.* Koror, Republic of Palau: Office of Planning and Statistics.

PacIOOS. (2008). *Republic of Palau.* Retrieved on September 5, 2008, from: http://www.soest.hawaii.edu/pacioos/region/palau.htm.

PALARIS. (2004). *Map of Kayangel State, Republic of Palau.* Koror, Republic of Palau: Ministry of Resources and Development. Retrieved from PALARIS Office, July 9, 2007.

PALARIS. (2008a). Personal communication: Irene Guzman. Map of Kayangel State, ROP. Koror, Republic of Palau: Ministry of Resources and Development. E-mail communication from October 9, 2008.

PALARIS. (2008b). Personal communication: Irene Guzman. Geographical information about Kayangel State, ROP. Koror, Republic of Palau: Ministry of Resources and Development. E-mail communication from November 11, 2008.

PALARIS. (2008c). *Map of Palau.* Koror, Republic of Palau: Ministry of Resources and Development. Retrieved from PALARIS Office, July 9, 2007.

Sinclair Knight Merz. (2000a). *Solid Waste Characterization Study: Fijii.* Apia: Sinclair Knight Merz. Retrieved August 22, 2008, from http://www.sprep.org/att/publication/000347_Solid_Waste_Characterization_Fiji.pdf.

Sinclair Knight Merz. (2000b). *Solid Waste Characterization: Republic of Kiribati.* Apia: Sinclair Knight Merz. Retrieved August 22, 2008, from http://www.sprep.org/att/IRC/eCOPIES/Countries/Kiribati/18.pdf.

Sinclair Knight Merz. (2000c). *Solid Waste Characterization Study: Papua New Guinea.* Apia: Sinclair Knight Merz. Retrieved August 22, 2008, from http://www.sprep.org/att/IRC/eCOPIES/Countries/Papua_New_Guinea/13.pdf.

Sinclair Knight Merz. (2000d). *Solid Waste Characterization Study: Samoa.* Apia: Sinclair Knight Merz. Retrieved August 22, 2008, from http://www.sprep.org/att/IRC/eCOPIES/Countries/Samoa/33.pdf.

Sinclair Knight Merz. (2000e). *Solid Waste Characterization Study: Solomon Islands.* Apia: Sinclair Knight Merz. Retrieved August 22, 2008, from http://www.sprep.org/att/IRC/eCOPIES/Countries/Solomon_Islands/17.pdf.

Sinclair Knight Merz. (2000f). *Solid Waste Characterization Study: Tonga.* Apia: Sinclair Knight Merz. Retrieved August 22, 2008, http://www.sprep.org/att/IRC/eCOPIES/Countries/Tonga/16.pdf.

Sinclair Knight Merz. (2000g). *Solid Waste Characterization Study: Tuvalu.* Apia: Sinclair Knight Merz. Retrieved August 22, 2008, http://www.sprep.org/att/IRC/eCOPIES/Countries/Tuvalu/20.pdf.

Sinclair Knight Merz. (2000h). *Solid Waste Characterization Study: Vanuatu.* Apia: Sinclair Knight Merz. Retrieved August 22, 2008, http://www.sprep.org/att/IRC/eCOPIES/Countries/Vanuatu/15.pdf.

SPREP. (1999). *Guidelines for municipal solid waste management planning in small island developing states in the Pacific region*. Apia, Samoa: South Pacific Regional Environmental Programme.

SPREP. (2007). *Member Countries.* South Pacific Regional Environmental Programme. Retrieved on November 11, 2008, from: http://www.sprep.org/members/map.htm.

Troschinetz, A. (2005). *Twelve Factors Influencing Sustainable Recycling of Municipal Solid Waste in Developing Countries*, Masters of Science in Environmental Engineering Thesis, Michigan Technological University. Houghton, Michigan.

Troschinetz, A. & Mihelcic, J. (2008). Sustainable Recycling of Municipal Solid Waste in Developing Countries. *Waste Management*, in press, 2008.

United Nations. (1987). *Report of the World Commission on Environment and Development: "Our Common Future".* Published as Annex to General Assembly document A/42/427, Development and International Economic Co-operation: Environment. New York: United Nations.

United Nations. (1995). *Resolution Adopted by the General Assembly 49/122. Global Conference on the Sustainable Development of Small Island Developing States.* 27 February 1995. New York: United Nations Department of Economic and Social Affairs. Retrieved on October 22, 2008, from: http://daccessdds.un.org/doc/UNDOC/GEN/N95/769/39/PDF/N9576939.pdf?OpenElement.

