Analysing vessel traffic and ballasting trends in the port of Pago Pago, American Samoa from 2004 to 2021

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Alisha M. Gill[1], Natasha S. S. Ripley[2] and Casidhe T. A. Mahuka[3]

Abstract

Commercial shipping has been associated with many introductions of marine invasive species globally. Unintentional transport stowaways in ship ballast water and biofouling account for the most unintentional marine introductions globally. Understanding vessel traffic and ballasting behaviours can aid managers in identifying research and biosecurity gaps. We provide a quantitative baseline assessment of commercial vessel activities in American Samoa between 2004 and 2021. Vessel traffic and ballast water data were downloaded from the National Ballast Information Clearinghouse and examined in R. Since reporting began, vessel arrivals in the territory gradually increased each year, reaching a peak of 229 vessels in 2017. Over a third of all arrivals are container ships. Although commercial vessels arrive from ports all over the world, most come from and remain in the South Pacific. Containers and tankers were responsible for most of the ballast water discharges in the territory. The use of alternative ballast water management systems began in 2015 and increased dramatically in the following years. Though American Samoa's vessel traffic patterns are similar with the United States as a whole, we highlight key differences in this small, yet important, South Pacific port. This article highlight the importance of assessments at individual ports to better inform biosecurity decisions with an emphasis on regional biosecurity measures and communication among the Pacific Islands.

Keywords: American Samoa; Ballast water; Marine invasive species; Maritime shipping; National ballast information clearinghouse

[1]Research Scientist, National Marine Sanctuary of American Samoa, National Oceanic and Atmospheric Administration, USA, email: alisha.gill@noaa.gov
[2]American Samoa Coral Reef Advisory Group, Department of Marine and Wildlife Resources, USA
[3] American Samoa Coral Reef Advisory Group, Department of Marine and Wildlife Resources, USA

Introduction

The introduction of non-native species to new environments has become increasingly common in recent decades. Once a non-native species becomes established in a new habitat, it can be extremely difficult, if not impossible, to remove (Thresher and Kuris 2004, Molnar et al. 2008). Invasive species are considered one of the leading causes of biodiversity loss, can disrupt ecosystem processes, harm human health and quality of life, impact local economies, and interfere with culturally important species and practices (Didham et al. 2005, Maraffini et al. 2017). Introductions of marine invasive species happen through a variety of pathways and can be intentional (releases and escapes), unintentional (contamination or stowaways), or via corridors of dispersal (Harrower et al. 2019). Here, we focus on unintentional transport stowaways which include ship ballast water and biofouling which account for the most unintentional marine introductions globally (Franklin 2008, Lo et al. 2011, Maraffini et al. 2017, Carlton et al. 2019).

Ballast water has been associated with many introductions; harmful algal blooms in coastal areas globally (Sellner et al. 2003, Anderson 2009, Morton et al. 2011), zebra mussels in the U.S. Great Lakes (Roberts 1990), and Caulerpa seaweed in the Mediterranean (Meinesz et al. 2001). Additionally, a new coral disease, Stony Coral Tissue Loss Disease (SCTLD), was described in Florida in 2014 and has since spread throughout the Caribbean, resulting in drastic changes in reef structure and composition (Alvarez-Filip et al. 2019, Estrada-Saldivar et al. 2020). Its pattern of dispersal may be influenced by commercial vessel movements across the affected area (Rosenau et al. 2021). While ballast water is well documented as the main source for introductions, biofouling can also act as an important source (Drake et al. 2007, Lo et al. 2011, Hayes et al. 2019, Evans et al. 2022) and although some guidelines exist, it is largely unregulated (Iacarella et al. 2020) and limited data is available. These issues make the monitoring and management of vessel traffic and ballasting protocols critical for marine resource managers.

Ballast water management began to draw global attention in the 1980's and was eventually addressed by the International Maritime Organization (IMO). In 2004, the International Convention for the Control and Management of Ship's Ballast Water and Sediments (BWM Convention) was adopted (International Maritime Organization, 2004). The Ballast Water Management Convention came into force in 2017, and 175 member states signed on. The Ballast Water Management Convention requires all ships of member countries to implement a ballast water management plan that meets their standards and keeps detailed records of their ballast water. In 2004, the United States Coast Guard (USCG) established rules for discharging ballast water in US waters that are at least as stringent as the IMO regulations (33 CFR Part 151 and 46 CFR Part 162). They also require maintaining an approved ballast water management plan with written records of uptake, transfers, and discharges. These ballast water records must be submitted by all foreign and domestic vessels to the USCG 24 hours prior to arrival in US ports, with some exemptions. For example, vessels that engage in "short distance voyages" are exempt from both ballast water management requirements and ballast water reporting requirements. "Short distance voyages" include vessels that operate exclusively in one Coast Guard Captain of the Port sector. This is of particular concern for the U.S. Pacific jurisdictions as Sector Honolulu COTP covers all of the Hawaiian island chain, American Samoa, Wake Island, Midway Island, Johnston Atoll, Kingman Reef, Palmyra Atoll, Jarvis Island, Baker Island, and Howland Island.

The ballast water management records that are submitted to the USCG are uploaded to the National

Ballast Information Clearinghouse (NBIC). The NBIC was created in 1997 by the National Invasive Species Act of 1996 and is a joint program of the Smithsonian Environmental Research Centre (SERC) and the USCG. Reporting by overseas arrivals to the US began in 1999 and subsequently , in 2004, coastal arrivals were also required to report. The database includes reports from nearly all vessels equipped with ballast water tanks bound for places in the US including the Great Lakes and Hudson River. The reports include ballast water source location, discharge amount and location, and ballast water management activities including date, location of management, volume treated or exchanged, and the management method used.

Understanding commercial vessel traffic patterns and ballasting behaviours of vessels entering ports is important to help inform policies regarding water quality, invasive species, and human health. There have been several summaries of United States commercial vessel traffic and ballasting behaviours in the past (Ruiz et al. 2001, Miller et al. 2007, Miller et al. 2011, Minton et al. 2015, Gerhard and Gunsch 2018). Additionally, VIDA requires annual reports on ballast water delivery and management as well as invasions of aquatic nuisance species for the preceding 2-year period. The first report is currently in review (USCG in review 2022). However, these reports and studies summarize data by region and do not provide a clear picture of what is happening at individual ports. American Samoa is usually lumped into the Pacific region (including Alaska, the west coast of the United States, Guam, and Hawaii) or left out entirely. American Samoa is quite isolated from the other Pacific ports and is the only U.S. port in the southern hemisphere. The territory receives a very small proportion of the vessel traffic for this region making much of the information provided in these reports inapplicable to American Samoa. Additionally, its isolated position from the rest of the United States means that all discharges are considered overseas.

The Samoan Archipelago is located in the South Pacific, about 2,600 miles southwest of Hawai'i. The unincorporated U.S. Territory of American Samoa and its neighbouring independent country of Samoa are distinct political entities. As isolated nations surrounded by a vast ocean, Samoans are highly dependent on marine resources for food, livelihood, and social culture purposes (Levine and Allen 2009, Charlton et al. 2016). Local marine resources have been critically impacted by a variety of natural and anthropogenic disturbances in recent years including overfishing, pollution, climate change, and invasive species (Craig et al. 2005, National Coral Reef Monitoring Program and University of Maryland 2018).

Samoa includes 12 islands, four of which are populated. Even though the easternmost island of Samoa is only 45 miles away from American Samoa, important differences regarding vessel traffic (commercial and recreational), regulations, and invasive species exist. There are at least nine introduced marine species in Samoa that do not yet occur in American Samoa, these include six species of algae, one barnacle, one crab, and the snowflake coral that is a highly invasive species in Hawaii (Skelton et al. 2002, SPREP 2022). Apia is the sole commercial port in Samoa and in 2014, 256 vessels arrived there. Although Samoa requires that all ballast water discharges in Samoan waters must comply with the International Maritime Organization's requirements, they are not signatories to the International Ballast Water Convention (Government of Samoa, 2015).

American Samoa includes five volcanic islands: Tutuila, Aunu'u, Ofu, Olosega, Ta'u and two coral atolls, Swains & Muliava. Tutuila is the main and largest island of American Samoa and is home to Pago Pago Harbour, one of the largest natural harbours in the South Pacific. While American Samoa has relatively little commercial vessel traffic (around 200 ships a year; NBIC database) cruise ships, fishing boats, cargo ships, and others from around the world move in and out of the harbour regularly. In 2003, Coles et al. conducted extensive surveys for marine introduced species and found 28 non-native species, 20 of which were only found in the harbour and determined to likely have been introduced via shipping (Coles et al. 2003).

Understanding vessel traffic patterns and the ballasting behaviours of the various vessels entering American Samoa is critical to identifying gaps in research and local biosecurity. With local and federal regulation changes in regard to ballast water and biofouling anticipated in the near future, understanding local trends will also be important in identifying post-regulation behavioural changes as well as better informing risk assessments for vessel entry. As a first step towards identifying biosecurity risk, this study provides a quantitative baseline assessment of information for commercial vessel activities in American Samoa.

Methods

Data acquisition

The data used in this study were obtained from the National Ballast Information Clearinghouse (NBIC). These data are included in Smithsonian Open Access and permission was not required for its use. Data for all vessel discharge reports for American Samoa from 2004 to 2021 were downloaded and saved locally. The source locations and treatment locations of discharged ballast water are self-reported to the NBIC either as latitude and longitude or the name of the port. Additionally, all reports include the last port and next port to be visited by the vessel. The location data for these reports were cleaned and converted into latitude and longitude by manually entering the latitude and longitude of the reported port. Reports with missing location data were excluded from this analysis.

The data obtained from the NBIC is not a complete dataset of vessel arrivals into the Territory as DoD vessels, recreational vessels, and vessels operating solely within the COTP Honolulu sector are exempt from reporting. To supplement the NBIC dataset, vessel arrivals reported in the American Samoa Department of Commerce's annual "Statistical Yearbooks" (ASDOC 2009, 2019) were transcribed and saved locally. This dataset is treated as the actual number of vessel arrivals per year.

Definitions

Arrivals refer to ports of call made by individual vessels with unique identification numbers. A single vessel may report multiple arrivals each year thus arrivals exceed the number of individual vessels. Vessel type data in the NBIC were self-reported by vessels and are based on IMO classifications. The vessel types included are container, general cargo, passenger, reefer (refrigerated), tanker, fishing, RoRo (roll-on roll-off vehicle carriers), and "other" vessel types. The "other" vessel type category includes fishing vessels over 79 feet, special purpose ships, and unknown vessel types. The contributions of "other" vessel types were grouped together. Vessel type data from ADOC differed from the NBIC data and included barge, cruise, fishing, freight, government local, military, other, reefer, tanker, and yachts.

Ballast water management types included in this study are alternate management systems (referred to as treated ballast water), empty-refill (referred to as exchanged ballast water), and flow-through (also referred to as exchanged ballast water). Alternate management systems (AMS) include any USCG-approved BWMS that uses mechanical, physical, chemical, or any combination of the three as means of filtering and disinfecting the water. The empty-refill method is a type of exchange in which ballast tanks are completely emptied and then refilled with open ocean water. The flow-through method is also a type of exchange; however rather than emptying ballast tanks first, water is continually pumped into tanks, causing the old water to overflow.

Statistical analysis

Classical statistical tests for this data are not appropriate as this analysis describes general vessel traffic and ballasting behaviours in the port of Pago Pago, American Samoa. Data collected from the ASDOC reports and downloaded from the NBIC were examined using R Statistical Software (v4.1.2; R Core Team 2021), the maps package (v3.4.0; Becker, 2021), and the ggplot2 package (Wickham, 2016). The assessments included: the number of arrivals, ballast water discharges by vessel type and by treatment type; ballast water source and management locations, and the last and next port of call of vessel arrivals.

Results

Vessel traffic

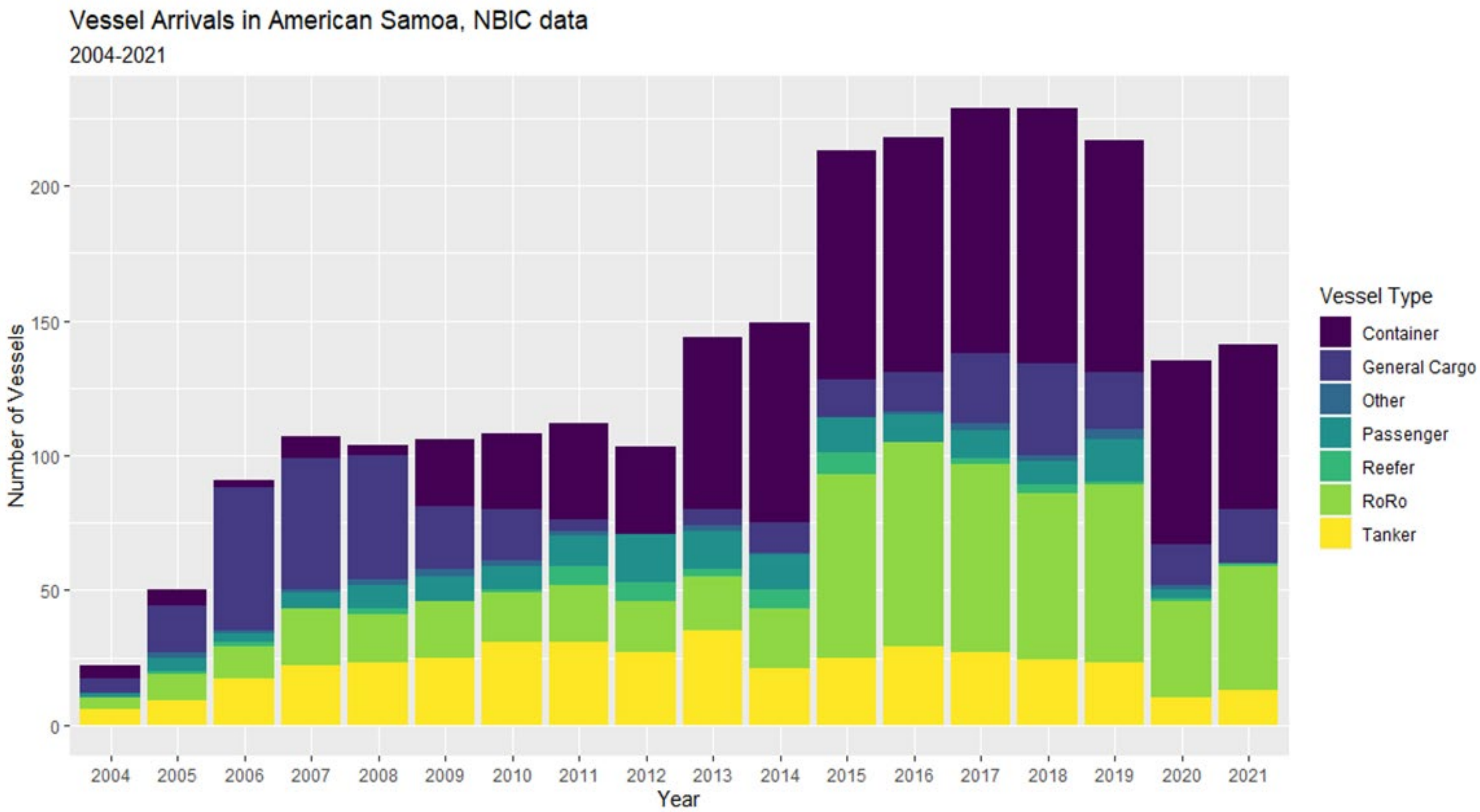

Figure 1. The total number of NBIC reported commercial vessel arrivals in American Samoa per year from 2004 to 2021. Vessel counts are divided into vessel types (container, general cargo, other, passenger, reefer, RoRo, and tanker).