United Nations. (2008). *End Poverty 2015: Millennium Development Goals*. UN Web Services Section, Department of Public Information. Retrieved on October 20, 2008, from: http://www.un.org/millenniumgoals/.

UNDESA. (2000). *United Nations General Assembly Report of the Global Conference on the Sustainable Development of Small Island Developing States, Bridgetown, Barbados, 25 April-6 May 1994, A/CONF.167/9*. New York: UN Department of Economic and Social Affairs. Retrieved October 22, 2008, from: http://www.un.org/documents/ga/conf167/aconf167-9.htm .

UNDESA. (2005). *Agenda 21-United Nations Conference on Environment and Development,* 1992 UN Conference on Environment and Development. Rio de Janerio, Brazil: Division for Sustainable Development, United Nations Department of Economic and Social Affairs. Retrieved October 3, 2008, from: http://www.un.org/esa/sustdev/documents/agenda21/index.htm.

UNDESA. (2007). *Small Island Developing States.* New York: UN Department of Economic and Social Affairs, Division for Sustainable Development. Retrieved on October 21, 2008 from: http://www.un.org/esa/sustdev/sids/sidslist.htm.

U.S. Department of State, Bureau of East Asian and Pacific Affairs. (2008). *Background Notes: Palau*. Retrieved on August 24, 2008, from: http://www.state.gov/r/pa/ei/bgn/1840.htm.

United States Environmental Protection Agency. (2007). *Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2006.* Washington, D.C.: Solid Waste and Emergency Response (5306P).

World Bank. (2005). *Regional Engagement Framework FY2006-2009 for Pacific Islands,* Report No: 32261-EAP.

APPENDIX A: Palauan Language KHSWGS Survey

Omesuub el Komi er a Beluu er a Ngcheangel

Alii! Ng soak el mesuub a komi er a beluu er a Ngcheangel el mo uchul a mo ungil el teletetel a blil a komi er kid. Chelechang, eng nga er ngii a beches el teletetel a blil a komi er a beluu er a Belau el nga er a Oreor. Te milruul a beches el blil a komi el nga er ngii a recycling er a beached, scrap metals (ua blil a tuna, blil a SPAM, me a blil a kerbou), me a PET bottles (a ike el blastik el blil a ralm me a soda me a lemon tea).

A utem er a beluad a mekngit el doruul a blil a komi er ngii e ng di sebeched el mo send a bebil er a recyclable me a hazardous el komi er kid el mo er a Oreor. Kot, ng kirred el mesuub el kmo, ngerang a komi er a Ngcheangel. Ongerung, ng ua ngera a ildisel a komi er kid, e merekong e kede mo meruul a beches el teletelel a blil a komi er kid.

Ng kirek el mo medengei a ildisel a klalo, el mo komi a blil, el miruul er a bek el blai er a beluu er a Ngcheangel. Dirrek, ng kirek el mo medengei a ildisel a kakerous el bedengel a komi er kid: recyclables (beached, blil a tuna me a blil a kerbou, blastik el blil a ralm, uai sei) hazardous waste (batteries ma e fluorescent el dengki), me nonbiodegradable waste (ike el komi el ousbech a dart me a lechub eng mo betok er a dart el rak el mo diak) (ildisel er a bead me a blastik el blil a ralm me a Ngcheangel el mo er a kakerous el beluu. Ak mo meruul a ildisel a komi er a bek el blai er a beluu, bek el sils er a chelsel a eru el sandei, se el temel a skuul. Ak dirrek el mo meruul er ngii se el ulenguel er a skuul (eru el sandei). Maleuaisei, eng mo okiu a ikal el omesuub, ekede mo medengei a komi er kid me a ildisel er a ta el rak.

Kom kmal mesulang el olngeseu er a ngak. Ng kirred el mo kaingesau el rokui el mo meruul er a ungil el teletelel a mo blil a komi er a kid.

****

House: Number of Residents: Date:

Waste Category	Survey Total (lbs.)	% by weight
Mixed metals (except aluminum)		
Aluminum		
PET bottles		
Hazardous		
Non-recyclable plastic		
Styrofoam		
Textiles		
Ceramic		
Glass		
Paper/cardboard		
Rubber		
Other (mixed materials)		
TOTAL		