A total of 2,478 vessel arrival reports for American Samoa from 2004-2021 were retrieved from the NBIC. Ballast water reporting began in 2004 (Figure 1 and Table 1) and there were very few arrivals recorded in the database in this year. Reported arrivals increased as time went on and by 2007 vessel traffic for American Samoa remained steady at around 100 vessels a year until 2013 when it increased to 150 vessels, a 40% increase from 2012. In 2015, over 200 vessel arrivals were reported, a 43% increase from 2014. This trend remained strong until 2020 when reported vessel arrivals dropped to 135, a 38% decrease from 2019 (Table 1). Most of American Samoa's vessel arrivals between 2004 and 2021 were container ships (35%), followed by RoRo's (25%), and tankers (16%). General cargo ships, passenger vessels, reefers, and "other" vessels account for the remaining 24% of vessel traffic in American Samoa.

Table 1. Total reported commercial vessel arrivals in American Samoa from National Ballast Information Clearinghouse database (2004-2021).

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	Totals	Proportion (%)
Container	5	6	3	8	4	25	28	36	32	64	74	85	87	91	96	86	69	62	861	34.8
General Cargo	5	17	53	49	46	23	19	4	0	6	11	14	15	26	34	21	15	20	378	15.3
Other	0	2	1	1	2	0	2	2	0	2	1	0	1	3	2	4	2	0	25	1.0
Passenger	2	5	3	6	9	3	9	11	18	14	13	13	10	10	9	16	3	0	154	6.2
Reefer	4	1	2	0	2	9	1	7	7	3	7	8	0	2	3	1	1	1	59	2.4
RoRo	0	10	12	21	18	21	18	21	19	20	22	68	76	70	61	66	35	45	603	24.3
Tanker	6	9	17	22	23	25	31	31	27	35	21	25	28	27	24	23	10	13	397	16.0
All	**22**	**50**	**91**	**107**	**104**	**106**	**108**	**112**	**103**	**144**	**149**	**213**	**217**	**229**	**229**	**217**	**135**	**141**	**2477**	

From 2003 to 2019 a total of 11,671 vessel arrivals were documented by the American Samoa Government (Figure 2 and Table 2). The most arrivals were reported in 2003 (1,000) and the least arrivals were reported in 2013 (527). The number of vessel arrivals reported by the American Samoa Government (ASG) exceeds those reported to the NBIC each year (Table 1 and Table 2). "Other" vessels accounted for the highest proportion of vessel traffic reported by ASG (37.4%) followed by fishing vessels (28.1%), freight (16.6%), and yachts (10.1%).

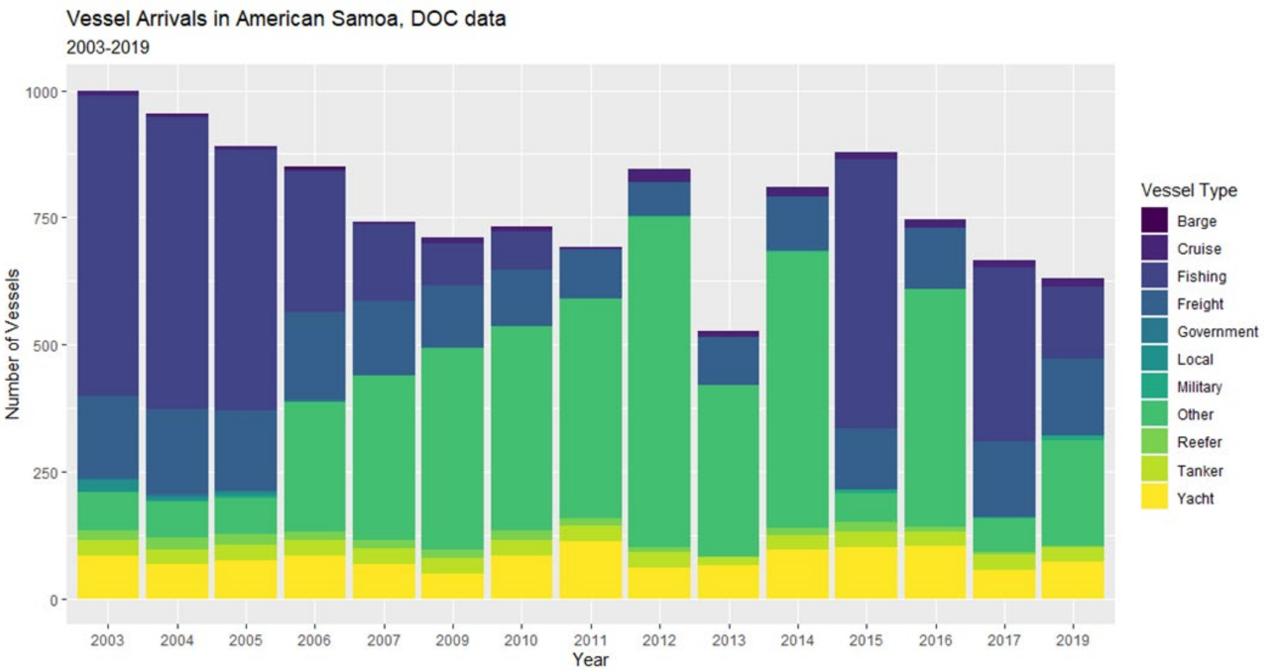

Figure 2. The total number of vessel arrivals reported by the American Samoa Department of Commerce per year from 2003 to 2019. Vessel counts are divided into vessel types (barge, cruise, fishing, freight, government, local military, other, reefer, tanker, and yacht).

Table 2. Actual vessel arrivals in American Samoa from American Samoa Department of Commerce Statistical Yearbooks (2003-2019).

	2003	2004	2005	2006	2007	2009	2010	2011	2012	2013	2014	2015	2016	2017	2019	Total	Poportion(%)
Cruise	9	5	6	6	5	10	8	7	26	10	21	13	16	14	15	**171**	***1.5***
Government	2	5	4	4	0	0	0	0	0	0	0	0	0	0	0	**15**	***0.1***
Freight	163	168	158	172	146	124	111	96	66	93	106	121	121	146	152	**1943**	***16.6***
Tanker	32	28	31	33	29	30	31	31	30	17	27	30	29	31	26	**435**	***3.7***
Fishing	590	573	513	276	152	83	75	0	0	0	0	529	0	344	143	**3278**	***28.1***
Yacht	84	68	76	84	69	50	84	113	60	64	96	101	102	56	73	**1180**	***10.1***
Local	24	8	6	0	0	0	0	0	0	0	0	0	0	0	0	**38**	***0.3***
Military	1	2	4	1	1	0	0	0	3	1	2	7	0	4	8	**34**	***0.3***
Barge	2	1	0	3	0	0	1	0	0	0	0	0	0	0	0	**7**	***0***
Reefer	19	23	19	17	18	15	18	15	9	3	15	18	8	3	3	**203**	***1.7***
Other	74	72	73	253	322	398	403	431	651	339	544	59	470	68	210	**4367**	***37.4***
All	**1000**	**953**	**890**	**849**	**742**	**710**	**731**	**693**	**845**	**527**	**811**	**878**	**746**	**666**	**630**	**11671**	

The last Port of Call (POC) of NBIC-reported commercial vessel arrivals in American Samoa between 2004 and 2021 were scattered across the globe. The top five last POC were Samoa (68%), Fiji (13%), French Polynesia (4%), Hawaii (3.4%), and Tonga (3%) (Table 3 and Figure 3). After leaving American Samoa, most vessels remained in the South Pacific. The top five next POC were Samoa (30%), French Polynesia (15%), Tonga (13%), California (10%), and New Zealand (6%) (Table 3 and Figure 4). Figures 3 and 4 use a log scale to better visualize the scale of vessels travelling to and from American Samoa.