APPENDIX B: Results of KHSWGS

School-year Household Solid Waste Data

Household	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Waste Category																	
Mixed metals (not aluminum)	1.8	2.8	6.8		1.9	2.3	0.7	1.2	1.9		0.2	0.8	0.4	2.3	1.0	2.6	
Aluminum	1.1	0.4	2.3		0.8	5.6	0.3	0.3	1.7		0.0	2.8	0.2	0.0	0.0	0.0	
PET bottles	0.0	0.6	3.1		0.3	0.7	0.2	0.0	0.1		0.2	0.8	0.0	0.2	0.1	0.1	
Hazardous	2.8	0.0	0.0		0.0	5.5	0.0	0.0	0.0		0.0	3.0	0.0	0.0	0.0	0.0	
Plastic (non recyclable)	2.1	1.3	4.5		2.9	4.8	1.1	0.3	1.0		1.8	2.3	0.8	3.3	0.4	0.6	
Styrofoam	0.9	0.1	0.0		0.0	0.3	0.0	0.0	0.0		0.4	0.0	0.0	0.0	0.0	0.0	
Textiles	0.0	0.1	0.0		0.4	0.8	0.0	0.0	0.0		0.8	0.0	0.0	0.0	0.0	0.0	
Ceramic	0.0	0.5	0.0		0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0	0.0	
Glass	0.0	0.8	0.8		0.0	0.1	0.0	0.0	0.0		0.3	1.9	0.0	0.0	0.0	0.0	
Paper/cardboard	0.0	1.5	0.0		1.1	0.0	0.1	1.6	0.0		0.3	0.1	0.3	0.8	0.0	0.1	
Rubber	0.3	0.0	0.0		0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0	0.0	
Other (mixed material waste)	0.0	0.3	0.0		0.2	11.0	0.2	0.2	0.0		0.1	0.3	21.6	131.0	0.1	0.0	
TOTAL	8.9	8.3	17.4	0.0	7.5	30.9	2.5	3.7	4.8	0.0	4.1	11.8	23.3	137.5	1.6	3.5	0.0

2+ salaried/self-employed   1 salaried/self-employed   Casual/unemployed   Retired   No data or off-island

Household	18	19	20	21	22	23	24	25	26	27	28	29	30	31	TOTAL	% by wt.
Waste Category																
Mixed metals (not aluminum)	3.0	0.2	2.7	4.3	1.2	1.5	6.9	0.1	4.1			0.0	1.8	4.1	56.3	14.8%
Aluminum	1.0	0.0	0.0	0.8	0.8	1.7	7.2	0.6	0.0			0.0	0.7	0.5	28.6	7.5%
PET bottles	0.2	0.5	0.2	0.3	0.2	0.0	0.8	0.0	0.1			0.8	0.3	0.1	9.5	2.5%
Hazardous	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			0.0	0.0	0.0	11.3	2.9%
Plastic (non recyclable)	3.5	0.8	1.1	2.6	2.0	2.6	2.5	0.0	5.6			0.8	5.3	6.4	60.0	15.7%
Styrofoam	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0			0.0	0.0	0.1	2.4	0.6%
Textiles	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			0.0	0.1	0.0	2.6	0.7%
Ceramic	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			0.0	0.0	0.0	1.1	0.3%
Glass	1.8	0.0	0.0	9.3	1.3	0.0	1.2	0.0	0.6			0.0	0.0	0.0	18.0	4.7%
Paper/cardboard	0.4	0.4	0.0	0.0	0.0	0.1	0.0	0.0	0.0			0.0	0.0	15.9	22.8	6.0%
Rubber	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			0.0	0.0	0.0	0.3	0.1%
Other (mixed material waste)	0.3	0.0	0.0	0.9	0.1	0.6	0.3	0.0	1.3			0.0	0.0	0.4	168.8	44.2%
TOTAL	11.1	1.9	4.0	18.8	5.6	6.5	18.8	0.7	11.6	0.0	0.0	1.5	8.1	27.6	381.6	100.0%

***School-year data based on household surveying representing 88 of 92 residents from 25 of 30 households plus JFK Elementary School (#31)**

Nonschool-year Household Solid Waste Data

Household	6	14	18	21	22	25	27	29	TOTAL	% by wt.
Waste Category										
Mixed metals (not aluminum)	6.9	4.7	1.3	1.4	9.8	0.5	14.3	0.0	38.8	13.7%
Aluminum	7.4	0.3	0.3	1.4	1.6	0.0	6.3	0.5	17.8	6.3%
PET bottles	0.6	1.0	0.1	0.0	0.9	0.5	0.0	0.0	3.1	1.1%
Hazardous	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0%
Plastic (non recyclable)	9.4	1.9	2.4	4.3	3.0	2.4	2.3	4.7	30.4	10.8%
Styrofoam	0.1	0.1	0.0	0.1	0.1	0.0	0.0	0.0	0.3	0.1%
Textiles	0.7	0.6	0.0	0.0	0.2	0.0	0.0	0.0	1.4	0.5%
Ceramic	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.6	0.2%
Glass	0.0	0.0	0.0	1.1	0.0	0.0	0.0	0.0	1.1	0.4%
Paper/cardboard	0.0	0.6	0.2	0.0	0.0	0.0	0.0	0.0	0.8	0.3%
Rubber	0.6	1.1	0.2	0.0	0.2	0.0	0.0	0.0	2.0	0.7%
Other (mixed material waste)	5.1	171.1	0.3	0.1	0.4	0.0	9.0	0.0	186.1	65.9%
TOTAL	30.8	181.3	5.4	8.4	16.1	3.4	31.8	5.2	282.4	100.0%