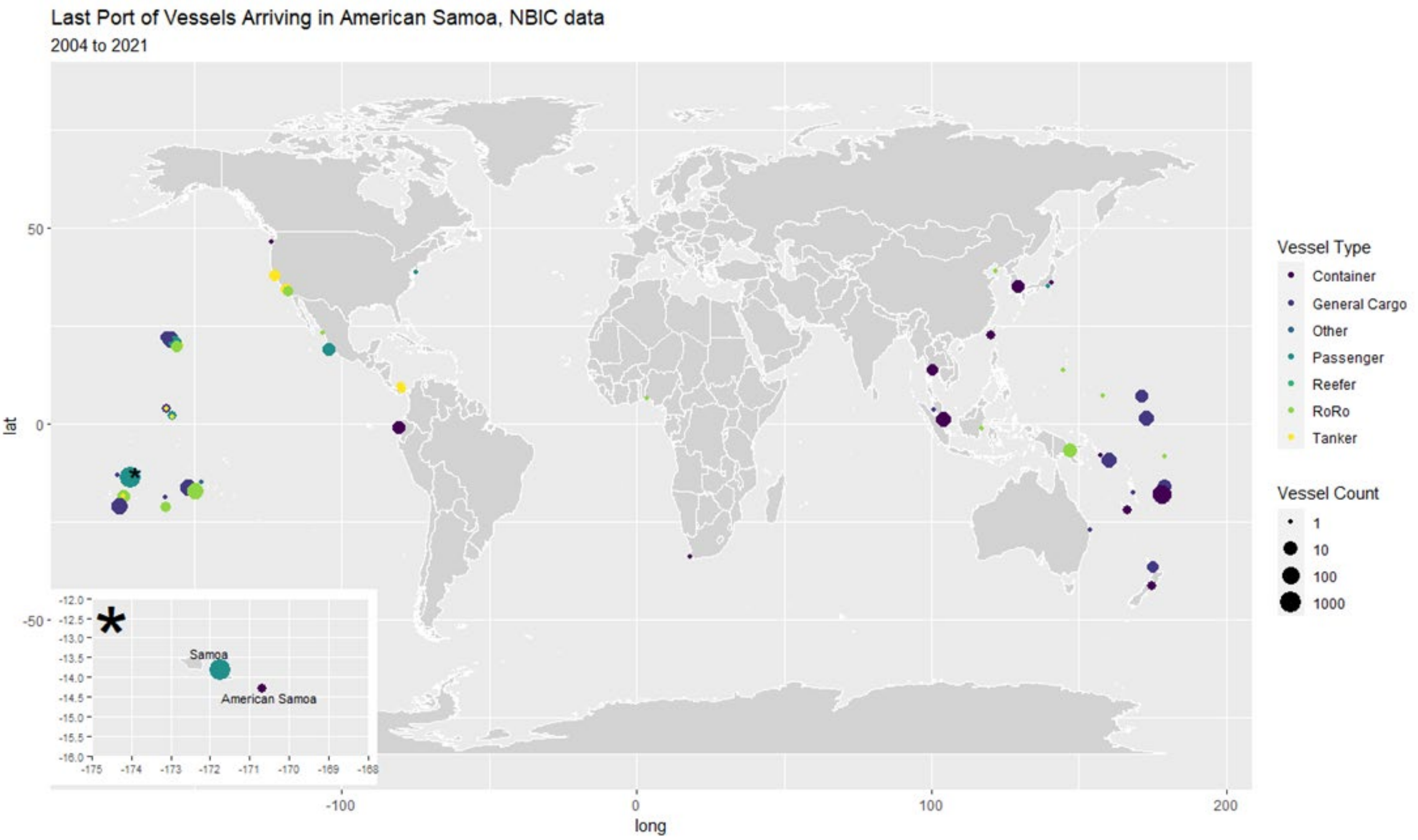

Figure 3. A map showing the NBIC reported last port of commercial vessels arriving in American Samoa from 2004 to 2021. The circle size represents a log scale of the number of vessels whose last port was at that location and the circle colour represents vessel types (container, general cargo, other, passenger, reefer, RoRo, and tanker). The general location of the Samoan Archipelago is annotated with a "*".