***Nonschool-year data based on household surveying representing 50 of 153 (projection) residents from 30 households**

Comprehensive Kayangel Household Solid Waste Data

Waste Category	SY sample	NSY sample	TOTAL	% by wt.
Mixed metals (not aluminum)	59	119	1922	14.3%
Aluminum	30	55	938	7.0%
PET plastic	10	10	257	1.9%
Hazardous	12	0	229	1.7%
Non-recyclable plastic	63	93	1830	13.6%
Styrofoam	3	1	55	0.4%
Textiles	3	4	81	0.6%
Ceramic	1	2	33	0.2%
Glass	19	3	389	2.9%
Paper/cardboard	24	2	481	3.6%
Rubber	0	6	45	0.3%
Other/mixed material	176	571	7150	53.3%
TOTAL	399	866	13410	100.0%

Annual Household Solid Waste Generation Equation

Annual generation = [(SY total x 0.75) + (NSY total x 0.25)] x 26

SY = school-year survey data (represents 75% of the year)

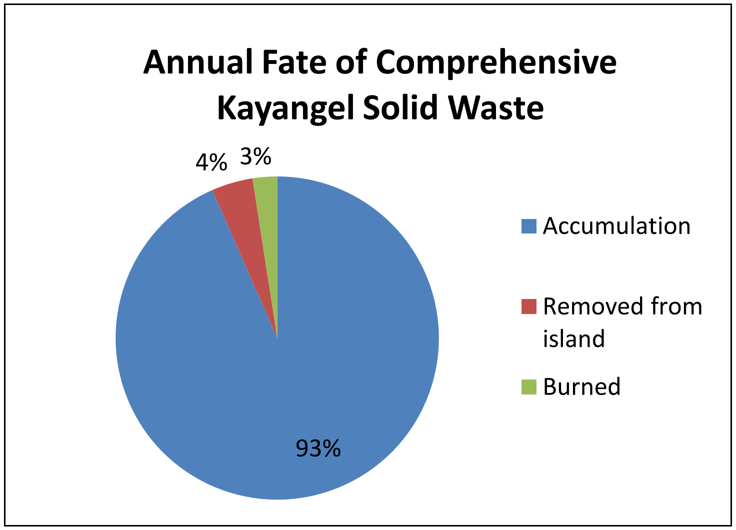
NSY = nonschool-year data (represents 25% of the year)

*data based on 14-day survey periods

APPENDIX C: Kayangel Solid Waste Generation in Terms of Material Fate

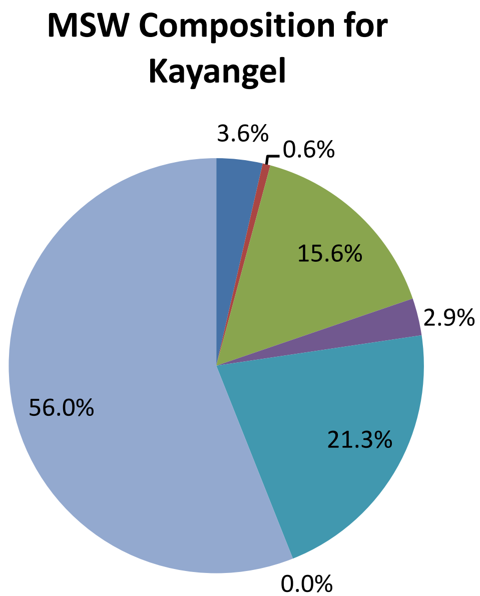
Waste Category	lbs/year	wt. %	lbs. /capita/day*
Accumulation	30,950	93%	0.87
Removed from island	1,380	4%	0.04
Burned	810	2%	0.02
TOTAL	33,140	100%	0.93

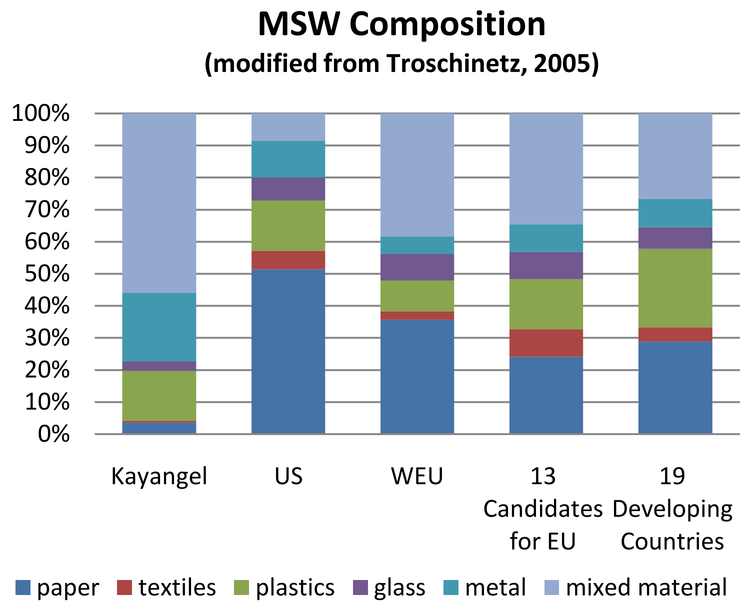
*assuming 98 Kayangel residents (based on averaging school-year and nonschool-year population counts conducted by author)

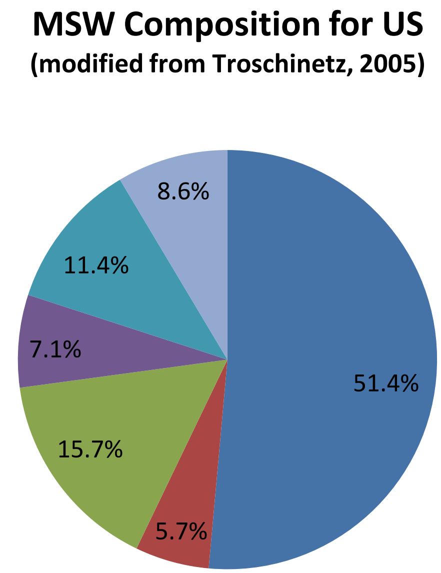


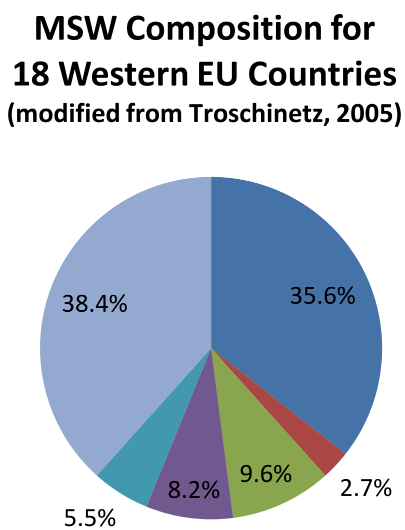
Waste Category	lbs/year
Mixed metals (not aluminum)	1920
Aluminum	400
Rubber	50
Other/mixed material	17250
Styrofoam	1160
Textiles	80
Ceramic	30
Glass	1790
Paper/cardboard	480
PET plastic	2960
Non-recyclable plastic	4830
Aluminum	940
PET plastic	80
Paper/cardboard	130
Hazardous	230
Non-recyclable plastic	730
Paper/cardboard	80
TOTAL SOLID WASTE GENERATED	33140

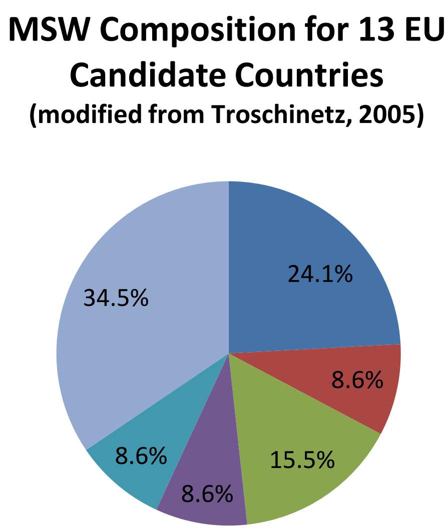
APPENDIX D: Global MSW Comparisons Excluding Organics