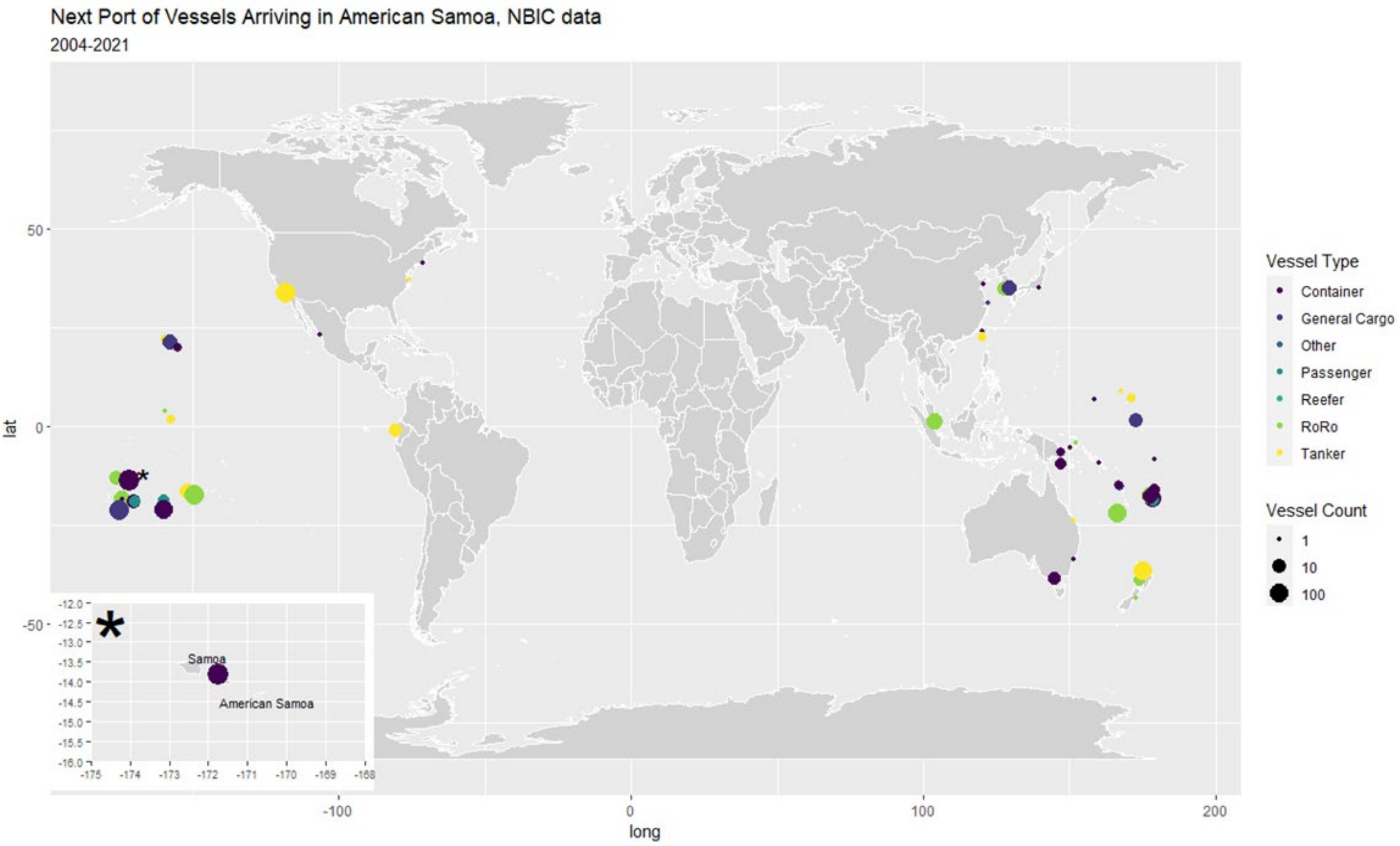

Figure 4. A map showing the NBIC reported next port of commercial vessels arriving in American Samoa from 2004 to 2021. The circle size represents a log scale of the number of vessels whose next port is at that location and the circle colour represents vessel types (container, general cargo, other, passenger, reefer, RoRo, and tanker). The general location of the Samoan Archipelago is annotated with a "*".

Most commercial vessels come from (91%) and remain (77%) in the Tropical South Pacific. Only 6% of traffic had ports in the Tropical North Pacific (including Hawaii) as their last port visited. About 11% of vessels planned on travelling to locations in the Temperate North Pacific (including California, USA) while 7% planned on travelling to Australia or New Zealand, and only 3% planned on travelling to the tropical North Pacific (Table 3).

Table 3. Reported last port visited before arriving in American Samoa and next port visited after arriving in American Samoa for all commercial vessel arrivals in American Samoa in the National Ballast Information Clearinghouse database (2004-2021) grouped by region.

REGION	COUNTRY	LAST PORT		NEXT PORT	
		Count	Proportion (%)	Count	Proportion (%)
Tropical South Pacific	American Samoa	3	0.1	8	0.3
	Cook Islands	6	0.2	141	5.9
	New Caledonia	2	0.1	124	5.2
	Papua New Guinea	16	0.7	9	0.4
	Solomon Islands	24	1	2	0.1
	Tuvalu	1	0	1	0
	Wallis	1	0	7	0.3
	Vanuatu	0	0	4	0.2
	Niue	0	0	11	0.5
	Fiji	326	13.4	136	5.7
	French Polynesia	104	4.3	375	15.6
	Tonga	75	3.1	319	13.3
	Samoa	1680	68.8	725	30.2
	Total	***2238***	***91.7***	***1862***	***77.7***
Tropical North Pacific	Kiribati	24	1	12	0.5
	Indonesia	1	0	0	0
	Malaysia	3	0.1	0	0
	Singapore	28	1.1	38	1.6
	Thailand	5	0.2	9	0.4
	Taiwan	2	0.1	3	0.1
	Marshall Islands	6	0.2	3	0.1
	Guam	1	0	0	0
	Pohnpei	1	0	1	0
	Hawaii	83	3.4	20	0.8
	Total	***154***	***6.1***	***86***	***3.6***
Temperate South Pacific	Australia	1	0	9	0.4
	New Zealand	6	0.2	156	6.5
	Total	***7***	***0.2***	***165***	***6.9***
Temperate North Pacific	China	1	0	2	0.1
	Japan	2	0.1	1	0
	South Korea	7	0.3	22	0.9
	California	11	0.5	254	10.6
	Oregon	1	0	0	0
	Total	***22***	***0.9***	***279***	***11.6***
Other	Ecuador	7	0.3	5	0.2
	Mexico	7	0.3	1	0
	Panama	4	0.2	1	0
	Nigeria	1	0	0	0
	South Africa	1	0	0	0
	Total	***20***	***0.8***	***7***	***0.2***

Ballast water

A total of 59 discharge records from 25 different vessels for American Samoa from 2008 to 2021 were retrieved from the NBIC. Most ballast water discharges in American Samoa are from containers (63%) and tankers (31%) (Figure 5). Reporting began in 2004 but no discharges were reported from 2004-2007 or in 2011-2012. Since 2008, a total of 109,217 metric tons of ballast water have been discharged in American Samoa. Ballast water discharges vary from year to year but remained under 13,000 metric tons per year until 2020 when discharges surpassed 37,000 metric tons, a 193% increase from 2019 (Table 4). Aside from the years that no discharges were reported, 2021 had the lowest volume of ballast water discharges.

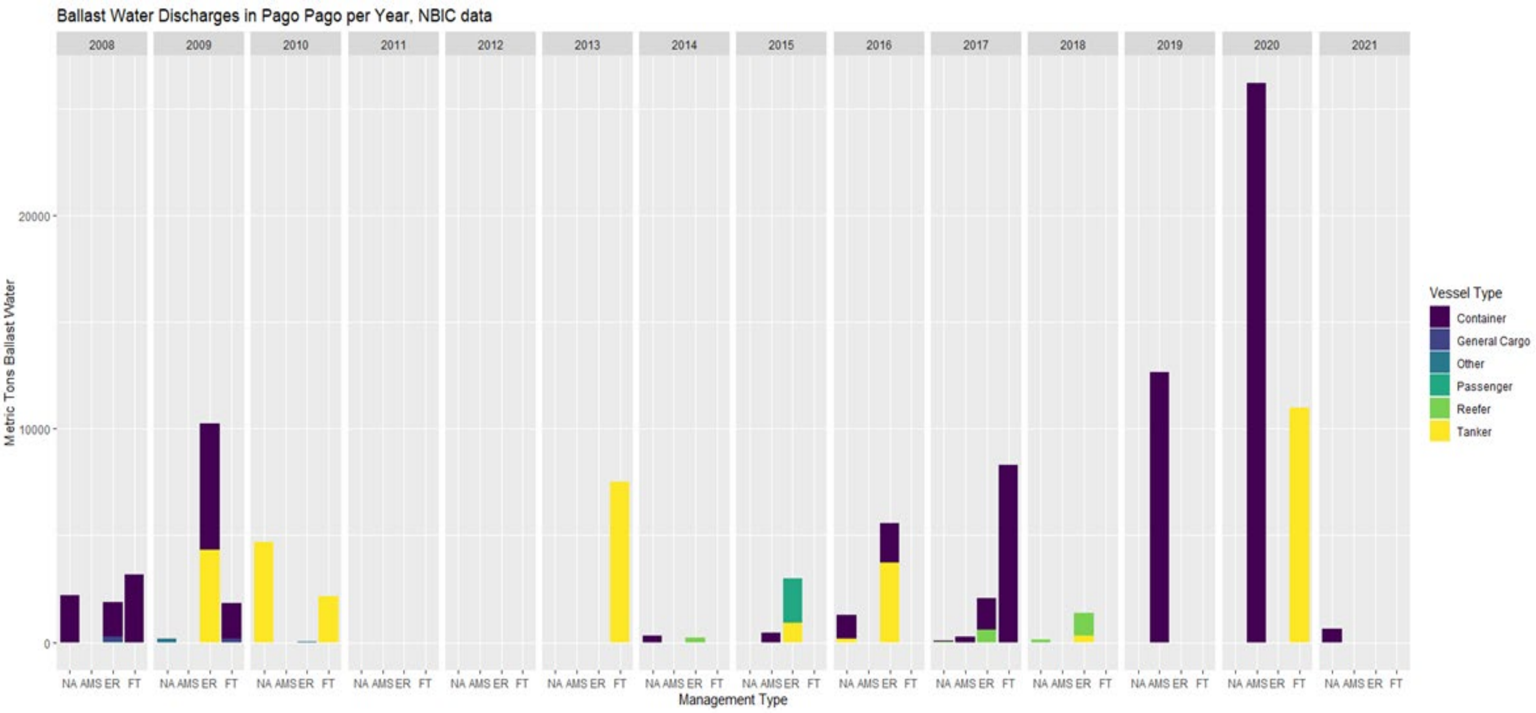

Figure 5. The total NBIC reported total ballast water discharges (metric tons) in American Samoa per year from 2004 to 2021. Discharges are divided into treatment types: unreported (NA), treated (AMS), empty-refill (ER), and flow-through (FT). Discharges are coloured by vessel type: container, general cargo, other, passenger, reefer and tanker.

Table 4. Reported ballast water discharges (metric tons) in American Samoa in National Ballast Information Clearinghouse database (2004-2021). Totals are indicated in bold text.

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	Total	Proportion (%)
Container	**7672**	**7566**	**0**	**0**	**0**	**0**	**322**	**444**	**2928**	**10502**	**0**	**12655**	**26185**	**620**	**68894**	**63.2**
Exchanged	5464	7566	0	0	0	0	0	0	1838	10230	0	0	0	0	25098	23.0
Treated	0	0	0	0	0	0	0	444	0	272	0	12655	26185	0	39556	36.3
Unreported	2208	0	0	0	0	0	322	0	1090	0	0	0	0	620	4240	3.9
General Cargo	**250**	**150**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**400**	**0.4**
Exchanged	250	150	0	0	0	0	0	0	0	0	0	0	0	0	400	0.4
Treated	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
Unreported	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
Other	**32**	**175**	**32**	**0**	**0**	**0**	**0**	**0**	**0**	**177**	**0**	**0**	**0**	**0**	**416**	**0.4**
Exchanged	32	175	32	0	0	0	0	0	0	0	0	0	0	0	239	0.2
Treated	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
Unreported	0	175	0	0	0	0	0	0	0	0	0	0	0	0	175	0.1
Passenger	**0**	**470**	**0**	**0**	**0**	**0**	**0**	**2077**	**0**	**0**	**0**	**0**	**0**	**0**	**2547**	**2.3**
Exchanged	0	470	0	0	0	0	0	2077	0	0	0	0	0	0	2547	2.3
Treated	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
Unreported	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
Reefer	**0**	**0**	**0**	**0**	**0**	**0**	**197**	**0**	**0**	**592**	**1230**	**0**	**0**	**0**	**2019**	**1.9**
Exchanged	0	0	0	0	0	0	197	0	0	592	1230	0	0	0	2019	1.9
Treated	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
Unreported	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
Tanker	**0**	**4350**	**6845**	**0**	**0**	**7502**	**0**	**905**	**3934**	**0**	**296**	**0**	**10964**	**0**	**34796**	**31.9**
Exchanged	0	4350	2144	0	0	7502	0	905	3745	0	296	0	10964	0	29906	27.4
Treated	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
Unreported	0	0	4701	0	0	0	0	0	189	0	0	0	0	0	4890	4.5
All	**7954**	**12711**	**6877**	**0**	**0**	**7502**	**519**	**3426**	**6862**	**11271**	**1526**	**12655**	**37149**	**620**	**10907**	

Vessels did not begin installing and using ballast water treatment systems until 2015 and their use has increased over the years (Figure 5). Treated ballast water made up very little of the total ballast water discharges until 2019 when all the discharged ballast water was treated, a total of 12,655 metric tons, which was a 1,667% increase since 2015. In 2020 over two-thirds of discharges that year were treated (26,185 out of 37,149 metric tons), which was a 51% increase from 2019 (Table 4). Overall, treated ballast water consisted of over 36% of discharges in American Samoa since reporting began. While both tankers and container ships use a variety of management methods, all of the treated discharges come from container ships (Figure 5).

Ballast that was discharged in American Samoa between 2004 and 2021 was sourced from all over the world, though most was sourced from the West Coast of the United States and the Indo-Pacific (Figure 6). Generally, container and cargo ships source their ballast from various locations throughout the Pacific, tankers source predominantly from the Indo-Pacific region, passenger ships ballasted from North America's West Coast and Hawaii, and reefers are the only vessels that source ballast water from the Atlantic. Container ships, general cargo, passenger, and "other" vessels generally managed their ballast in the waters between North America and their destinations in the Pacific while tankers managed their ballast at various locations throughout the Indo-Pacific (Figure 7). Reefers are the only vessels that sourced and managed ballast water in the Atlantic Ocean.

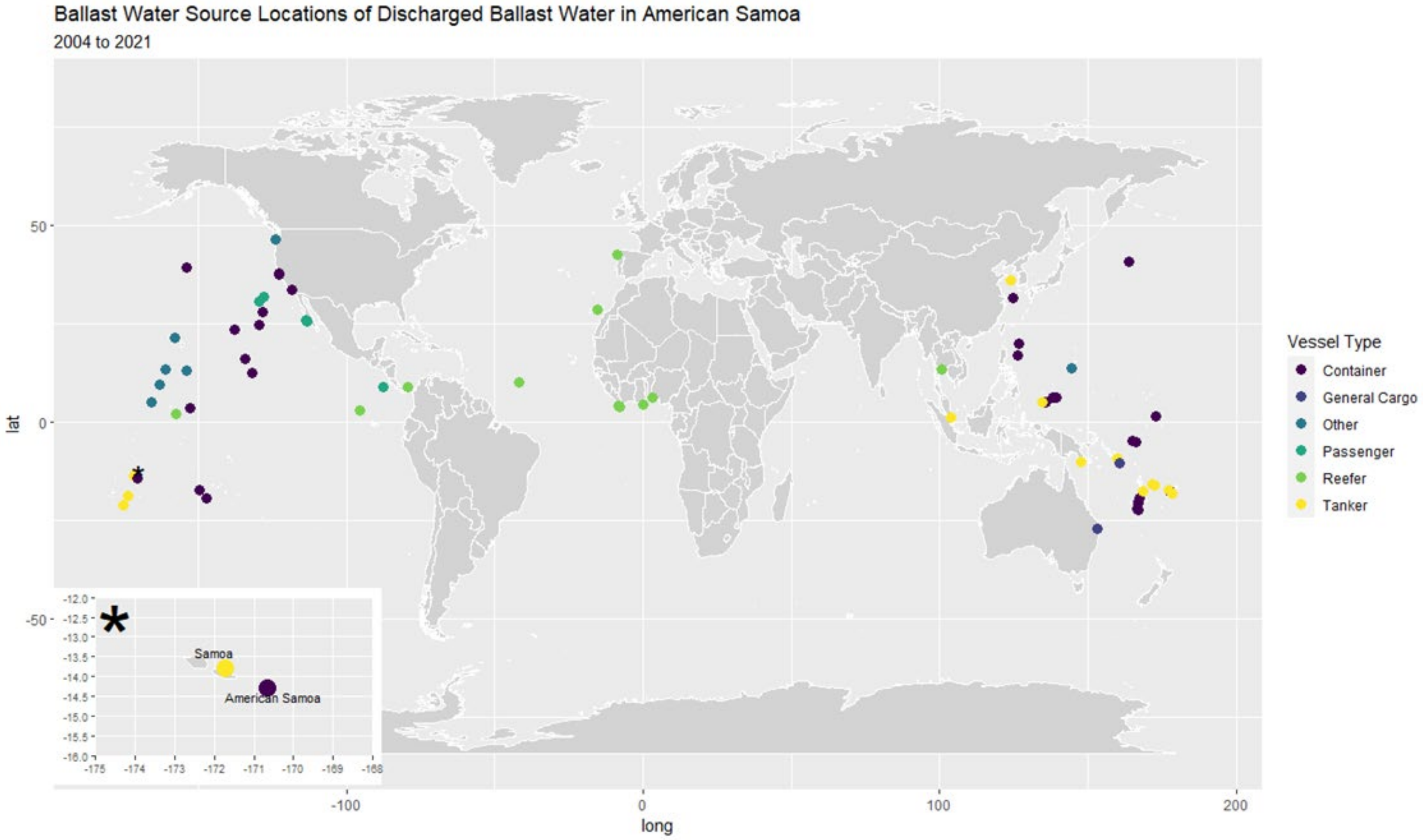

Figure 6. A map showing the NBIC reported source location of discharged ballast water in American Samoa from 2004 to 2021. Circle colour represents vessel types (container, general cargo, other, passenger, reefer, and tanker). The general location of the Samoan Archipelago is annotated with a "*".