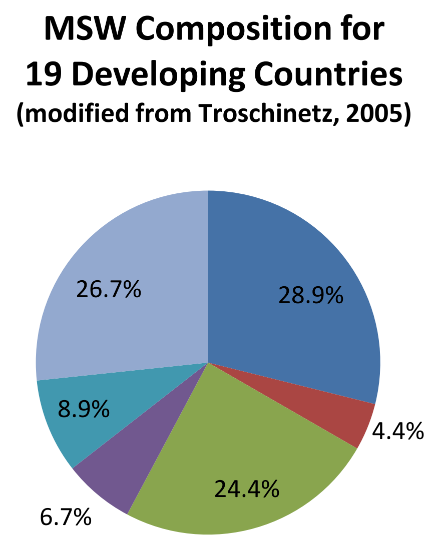












APPENDIX E: Pacific Region Solid Waste Composition Comparison

Waste Category	Kayangel	Kiribati	Samoa	Solomon Islands	Tonga	Tuvalu	Vanuatu	PNG	Fiji	SPREP avg.
Paper	3.6%	14.4%	13.3%	16.7%	59.3%	21.9%	39.3%	23.6%	45.8%	29.3%
Textiles	0.6%	6.2%	17.5%	5.1%	7.0%	4.6%	5.5%	3.0%	9.3%	7.3%
Plastics	15.6%	14.8%	30.1%	47.6%	9.8%	19.6%	26.6%	25.4%	25.2%	24.9%
Glass	2.9%	27.9%	10.0%	12.7%	6.3%	20.0%	11.4%	17.8%	8.4%	14.3%
Metal	21.3%	19.3%	17.5%	17.3%	15.2%	20.6%	12.4%	24.4%	10.0%	17.1%
Organics	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Other	56.0%	17.5%	11.5%	0.6%	2.5%	13.3%	4.8%	5.8%	1.2%	7.1%
TOTAL	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

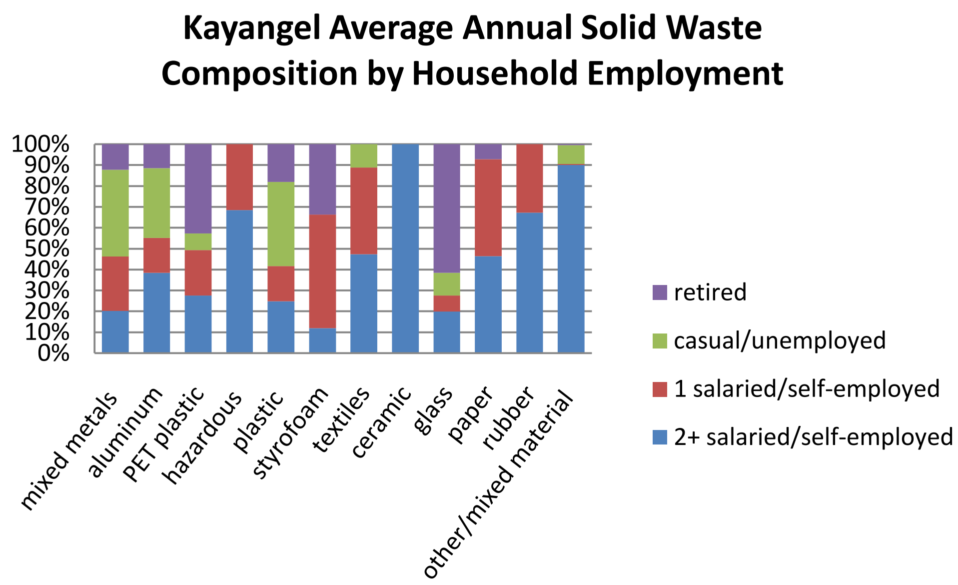
Note: SPREP solid waste data from Sinclair Knight Merz, 2000a-h.
Weight (kg) data from Samoa used for weight % calculation due to error within Sinclair Knight Merz, 2000d

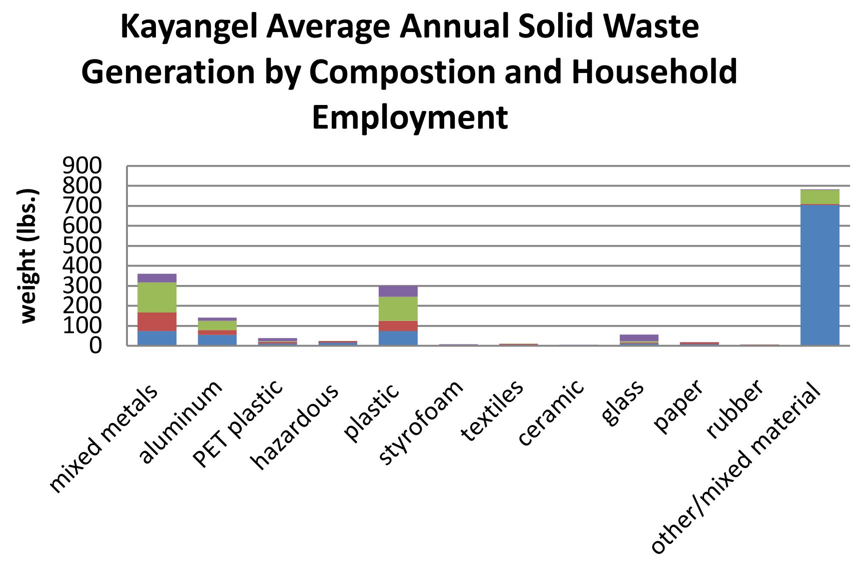
SPREP Solid Waste Composition Studies and Country Information

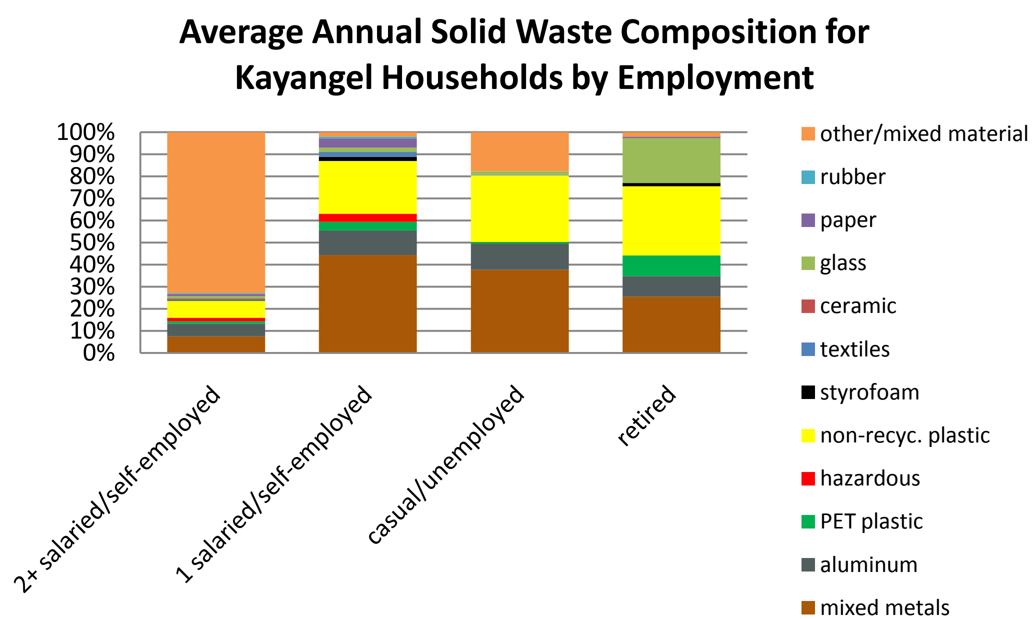
	2000 Population Estimates			Solid Waste Studies Information			
Country	**Population**	**Pop density (persons/km^2)**	**National per capita GDP**	**Location (all local population centers)**	**MSW type**	**Population**	**Year**
Fiji	824,700	45	$3900 (2007)	Lautoka	landfill	59,000	2000
Kiribati	90,700	112	$3600 (2007)	South Tarawa	household	28,350	2000
Papua New Guinea	4,790,800	10	$2100 (2007)	Waigani, Port Moresby	household	300,000	2000
Samoa	169,200	58	$5400 (2007)	Apia	household	34650	2000
Solomon Islands	447,900	16	$1900 (2007)	Honiara	landfill	40,000	2000
Tonga	100,200	154	$5100 (2007)	Kolofo'ou District	landfill	16,953	2000
Tuvalu	9,900	381	$1600 (2002)	Funafuti	household	4,600	2000
Vanuatu	199,800	16	$3900 (2007)	Port Vila	landfill	38,000	2000
Palau	19,100	39	$7600 (2005)	Kayangel	household	98	2008