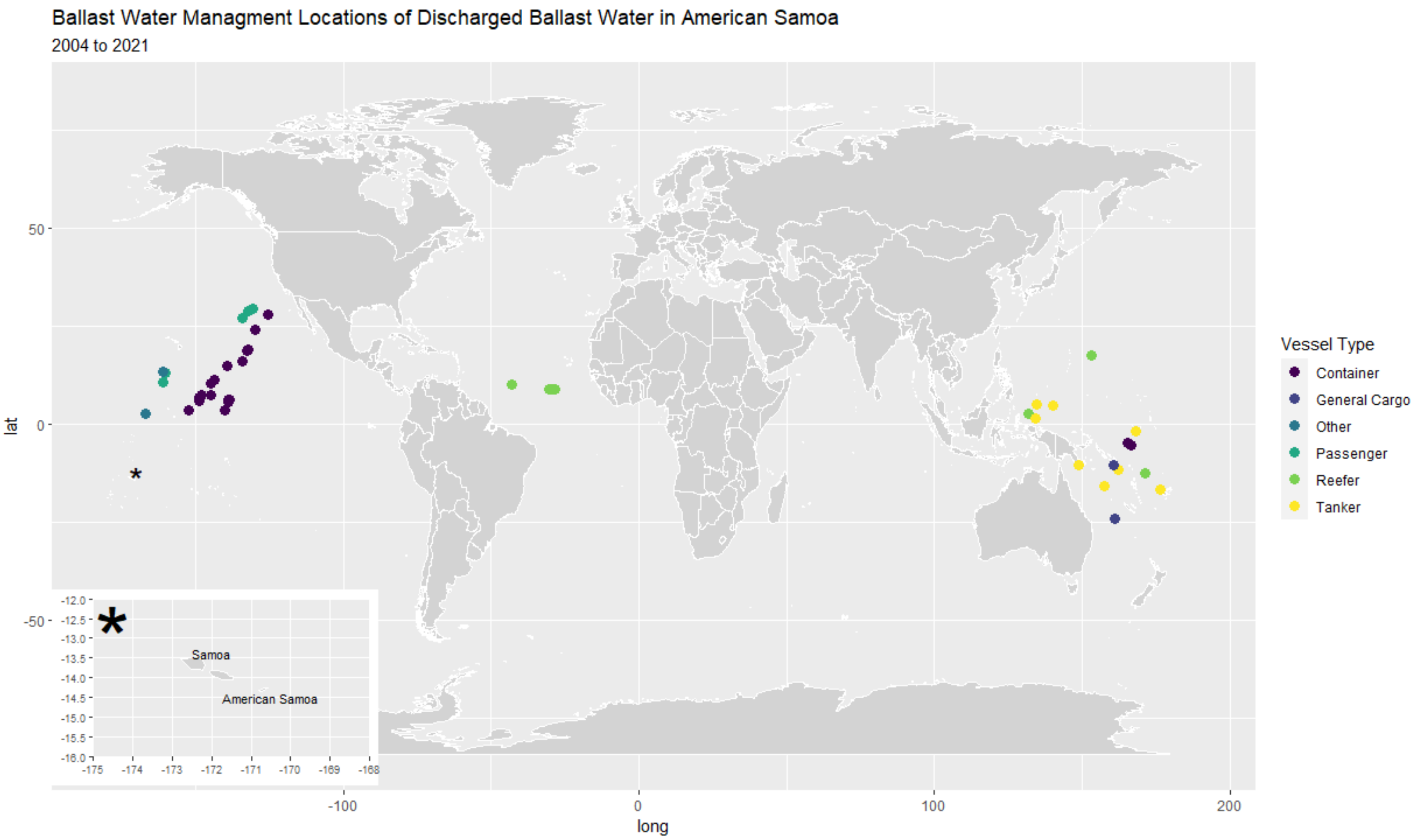

Figure 7. A map showing the NBIC reported management locations of discharged ballast water in American Samoa from 2004 to 2021. Circle colour represents vessel types (container, general cargo, other, passenger, reefer, and tanker). The general location of the Samoan Archipelago is annotated with a "*".

Discussion

Though American Samoa's vessel traffic and ballasting behaviours align with those of the rest of the United States (Ruiz et al. 2001, Miller et al. 2007, Miller et al. 2011, Minton et al. 2015, Gerhard and Gunsch 2018), this study provides insight into the important differences in this small port. Much of the United States' traffic occurs in the Northern Hemisphere and ballast water discharges are dominated by bulkers (Minton et al. 2015, Gerhard and Gunsch 2018), while American Samoa's traffic is mainly in the South Pacific and relies heavily on containers and tankers. Though American Samoa's traffic is a minuscule proportion of the United States traffic, its location is incredibly unique and has specific management needs, requiring a closer look at vessel traffic and ballasting trends for the Territory.

Shortcomings of the data used in these analyses include inconsistencies with record-keeping, as these data are self-reported, and data management and entry errors. Small fishing vessels, recreational vessels, DoD/USCG vessels, and vessels solely operating the COTP Honolulu sector are exempt from reporting to the NBIC and left out this data analyses. Additionally, without ballast water tank analyses and field-based monitoring, quantifications of ballast water discharges can only provide a picture of opportunity for ballast-mediated introductions and are not a direct measurement of risk of introduction (Miller et al. 2011, Minton et al. 2015). The age of ballast water, ballast water treatment type, and abiotic factors of source and discharge location, all impact the risk associated with ballast water discharges (Minton et al. 2005). Similarly, vessel arrivals are not a direct measure of the risk of introduction via biofouling and the duration of a vessel's stay in port, the time since their last dry dock date, as well as their antifouling management measures, affect the risk of introduction (Davidson et al. 2009). We also recognize that using the NBIC data to show the diversity of last and next port calls provides an incomplete picture as these reports only include commercial vessels. Finally, the data included in the ASDOC Yearbooks are treated as a complete record of vessel arrivals in the Territory. It is important to note that these data are simply reported as a count of each vessel type per year and information on their voyages and ballasting behaviours are not included and therefore cannot be used as a measure of NBIC reporting compliance. These data also have different vessel type categories than those reported to the NBIC.

Ballast water

Commercial vessel reporting to the NBIC began in 2004 for American Samoa but there was little compliance in these early years. The USCG established penalties for non-submission of ballast water management records in 2004, which likely explains the increase in commercial vessel traffic reported in 2005. This increase in traffic after 2004 is consistent with Gerhard and Gunsch's 2018 findings for vessel arrivals in all United States ports. In recent years, NBIC reported vessel arrivals have averaged around 223 vessels each year. However, in 2020, the global COVID-19 pandemic put a halt to vessel traffic worldwide and American Samoa's NBIC vessel reports dropped to 135 in 2020. Traffic appears to have begun to recover and an assessment of post-COVID impacts would be useful.