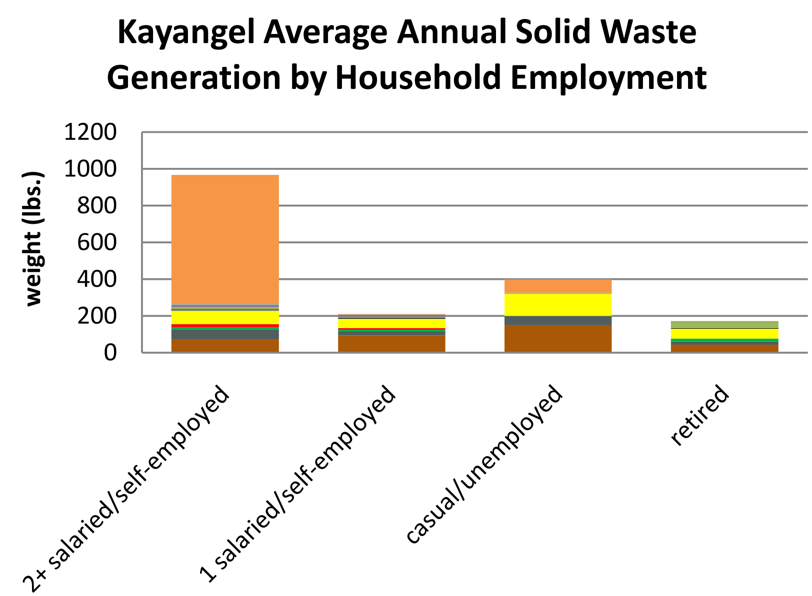
From: SPREP. (2007). *SPREP Members*. Retrieved November 11, 2008, from: http://www.sprep.org/members/map.htm .
From: CIA factbook. (2008). *Country Profiles: Fiji, Kiribati, Papua New Guinea, Samoa, Solomon Islands, Tonga, Tuvalu, Vanuatu, Palau.* Retrieved November 11, 2008, from: https://www.cia.gov/library/publications/the-world-factbook/index.html .
From: Sinclair Knight Merz. (2000). *SPREP Solid Waste Characterisation and Management Plans Project for Fiji, Tonga, Vanuatu, Papua New Guinea, Kiribati, Tuvalu, Solomon Islands and Western Samoa.* Apia: Sinclair Knight Merz. Retrieved August 22, 2008, from: http://www.sprep.org/att/publication.

APPENDIX F: Kayangel Average Annual Solid Waste Generation & Composition by Household Employment









APPENDIX G: Kayangel Average Annual Solid Waste Generation by Household Employment (weight in lbs.)

	2+ salaried/self-employed				1 salaried/self-employed				Casual/unemployed				Retired			
Waste Category	SY avg.	NSY avg.	Yr. avg.	wt %	SY avg.	NSY avg.	Yr. avg.	wt %	SY avg.	NSY avg.	Yr. avg.	wt %	SY avg.	NSY avg.	Yr. avg.	wt %
Mixed metals (not aluminum)	2.3	4.3	73.2	7.6%	1.6	9.8	93.7	44.4%	2.9	14.3	150.1	37.7%	2.0	0.6	44.0	25.4%
Aluminum	1.9	2.7	54.5	5.6%	0.7	1.6	23.6	11.2%	0.3	6.3	47.3	11.9%	0.6	0.6	16.2	9.4%
PET bottles	0.3	0.6	10.6	1.1%	0.1	0.9	8.3	3.9%	0.2	0.0	3.0	0.8%	0.8	0.2	16.3	9.4%
Hazardous	0.9	0.0	16.6	1.7%	0.4	0.0	7.7	3.6%	0.0	0.0	0.0	0.0%	0.0	0.0	0.0	0.0%
Plastic (non recyclable)	2.3	4.6	74.0	7.7%	1.6	3.0	50.5	23.9%	5.4	2.3	120.0	30.1%	1.5	3.8	54.2	31.3%
Styrofoam	0.0	0.0	0.9	0.1%	0.2	0.1	4.0	1.9%	0.0	0.0	0.0	0.0%	0.1	0.0	2.5	1.4%
Textiles	0.1	0.4	5.1	0.5%	0.2	0.2	4.5	2.1%	0.1	0.0	1.2	0.3%	0.0	0.0	0.0	0.0%
Ceramic	0.1	0.2	3.3	0.3%	0.0	0.0	0.0	0.0%	0.0	0.0	0.0	0.0%	0.0	0.0	0.0	0.0%
Glass	0.6	0.0	11.3	1.2%	0.2	0.0	4.4	2.1%	0.3	0.0	6.1	1.5%	1.7	0.4	34.9	20.2%
Paper/cardboard	0.3	0.3	8.5	0.9%	0.4	0.0	8.5	4.0%	0.0	0.0	0.0	0.0%	0.1	0.0	1.3	0.8%
Rubber	0.0	0.6	3.9	0.4%	0.0	0.2	1.9	0.9%	0.0	0.0	0.0	0.0%	0.0	0.0	0.0	0.0%
Other (mixed material waste)	16.5	58.9	705.2	72.9%	0.1	0.4	4.3	2.0%	0.6	9.0	70.7	17.7%	0.2	0.0	3.5	2.0%
TOTAL	25.4	16.5	603.0	100.0 %	5.5	16.1	211.3	100.0 %	9.8	31.8	398.5	100.0 %	7.0	5.7	172.9	100.0 %