Ballast water discharges in American Samoa were not reported to the NBIC prior to 2008, probably due to non-compliance or reporting errors. Additionally, no ballast water discharges were reported in 2011 or 2012. It is possible that there were no discharges in those years; however, it is more likely that these data are missing due to reporting or entry errors. Interestingly, even though vessel traffic decreased in 2020, there was more ballast water discharged than any other year. This suggests that the amount of ballast water being discharged per vessel grew, which could be attributed to an increase in the size of vessels arriving in 2020 or an increase in exports, as suggested by Gerhard and Gunsch (2018). Additionally, Gerhard and Gunsch (2018) noticed that ballast water discharges outpaced the growth of vessel arrivals in the United States as a whole. Interestingly, discharges by vessel type vary greatly between American Samoa and the United States. Most discharges in American Samoa are from containers and tankers while bulkers rank the highest in the United States, with containers discharging the lowest volumes across all United States ports (Minton et al. 2015, Gerhard and Gunsch 2018).

If trends from 2019 and 2020 NBIC data are any indication, ballast water treatment system use, as well as reporting, will likely continue to increase in the coming years as more vessels install these systems. Though these trends are encouraging, and ballast water treatment systems are safer and better at treating ballast water than open ocean exchanges, these systems are not foolproof and can break down if not well-maintained. Additionally, these systems are only tested for efficacy against three specific organism groups in the size category of less than 10 micrometres: Toxicogenic Vibrio cholerae, Escherichia coli, and Intestinal Enterococci. Little is known about the effectiveness of ballast water treatment systems on pathogens as much of the literature focuses on organisms larger than 10 micrometres (Drake et al. 2007, Gerhard and Gunsch 2018). This is especially concerning regarding stony coral tissue loss disease (SCTLD), which is rapidly spreading throughout the

Caribbean. This disease is caused by a host of microorganisms that may not be eliminated by ballast water treatment systems (Rosenau et al. 2021, Studivan et al. 2022) and highlights a need for additional research in this area.

Ships typically ballast in port prior to their departure, which explains why many of the ballast source locations appear to be near shore. However, some ballast source locations in Figure 2 appear to be from open ocean sources. Vessels may be misreporting their ballast source locations or reporting the location where they performed an open ocean exchange. Some ballasting patterns that stand out are passenger vessels ballast in the East Pacific, container and cargo vessels ballast throughout the Pacific, tankers ballast in the Indo-Pacific, and reefers ballast in the Atlantic and Indian Oceans. The analysis also indicated that reefers may ballast in areas affected by SCTLD prior to transiting through the Panama Canal.

Ballast water exchanges (including flow-through, sequential, and empty-refill methods) are required to be conducted at least 200 nm from shore and at depths of 200 m. They typically occur somewhere along the voyage route of the vessel. Passenger vessels, cargo vessels and container ships are managing their ballast water between California and American Samoa while tankers are managing their ballast water in the highly biodiverse and island-rich Indo-Pacific (Figure 7). Tankers are second in discharges in American Samoa and this map suggests that they are a high risk for species transfer as their ballast water sourcing and management occurs in similar environments to American Samoa. Additionally, all the discharges by tankers were treated by exchanges rather than alternate management systems. Exchange requirements can be difficult to meet on some journeys such as those in the Caribbean and those in the Indo-Pacific as vessels may not be able to get 200 nm from land on their voyages (Miller et al. 2011; Minton et al. 2015). If the tankers ballasting in the Indo-Pacific are unable to meet these requirements, it is probable their ballast water contains coastal organisms, which are more likely to become established when discharged at subsequent ports.

Though ships typically ballast and deballast in port, it does not occur at every port visited on their voyage. The ballast water on board could have been sourced at several ports (and/or over several days or weeks) prior to their arrival in American Samoa. Figures 6 and 7 show important differences in ballast source locations and management locations. Even though discharged ballast water is managed in more consistent locations that appear to be offshore and in deep waters, it is important to keep in mind that there could be residual water, sediments, and/or biofilms in the tanks from the various sources and management location of the ballast water on board.

Vessel traffic

The vessel arrivals reported by the ASDOC for 2004 to 2019 averaged 778 per year. Most of the arrivals reported by ASDOC were classified as “other”, followed by fishing vessels, freight, and yachts. It is important to note that no fishing vessels were reported as arriving in 2011, 2012, 2013, 2014, and 2016. During these years the “other” vessel count went up dramatically and it is likely that fishing vessels were captured in this category. Though most of these vessels are smaller and do not carry ballast, they are still at risk for introduction via biofouling as these small vessels are likely traveling from port to port throughout the Pacific.

The vast majority (over 91%) of NBIC commercial vessel reports for American Samoa arrived from other South Pacific Ports, with Samoa accounting for the last port call of over 68% of commercial vessel reports. The next largest region for reports is the Tropical North Pacific (over 6%). Thus, over

97% of commercial vessel reports are coming from the Tropical Pacific and species transfers are more likely to occur between regions with similar abiotic factors (Chan and Briski 2017). This highlights the importance of close communication and cooperation among the Pacific Islands. However, some species can tolerate a broad range of abiotic conditions and invasions across different environments are known to occur (Chan and Briski 2017). This makes it important to be aware that vessels have arrived from ports around the world and biota are likely travelling with the vessels from the various ports on their voyage. Especially when considering that biofouling, sediments, biofilms, and residual water contribute to species introductions, particularly in regard to pathogens and microalgae (Drake et al. 2007, Hayes et al. 2019, Rosenau et al. 2021, Studivan et al. 2022). Additionally, the true diversity of port calls is not represented well in the NBIC data as non-commercial vessels are not included.

It is also important to keep in mind that American Samoa can just as easily be a source of invasive species, and the biosecurity measures taken here can help the rest of the Pacific. With over 77% of commercial vessels reporting that their next port call is in the South Pacific, vigilance and communication between Pacific neighbours is very crucial. While the biota of many South Pacific Islands is similar, there is still potential for introduction of new species from neighbouring islands. For example, Samoa currently has at least nine introduced marine species that have not yet been recorded in American Samoa (Skelton et al. 2002, SPREP 2022). The next largest region for departures is the Temperate North Pacific including Hawaii and California. Hawaii already has several marine introduced species that are native to the tropical South Pacific including Scylla serrata, the Samoan Crab (Eldredge and Smith 2001).

Though American Samoa is politically part of the United States, the port of Pago Pago has much closer similarities with the port of Apia, Samoa. Apia averages under 300 vessels a year and its traffic is dominated by containers. About 82% of Apia's traffic came from the Oceanic regions, 13% from Asia, 3.5% from America, and 1.4% from Europe (Government of Samoa, 2015). This shows the importance of regional biosecurity measures and good communication among the Pacific islands.

Conclusion

Vessel arrivals and ballast water discharges are minimal in American Samoa when compared with other ports in the Pacific and the United States. This increases the risk of unintentional introductions of marine invasive species via biofouling or ballast water. Container ships contribute to the highest number of commercial vessel arrivals as well as ballast water discharges in the Territory and should be a priority for monitoring and prevention. American Samoa's vessel traffic is closely connected with much of the tropical Pacific, especially the South Pacific Islands, calling attention to the need for regional communication. This study emphasizes the necessity for additional research into vessel-mediated transfers of marine invasive species, particularly regarding biofouling and pathogens, highlights the importance of monitoring vessel traffic, and the urgency of creating local policy. The marine environment of American Samoa is remote, biodiverse, and resilient to change, however, the potential for introducing new species via vessels remains high. Preventative measures are the most effective way to reduce the impact of marine invasive species, but regulations cannot be applied uniformly across all ports and all vessel types. It would be beneficial for Pacific Island governments to review local and regional marine biosecurity risks and consider policy options regarding ballast water and biofouling. Additionally, programs to target vessel operators for education and outreach may be useful in improving ballast water compliance and helping mitigate risk.

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